THE EXTENT AND RELEVANCE OF INSTRUMENTALISM, CONSTRUCTIVISM AND CRITICAL REALISM IN HIGH SCHOOL PHYSICAL SCIENCE TEXTBOOKS - A CRITICAL STUDY

A Dissertation submitted

in fulfilment of the requirements of the Degree of

Master of Philosophy

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University of Cape Town

March 1990

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ACKNOWLEDGEMENTS:

Professor P.E. Spargo, of the Science Education Unit, School of Education, University of Cape Town, my Supervisor, for all his advice and encouragement, as well as his suggestion to write a joint Paper for *Interchange* (published in July 1989), and also to take part in the International Conference on 'The History and Philosophy of Science in School Science Teaching' held at Florida State University, Tallahassee, in November 1989.

Professor K. Rochford (School of Education, University of Cape Town), for his initial most useful Master's Degree course, held in January 1985. This course provided me with much invaluable information of a practical nature regarding Research Methods, as well as hints about the selection of a research topic. I am also indebted to Professor Rochford for inviting me to participate in several subsequent Seminars for Masters students.

Dr A. Shutte (Philosophy Department, University of Cape Town), for reading the final draft, particularly Chapters 2 and 3, and for his helpful comments and criticisms about the philosophical content of the thesis. It was Dr Shutte who first introduced me to the philosophy of Bernard Lonergan, a fact for which I am most grateful.

Professor P. Tamir, of the Hebrew University, Jerusalem, for his helpful discussions during brief meetings with him in Cape Town in 1987 and 1988.

The Cape Education Department, for financial assistance in the form of a two-year bursary, as well as for granting me several months study leave in 1987 and 1989.

The Human Sciences Research Council: The financial assistance of the Institute for Research Development of the Human Sciences Research Council towards this research is hereby acknowledged with thanks. Opinions expressed in this work, or conclusions arrived at, are those of the author and are not to be attributed to the Institute for Research Development of the HSRC.

Pinelands High School, Cape Town, for agreeing to my absence during several months of study leave. Also to the Principal and my colleagues for accepting so willingly the inconvenience caused by my absence from the School during this time.

Thanks also to **Mike and Christa Steyn,** for all the hours so readily spent with me, in decisions concerning the formatting and laser printing of the document.

To members of **my family,** who willingly put up with me during the writing of this thesis, and who helped with the proof-reading.

ABSTRACT

Instrumentalism is a philosophy of science which holds that scientific theories are merely useful fictions for making computative predictions. Its pragmatic purpose of 'saving the appearances' downgrades the role of theory in science. Realists, on the other hand, take the implications of theories seriously.

This study investigates the attributes of both instrumentalism and realism, taking theory as its point of departure. It is pointed out that constructivism is closely related to instrumentalism, both being forms of pragmatism. Since both tend to concoct and relinquish theories too easily, they tend to be relativist and subjectivist.

It is therefore concluded that neither instrumentalism, nor constructivism, nor empiricism is sufficient for a rounded science education. What is needed is a type of realism which acknowledges both the empirical physical world 'out there' and the constructivist nature of scientific knowledge. The naive (empiricist) realism so prevalent in school science textbooks cannot do this. It is contended that critical realism, and especially that of Bernard Lonergan, can meet this requirement. Reality is more than what is given in sensory experience. Therefore, in order to help solve the problem of relativism and subjectivity inherent in constructivism, we need to revise our notion of reality and objectivity.

Twenty-three selected British, American, South African, and African Third World high school physical science textbooks were examined in detail to determine the extent of an instrumentalist philosophy in them. They were subjected to several textual analyses, including one especially devised for this study. The results reveal that our high school physical science textbooks do indeed contain a high degree of instrumentalism.

This study postulates that this instrumentalism may be used to help pupils move towards realism. However, this needs to be augmented by a full-blooded critical realist approach which takes theoretical entities seriously. One way of doing this is through the use of suitable material in the preface of every textbook. Not only should the dangers of instrumentalism (and naive constructivism) be pointed out, but the role of theory in science should be emphasised. This may be achieved by simulations to encourage growth of models and theories, historical case studies involving theory-development, and additional reading of scientists in action. Some examples of these are provided.

"The roads by which men arrive at their insights into celestial matters seem to me almost as worthy of wonder as those matters in themselves."

Johannes Kepler: *Astronomia Nova* (1609)

Chapter 1

INTRODUCTION: THE PROBLEM POSED

1.1 Instrumentalism as a form of anti-realism

No form of anti-realism can do justice to the scientific enterprise, for modern science is pre-eminently realist. Its chosen object of study is the real physical world, and it assumes that such a physical world exists independently of our knowledge of it.

It is disconcerting to find, therefore, that instrumentalism is a particular kind of anti-realism (Hacking 1983, p.63), that instrumentalism is the prevailing view in science today (Popper 1956; Powers 1982), that school science has an instrumentalist leaning (Hodson 1989), and that our school science textbooks are becoming increasingly so (Selley 1989). Even more disquieting is the revelation that constructivism, so popular and prevalent in current science education research literature, is closely related to instrumentalism (Pope and Keen 1981; Von Glasersfeld 1989). For both are rooted in pragmatism, a practical philosophy which is avowedly anti-realist (Dewey 1929), and of which Bertrand Russell (1946) wrote dramatically that pragmatism is a step "on the road towards a certain kind of madness". Pragmatism can be traced back to Hegelian idealism, and is, to boot, relativist regarding the notion of truth. Therefore both instrumentalism and constructivism are relativist. Finally, constructivism involves both the creation of imaginative intellectual structures called theories, and the notion of choosing between competing theories, which seems to make it not only relativist, but also subjectivist!

The bewildering feeling of being sucked into a vortex, and the consequent desire to find solid ground, resulted in this study, which focuses on a quest for reality. For it seems that the circular debate involving instrumentalism, constructivism, and anti-realism, can be broken only by concentrating on the **realism** problem. Further, as this study began to move into the instrumentalism and constructivism areas, it became more and more clear that the debate centred on the **role of theory** in science.Thus it is important to clarify the meaning of theory, and its role in science. Once the role and status of theory are established, the true nature of science may begin to emerge. Also, the notion that scientific knowledge and scientific theories are intellectual constructs calls for some sort of validation.

Bearing the above in mind, it is clearly important to probe the characteristics of instrumentalism and clarify its philosophical implications. If, indeed, it is anti-realist and relativist, and if our school textbooks **are** instrumentalist, then a way has to be found as to how an instrumentalist approach can be used in science education without falling into either relativism or naive realism.

A similar problem arises with constructivism. How do we avoid the apparently inexorable spiral into relativism and subjectivity? If constructivist psychology is accepted uncritically by teachers, where does it ultimately lead? The spectre of relativism is not, in my view, an attractive one. Nor is that of subjectivism. It is postulated in this dissertation that a constructivist approach in school science textbooks may be a way of overcoming the shortcomings of the inductivist-empiricism and instrumentalism contained in them. Yet, if constructivism is itself relativist and subjectivist, then what good would that achieve for school science educators?

The whole question revolves around **reality** and our **knowledge** of reality. Instrumentalists, heavily influenced by British empiricism, hold that "reality" and the "existing physical world" are identical. Reality is precisely what is directly observed. Instrumentalists would not, therefore, believe that theories are real. What, then, is the reality status of electrons and atoms? Instrumentalists refuse to acknowledge the reality of such theoretical entities. Electrons and atoms do not exist. They are simply fictions, only useful intellectual tools for solving problems. So instrumentalists are strongly anti-realist.

Constructivists acknowledge the reality of invented intellectual structures (theories). Electrons and photons, as well as dragons and phlogiston, are real, for children create imaginative theories in an attempt to make sense of their experience: they construct their own reality. Thus reality is not just what is "out there". It is much more, for it includes all one's explanations amd imaginings, all one's theoretical presuppositions and experiences. Theory is part of reality. In this sense, constructivists are realists.

Yet in another sense, they are anti-realists, at least to some degree. For constructivism is a form of pragmatism. Children construct theories to enable them to **cope with** their environment. Electrons and dragons may be real, but do they exist? Theories, say constructivists, are not representations of reality; they are simply functional adaptations to help them 'get by' in life. Children simply choose the best theory they construct. They live in a world of theories, with little or no contact with an ontologically existing world.

So, on the one hand, the instrumentalist seems to be anti-realist because, for him, there is no underlying reality behind the directly-observable world. Reality is appearance. Electrons do not exist. On the other hand, the constructivist, whose roots, like those of instrumentalists, lie in pragmatism, cannot escape from his world of theories. His form of anti-realism is more a type of unreality.

No school science educator should, in my view, tolerate anti-realism in any form, for it is a self-destructive philosophy. Yet the fact is, it is prevalent in our contemporary science education and our school science textbooks. Therefore, it is very important to find a solution to the problems of relativism, subjectivism, and anti-realism inherent in the instrumentalism/constructivism scenario. Hence the following discussion should be of great interest to those science educators who are inclined towards the constructivist psychology embedded in what Gilbert and Swift (1985) call the 'alternative conceptions movement'.

An essentially realist stance seems to be the answer, but which realism fits all the requirements? We must acknowledge the practical success of empiricism and instrumentalism in science, and we cannot ignore the constructivist nature of scientific theories. It will be shown that the only type of realism which, in my view, ably reconciles the best in empiricism, instrumentalism, and constructivism, is **critical**

realism. There is a growing conviction that critical realism is a way out of the philosophical impasse caused by naive realism (Bhaskar 1975; Selley 1981a; Hodson 1985). My particular contribution to this discussion is, I believe, the fact that, not only have I endeavoured to promote the cause of critical realism, but also that I may also have introduced the reader to the critical realism of Bernard Lonergan. I hope to show that his brand of critical realism offers a viable solution to the problems raised above, especially those of subjectivity and objectivity.

These philosophical problems form one of the three main questions which this dissertation sets out to address, and may be summarized as follows: what are the philosophical attributes of the instrumentalism/constructivism relationship which can guide us towards an answer to the problems of anti-realism, relativism, and subjectivism?

1.2 Definition of terms

Before proceeding further, the definition of several key terms is required in order to assist the reader who is not familiar with the technical language of philosophy.

(a) **Inductivism**: This is a view of science which is based on inductive reasoning, that is, generalising from a number of particular observations. By observing the regularities in a number of phenomena, a universal rule or law is arrived at. For inductivists, science begins with observation, and by using a rigid experimental method, observations are made as objective as possible. The scientific knowledge obtained is therefore as free from personal prejudice as possible. Scientific knowledge obtained in this way is seen as completely reliable and objective. It is regarded as proven knowledge and absolutely true.

(b) **Empiricism**: This is a theory of knowledge which is based on the common-sense view that all our knowledge about the physical world comes through our five senses. Sensory experience is the only source of our knowledge. Therefore, we can never have any knowledge of any entity which is incapable of being observed. It is closely related to **inductivism** in that both hold that science begins with objective sensory observations.

(c) **Positivism**: This is a tough-minded extension of the **empiricist** view that we cannot know that which we cannot observe. Therefore, any statement which cannot be strictly **empirically verified** would be regarded as being **meaningless**, and must be ruthlessly excised from science. This approach would not only eliminate metaphysics from science, but would provide the simplest and most **economical** way of coordinating the facts of experience.

(d) **Instrumentalism**: This is an approach to science which follows from **positivism**. Because certain **theoretical** entities in science are **not directly** observable by the senses (for example, electrical resistance), they can be defined in terms of the **operations** used to measure them. This results in an **instrumentalist** approach, which is essentially interested only in computative predictions, and not whether the theoretical entity exists or not, that is, in questions of **realism**. Note that instrumentalism is a broad concept involving inductivism, empiricism and positivism.

(e) **Phenomenalism**: The **phenomenon** is that which **appears directly to the senses.** Only the outer appearance of an object presents itself to the senses. Any deeper reality which may or may not exist "behind the appearances" remains hidden to sensory observation. Since an empiricist would maintain that what cannot be observed does not exist, he would contend that only **phenomena** can be observed by the senses. **Phenomenalism** is therefore a direct consequence of **empiricism.** An empiricist would hold that only the phenomenon exists, and that there is no reality "behind" what appears to the senses. However, both the positivist and the instrumentalist would say that they are interested only in phenomena, and not in questions of realism. **Phenomenalism** is thus opposed to **realism.** Note that empiricists, positivists and instrumentalists are all phenomenalists.

(f) **Realism**: This has many meanings, only two of which will be referred to now. The **naive realist** believes that an external reality exists apart from himself, and that knowledge of this reality comes through his senses. For the purposes of this dissertation, there is no difference between a naive realist and an empiricist. We must be careful to distinguish between the existing world (ontology) and our knowledge of it (epistemology). The naive realist (empiricist) holds that reality is what he directly observes. He identifies reality with the independently existing object. The **critical realist**, like the naive realist, holds that a real world exists independently of his knowing it, but that he somehow actively has a part in **constructing** reality. For the critical realist, reality is not only that which is **given** from without by the senses, but the Gestalt of sensory experience, understanding and judgement. He does not identify reality with the existing object.

(g) **Constructivism**: In order to make sense of his experience, the knowing subject interprets his experience in terms of his previous knowledge. He actively constructs his reality. He builds up conceptual schemes or theoretical structures to explain reality.

(h) **Idealism**: This is the view that the world exists only in the mind. Mind is the primary and only reality. Matter cannot exist apart from the mind.

(i) **Relativism**: This is the doctrine that knowledge is of relations only. There is no absolute criterion of truth. Truth is what is agreed upon. Truth is pragmatic. The relativist says that it is possible only to assess one theory relative to another. It cannot be firmly grounded on an empirical base, because all observation is prejudiced in some way. As Petrie (1981, p.34) points out, this is a typically Hegelian idealist position, namely, that the theory is best which most accords with the freedom and spontaneity of the human mind.

(j) **Subjectivism**: This is the philosophical theory that all knowledge proceeds from, and takes place within, the thinking subject. It is associated with relativism. Subjectivists hold that knowledge is only a personal construct, and that there is no independent standard of theory evaluation, because observation is influenced by prior theory. They are opposed to the objectivist view of testing theories by observation (Martin 1972, p.116), because objectivists emphasise the passivity of the mind as the test of objectivity (Lindsay 1959, p.xv).

1.3 Instrumentalism is the prevailing view in science today

The instrumentalist approach is still the prevailing view in virtually all contemporary science. Indeed, as Powers (1982, p.1) notes,

> "the revolution in modern physics has been hailed as a triumph for the 'no-nonsense' philosophical approach of 'positivism' and 'operationalism'",

that is, instrumentalism. Instrumentalist philosophy follows from a strict adherence to positivism, which in turn is a rigid form of empiricism.

Hacking (1983, p.24), referring to positivists and their rejection of theoretical entities, says: "This kind of anti-realism is in full spate today."

According to Popper (1956, p.360),

> "the instrumentalist view ... has become an accepted dogma" in contemporary physical science, and in fact "has become part of the current teaching of physics".

1.4 Instrumentalism in school science textbooks

Many researchers in science education have recently pointed out that contemporary school science is still permeated by an **empiricist** philosophy (eg Cawthron and Rowell 1978; Factor and Kooser 1981; Driver 1983). This empiricism is usually associated with an **inductivist** approach. The question is: Is an **instrumentalist** view also present in school science?

Cawthron and Rowell (1978, p.31) suggest that one way of investigating whether a philosophy such as instrumentalism is present in school science is to analyse the contents of the most widely-used **textbooks** in school science courses. No matter how objective a science textbook purports to be, it contains explicit or tacit assertions which reflect a particular philosophy of science. Although it is recognised that the contents of textbooks represent the beliefs of their authors, nevertheless they must also heavily reflect the views of the practising school science community who give the texts their popularity in the first place, and who presumably then become influenced by them.

The literature on the subject suggests that current school science textbooks portray a philosophical stance which is empiricist. Such a standpoint is revealed by its emphasis on the objectivity of scientific inquiry, and its view that scientific knowledge provides absolute truth. Cawthron and Rowell (1978, p.32) state that

> "a scrutiny of school science texts almost invariably reveals an implicit epistemological preoccupation with the existence of 'objective' reality."

They state further that such textbooks

> "project an image of science which can be called empiricist-inductivist."
> (Cawthron and Rowell 1978, p.33)

In another paper, Rowell and Cawthron (1982, p.93) state that "our texts portray science as some inexorable linear pursuit of truth."

In a careful reading of nearly all the introductory first-year non-major chemistry and physics textbooks in use in the United States during the 1979-1980 academic year, Factor and Kooser (1981, p.28) point out that,

> "as with the science and society texts, the narrow inductivism and empiricism of the 19th century, particularly that of John Stuart Mill, plays a formative role in the image of science in skills and drills texts."

According to this empiricist or positivist view, scientific knowledge purports to be authoritative, objective, and superior to other forms of knowledge, because scientific method is deemed to be unbiassed and completely reliable. As Bentley, Ellington and Stewart (1985, p.664) point out,

> "such an image of science seems to be promoted in textbooks and by the use of heuristic methods in science classes".

The inductivist-empiricist view is strongly present in textbooks advocating the heuristic method of science education. Discovery by activity, as proposed generally by Dewey, and more specifically in science education by Armstrong, and more recently in *Science - A Process Approach* and *Nuffield O-Level Physics*, emphasises the role of observation and induction. Driver (1983, p.48) criticises inductivism, in that it

> "suggests that there is one unique interpretation of the data."

However, as Piaget and other constructivists, including Driver, have shown, observation is in fact theory-laden, and children can and do form multiple explanations for events, each of which accounts for the data in a particular way. Driver (1981, p.99), in a discussion of pupils' alternative frameworks in science, notes that, in spite of many voices being raised to show the limitations of empiricism,

> "rational empiricism is still the view of science which predominates in our classrooms".

The philosophy of science which a teacher consciously or unconsciously holds, or which a textbook tacitly or explicitly portrays, must inevitably affect the type of teaching provided and the type of learning which results. Pope and Gilbert (1983b, p.249) postulate that some teachers may take an empiricist-inductivist view of knowledge, and others a constructivist view. They say:

> "Within the various theories on the nature of knowledge put forward by philosophers, there are two polar positions: the '(naive) realist' and the 'constructivist' viewpoints. In the (naive) realist's view, reality is a stable arrangement of subdivisions of objective facts. ... It is expected that, as all disciplined enquirers are presumed to see phenomena in an identical manner, the confirmation of these facts will be a cumulative process. In the 'constructivist' view, reality is personally negotiated so that each enquirer will perceive a different world. The differences in perception will depend on the range of preconceptions brought to bear in the enquiry."

The teacher or textbook taking a **naive realist** stance will tend to emphasise the transmission of information, rules or values which have been collected in the past. The learner can acquire absolute truth by a process of iterative accumulation. This is the **inductivist-empiricist** model. In contrast, a teacher or textbook which encourages imaginative theory construction within the framework of the scientific community, helps the pupil to make sense of the natural world by engaging in interpreting experiences and so actively constructing his reality. This is the **constructivist** model.

Selley (1989, p.29) believes that, since 1980, there has been a return to a non-participatory transmission style in high school science textbooks. Authors are again implying that the information and explanations in the texts are simply the truth. He says that it is tempting to interpret this confident, assertive style as being due to the author's naive realist metaphysics. However, it is possible to read into school science a very different interpretation, namely **instrumentalism**. Selley believes that this instrumentalism could be developed into a philosophical view (that is, critical realism) which would solve many of the old inductivist problems.

Hodson (1989, p.57) maintains that misconceptions about the nature of science and scientific method are entrenched and perpetuated in textbooks. He says elsewhere (Hodson 1986c, p.219) that it is quite common in school science to have a **realist** theory (for explanation) and an **instrumentalist** model (for prediction) for the same phenomenon. Also, he contends that, because of the low esteem for theory (a characteristic of instrumentalism) in such science courses (and by implication, in textbooks), different, conflicting models for the same phenomenon (for example, wave-particle duality) cause confusion in pupils. We should, he says, try to avoid an excessively instrumentalist view without falling "into the trap of naive realism".

Thomas Kuhn (1970, p.136) observes that textbooks

> "address themselves to an already articulated body of problems, data, and theory ..."

That is, they tend to be seen as bodies of accumulated knowledge. This may often reinforce an empiricist view in the reader. However, the emphasis in most textbooks on problem-solving tasks may also strengthen an **instrumentalist** view in the student. The increasing reliance on textbooks, says Kuhn, accompanies the emergence of a first paradigm in any field of science. Furthermore, reliance on textbooks is becoming increasingly evident especially in Third World countries, where the teacher often has little, if any, formal training in science. Thus in many areas the **textbook is fast becoming the only vehicle for transmitting an image of science**. As Kuhn (1970, p.143) says:

> "More than any other single aspect of science, that pedagogic form (namely, the textbook) has determined our image of the nature of science ..."

It is therefore important not only to determine whether high school science textbooks are empiricist, but also whether they are instrumentalist.

Hence the second main aim of this study is to establish whether science textbooks, especially those in current use in South Africa, actually are instrumentalist, as suggested by the literature. Because **instrumentalism is a form of empiricism**, evidence of the latter will also be sought in textbooks. The presence of empiricism and instrumentalism may be found by determining the **nature of science** portrayed in a number of selected British, American and South African high school physical science textbooks widely used in schools today. On the basis of the above literature, as well as my acquaintance with some school texts, the **hypothesis** is put forward that **high school physical science textbooks in current use portray an empiricist-inductivist and an instrumentalist image of science.** This will be tested by various empirical textual analyses, as well as by direct reading, of a sample of high school science textbooks.

1.5 Out-dated view of the nature of science

The third aim of this study is as follows: to achieve a more correct view of the **nature of science** and **scientific method.** It is postulated that this may be done by revealing the philosophical weaknesses and strengths of both instrumentalism and constructivism, and by promoting the adoption of critical realism in science education.

According to Hodson (1986c, p.222), the failure of modern science courses to achieve fully some of their declared goals in relation to children's understanding of the nature of science is due, in part, to a degree of confusion in the philosophical position underpinning many contemporary curricula and, in part, to the continuing failure to provide teachers with an adequate understanding of basic issues in the philosophy of science and their importance in the design of learning experiences. In many current science curricula, there is too much emphasis on **inductive methods**, a too ready acceptance of an **instrumentalist view of scientific theory**, a serious underestimation of the complex relationship between **observation and theory**, and a neglect of the activities of the **scientific community in validating** and disseminating scientific knowledge.

Textbooks tend to encapsulate and perpetuate out-dated views of the nature of science and scientific method. Most science teachers (and the majority of science textbook authors are teachers) would appear to be at least thirty years behind current thinking in the philosophy of science. They pass on this out-dated and incorrect view to their pupils, who then become the scientists and teachers of the next generation.

For example, one prevalent myth in science textbooks is that all science results from experimentation. This is an out-moded empiricist notion, which, according to contemporary philosophy of science, is blatantly false. Another even more damaging myth preserved in textbooks is the notion that observation and experiment provide objective, reliable data. This is especially so in books promoting the discovery learning approach. Textbooks, says Hodson (1989, p.57), help to sustain the myth that the path of science is certain, clear-cut, and linear. The way practical work is presented in textbooks is a prime source of misconceptions about the nature of science. No clear distinction is drawn between the role of experiments in teaching, and their role in scientific practice. In schools, the majority of experiments usually have the pedagogic role of **illustrating** a particular theory, whereas in science the purpose is to assist the development of theory. The textbook approach (especially in discovery or process approaches) of pretending that experiments are open inquiries all too often gives a distorted view of experiments and scientific methodology. The continuation of this kind of stage-managed science present in textbooks should be re-examined with utmost care.

Selley (1981) agrees that pupils see the inquiry method, or discovery method, or process science, as a kind of 'stage-managed heurism'. One of the major misconceptions behind this method is that pupils may come to believe that the path from experiment to theory is fixed, and that there is no room for creative thinking.

Referring to the original *Nuffield Chemistry* (1966), Selley finds the philosophical stance of the investigations "falsificationist, or even positivist". The impression is given that the results of the experiments provide good reasons for belief in the theory. However, in no sense are the experiments 'tests' of the theories. Hence the original *Nuffield* scheme could give pupils misleading impressions. They could end up by thinking that theories can be refuted by a single experiment, or that theories are directly derived from experiments.

As for the role of theories and models, Selley (1981b) says that the *Nuffield Handbook for Teachers* (1967) makes no provision for questions which prompt pupils to explore the explanatory power of models in new situations, or to speculate on the limits of models. In spite of the many beneficial advances of a Nuffield-type course, a serious weakness is that models are presented as 'given'. Pupils are not invited to comment on their validity, nor to suggest changes to them. While it is accepted (says Selley) that a published course is a resource, rather than a directive, the pupil's handbook would be more effective in stimulating discussion or thought about the nature of scientific theories and models if it contained some definite questions at appropriate points, or perhaps a short chapter setting out the basic issues. Teachers may welcome some advice on ways of turning alternative models to advantage. For the use of models in science education raises an important question about the relationship between scientific theories and the real world.

The point is that out-moded views about scientific method and the nature of science are still being perpetuated in school science textbooks, even in those which promote inquiry and process methods. Millar and Driver (1987) hold that process science reflects an inadequate appreciation of the nature of science. 'Process ' is often seen as active and constructivist, and 'content' as passive and empiricist. However, process should not be opposed to content, for content-learning also involves personal knowledge construction. All the processes (observing, classifying, hypothesising), as well as the cognitive processes of content-learning, are theory-laden. Hodson (1989, p.65) sums it up:

> "As far as **learning about science** is concerned, it is imperative that the traditional inductivist notion that experiments are the open-eyed and open-minded confrontations of nature as a means of acquiring objective, value-free and certain knowledge of the world, be discarded. The simplistic interpretation of the Popperian notion that experiments provide crucial tests of a theory's empirical adequacy must also be replaced

> by a more multifunctional view of experiments and a more sophisticated view of the relationships between observation, theory and experiment.
>
> As far as **learning science** is concerned it seems that there is a strong case for constructing a curriculum along Kuhnian lines. Conceptual development in individuals can be described in terms similar to those employed by Kuhn to describe conceptual change in scientific communities (scientific revolutions)."

This is a plea for a better appreciation of the role of **theory** in science. A study of the way instrumentalists regard theory, as well as contemporary views on the role of theory, can lead to a better perspective of the nature of science.

Unfortunately, most science teachers are still of the **cultural transmission** type. According to Pope and Keen (1981), proponents of this type of education see the primary task of the educator as the transmission of information, rules or values collected in the past. Knowledge is internalised by children through explicit instruction. The criterion of successful education is accepted as being the ability of the student to incorporate what he has been taught and to respond to the demands of the system. The major objectives are literacy and mathematical skills necessary for integration into a technological society. Textbooks are used by the cultural transmission teacher as the main vehicle for imparting knowlege.

The philosophical approach underlying this approach is that of naive realism or empiricism. Empiricism, such as that of Locke, assumes that the mind is a *tabula rasa*, and that the intellect is essentially passive. Knowledge is acquired through the impact of the senses. The world we perceive is not the world that we have recreated but the world as it is. The Lockean (empiricist) tradition is central to educational theories which stress the **passivity** of man's mind. It holds that absolute truth can be attained by the bit-by-bit accumulation of individual subjects. Knowledge is repetitive and objective, and can be measured by suitable test procedures. The view of linear accretion of absolute truth corresponds to the basic principles of naive philosophic realism. In the naive realist's view, the world exists independently of man and is controlled by its own laws.

Although it is still widespread in science education, the empiricist philosophy on which it is based was rejected decades ago. Indeed, seventy years ago, John Dewey opposed this cultural transmission theory of education, and founded the Progessive School movement. Progressivism holds that education should encourage the person's natural **interaction** with society and environment. The pedagogical environment should actively stimulate development through the presentation of a milieu in which the organising and developing force in the person's experience is the **person's active thinking**. Thinking is stimulated by cognitive conflict. Like the cultural transmission theorists, progressivists emphasise knowledge as opposed to feelings and experience, but they see the acquisition of knowledge as an act of change in the pattern of thinking brought about by **experiential** problem-solving situations.

Dewey maintained that learning should be directly related to the interests of the person; motivation should come from within rather than that knowledge be imposed upon him. The teacher is seen more as a guide or adviser in a process in which the person reconstructs the subject matter in accordance with its perceived relevance to his own life. Learning should take place through problem solving and grappling with the subject matter. The child learns by doing. This involves the critical thinking process of reconstruction of previous ideas. The teaching method which best assists this is student-student and student-teacher interaction.

The particular philosophy aligned with Progressivism is that of Pragmatism. Dewey called his philosophy 'pragmatic experimentalism' or 'instrumentalism'. Pragmatism is mainly a twentieth century philosphy which has grown out of the British empiricist tradition, which maintains that we know only what our senses experience. Pragmatism holds that reality is the **interaction** of the human being with his environment; it is the sum total of what we **experience**. For Dewey, this reality is **phenomenal** only. There is nothing behind appearance. Man reaches out to make sense of his universe by engaging in the reconstruction and interpretation of his own experiences. Ideas are tentative, instrumental plans of action designed to achieve human ends.

In this sense, Dewey has much in common with constructivists. Piaget claims that thought emerges by means of an active re-organisation of psychological structures resulting from organism-environment interactions. Cognitions are organised wholes attained by the active processes of accommodation and assimilation. For Piaget, the teacher's role is to facilitate development by exposure to higher levels of thought and conflict requiring active application of current thoughts to problematic situations.

According to Pope and Keen (1981), the 'activity' methods of the Progressivists have had a big impact on modern education, especially in the United States. Tasks are set in a series of assignments and projects. Team-teaching is often used. The 'inquiry method' has probably had a more lasting influence on the educational procedure in England than the efforts of the Romanticists. Whereas the latter allowed each pupil to learn what he wanted to learn when he wanted to learn it, the Progressivism of Dewey is much more pragmatic: while allowing for active participation in the acquisition of knowledge and some choice of subject, the choice is not necessarily completely free. Further, the Progressivists' notion of active learning received much support from the psychological research of Piaget, Bruner and Ausubel. Today in our schools (say Pope and Keen) there is a growing trend towards the acceptance of many of the principles of Dewey-type Progressivism.

In my opinion, neither the cultural transmission nor the progressivist theories of education have the full solution, for **both are ultimately based on empiricism.** Although Dewey's method is a great improvement on the transmission approach, both, in their own way, tend to perpetuate an out-moded view of the nature of science and scientific method. What is needed is a balancing factor. Contemporary philosophy of science has supplied this in the form of Critical Realism (Bhaskar 1989; Selley 1981a; Hodson 1982).

1.6 Point of departure and summing up

One can attack the problem of an out-dated view of scientific method and the nature of science from several angles. It could be approached by a direct discussion (along Popperian lines) of the errors of traditional Baconian scientific method. Another approach might take a Kuhnian sociological slant and examine actual scientific practice. The point of departure chosen in this study is a discussion of the realist/instrumentalist debate as seen by contemporary philosophers of science. This debate centres on the role of scientific theories and models.

Scientific theories are our intellectual constructions about the nature of the physical world. There are at least two ways of relating scientific theories and the world: the first is called **realism**, and the second **instrumentalism**.

A **realist** believes that theories attempt to describe what the natural world is actually like. For the realist, the world exists independently of our minds. In order to make sense of what we observe, we build theories about our observations. Theories provide coherence and structure. By placing individual observations in a context, they make the natural world intelligible. They **explain.** The realist takes his explanations (theories) seriously, and holds scientific theories in high regard. Scientific theories, says the realist, do tell us something informative about the world, for the realist believes that the theoretical entities, such as electrons and photons and fields, which he postulates in order to explain his observations, really do exist. For example, the realist holds that the kinetic theory of gases claims that "gases really are made up of molecules in random motion". (Chalmers 1986, p.146)

On the other hand, an **instrumentalist** holds that scientific theories do not actually describe the physical world, but simply relate sets of observations. For the instrumentalist, the kinetic theory of gases is a mere convenient fiction enabling scientists to relate and make predictions about the observable properties of gases in order to make use of them in a variety of ways. Theories are only useful devices for prediction. They need not be taken seriously. It does not matter whether molecules exist or not, just as long as they yield correct predictions.

Because instrumentalism is difficult to define, perhaps a concrete example will help clarify its meaning. Consider a pupil performing an experiment to verify Newton's Second Law of motion. He is using a stretched elastic to exert a constant force on a trolley in order to see how it affects the trolley's acceleration. As a realist, the pupil would observe that the force of the elastic accelerates the trolley. He would be quite happy to say that 'the force given by the elastic **causes** the trolley to accelerate'.

If, however, he were to adopt an instrumentalist interpretation of his experiment, he would be far more restricted. He would adopt a strict empiricist approach, which holds that only what can be empirically observed can be taken as true scientific knowledge. He would say that his observation of a constantly extended elastic was always associated with an acceleration. He would make no mention of 'force', because he did not strictly empirically **observe** a force. Nor does he say that 'the stretched elastic **causes** the acceleration', but rather that 'whenever the elastic is stretched, an acceleration occurs'. As an instrumentalist, he is committed to record only what he observes. To introduce concepts like 'force' or 'cause' is to go beyond the facts. He refuses to introduce speculative ideas, fearing that such concepts are metaphysical and therefore not the business of science. Science must confine itself to the the empirical facts only. Therefore, he is interested only in saying that, whenever one phenomenon occurs (ie stretched elastic), the other also occurs (ie acceleration). He simply **relates variables**, and is not interested in seeking explanatory causes. Indeed, his generalisation that the 'stretched elastics always make trolleys accelerate' is accepted only because it can be used to **predict** the motion of other bodies, not because it has expanded our knowledge for its own sake. Our pupil would regard the result of his experiment as true, not because Newton's theory agrees with his observations, but because his calculative predictions actually work. He treats force **as if** it has a real existence, but actually regards it only as a useful fiction. He is essentially a pragmatist, not a realist.

Instrumentalism, then, is an approach to scientific inquiry which avoids questions about the real nature of the universe, and is solely interested in whether its practical purpose of computative predictions works or not. The instrumentalist scientist regards questions of realism as metaphysical, and therefore invalid from an empirical point of view. The instrumentalist is anti-realist. For this reason, theories do not have an explanatory role. Indeed, the instrumentalist shies away from explanation, holding that explanation also goes too far beyond empirical facts. The status of theory is down-graded.

Thus, the significance of theoretical ideas is held in low esteem by instrumentalists. The naive instrumentalist scientist will refuse to admit, for example, that electrons and photons are real: they are simply very useful theoretical ideas. The very unity of scientific knowledge is thereby weakened, because our unifying concepts are splintered by trying to anchor their meaning in 'actions' rather than 'reality'. This is indeed a paradox: that the same method which made scientific knowledge so great, should also lead to an anti-realist position which is only interested in utilitarian considerations.

Therefore an important spin-off of an analysis of the relationship between **instrumentalism** and **scientific theory** will be a more correct notion of the nature of science and scientific method. Such an investigation should serve very usefully to bring out all the various facets of the problems surrounding constructivism, the contemporary views about the role of theory and the nature and methods of science. For all these are inter-linked. Thus, in the end, it is hoped that a detailed discussion of instrumentalism will throw light upon some far wider questions.

1.7 Outline of this Study

This dissertation therefore sets out to examine the following questions:

(1) What is instrumentalism? Is it pragmatic and hence relativist? How can these pitfalls be circumvented? Is a constructivist approach a way of doing this?

(2) Is constructivism well-founded philosophically and psychologically? Is it also pragmatic and relativist? How does it guarantee objectivity? Does objectivity lie in conceptual **structures** as suggested by Piaget? How does Piaget's constructivism compare with Dewey's instrumentalism? What does it mean to say that 'reality is constructed' as opposed to the 'givenness' of reality?

(3) Of the various types of realism, which is the best option? What is wrong with the naive realism of empiricism? Does Thomistic (classical) realism apply? Why does instrumentalism, as a form of pragmatism, reject reality altogether? What is critical realism? Which form of critical realism offers the best choice?

(4) Are our textbooks indeed instrumentalist? If so, in what way? Is the instrumentalism in school textbooks strong or weak? What empirical methods may be used to detect instrumentalism in school science textbooks?

(5) Armed with the answers to these questions, how does this affect science education? In particular, how can textbooks incorporate this critical realism? What practical strategies can be employed to try to use the instrumentalism present in textbooks to create a constructivist attitude?

It should be noted that **critical realism** actually emerged during this study as a possible way of solving the problems of (a) anti-realism in instrumentalism; (b) relativity and subjectivity in constructivism; (c) misconceptions about the nature of science and scientific method among both teachers and pupils.

The investigation will take place in two distinct but related phases: (i) exploration of the **philosophies behind instrumentalism and constructivism**, in an attempt to find a type of **realism** which would unify the different ways these regard the role of scientific theory; (ii) a detailed survey of **school science textbooks** to see if they are indeed inductivist-empiricist and instrumentalist, followed by some practical suggestions for textbook authors to overcome the philosophical weaknesses inherent in this.

In **Chapter 2** it will be shown that instrumentalism is a form of empiricism and positivism, and that it is an anti-realist approach to science. The philosophical characteristics of the phenomenalism of instrumentalism will be discussed. It will be contended that a constructivist approach can off-set this tendency towards anti-realism. The pragmatism of both instrumentalism and constructivism threatens to destroy the unity of scientific knowledge and lead to anti-realism, but the emphasis constructivism places on theory gives the latter a stronger role. The contemporary constructivist notion of competition between rival theories will be examined.

Chapter 3 will explore the philosophical basis of constructivism. It will try to show that the conceptual structures of Piagetian constructivism have a more secure foundation than the interactional functionalism of Dewey's. It will be postulated that a full-blooded realism which incorporates a constructivist element as well as a sound empirical base is a better option than the weak realism of instrumentalism.

The critical realism of Bernard Lonergan will be put forward as the type of realism required to meet the requirements of the objectivity of scientific theories.

In **Chapter 4** the question of instrumentalism in high school physical science textbooks will be discussed. The methodology of the empirical study will be described. This entails methods of text analyses, based on those of previous researchers, as well as a direct, critical reading of the textbooks, to find the degree of instrumentalism present in them.

The results of the various text analyses and preface and metaphor analyses are given in **Chapter 5**. In order to support the quantitative results, many additional quotations and examples of instrumentalism in school science textbooks are provided. This chapter concludes that the school textbooks studied do indeed portray an instrumentalist approach to science. Further, there seems to be a trend towards instrumentalism, both in British and South African school science textbooks, especially those orientated towards educationally disadvantaged pupils.

Chapter 6 concludes that textbooks, of their very nature, cannot do otherwise than present a strong instrumentalist image. Therefore it is very important for teachers to be aware of the shortcomings, not only of instrumentalism, but also of constructivism. Ignorance about these stems largely from an out-dated notion of the nature of science and scientific method. For this reason, it is recommended that every school science textbook should contain a preface, or short chapter, or appendix, in which both the out-moded and the accepted contemporary nature of science is given. In addition, several exercises and historical cases studies are provided as guidelines to textbook authors, in order to encourage a more critical realist approach to the role of scientific theory.

Chapter 2

INSTRUMENTALISM: ITS ORIGINS AND CHARACTERISTICS

2.1 Introduction

Scientific knowledge differs from other human knowledge in the great emphasis it places on **theory.** Science has built up a great body of conceptual networks and structural schemes to help explain the relationships between facts. Because theories are social possessions, and because they are deliberately subjected to very severe empirical tests in an effort to refute them, scientific theories are so well corroborated that they themselves take on the form of tentative facts. To a very large extent, theoretical entities, such as forces and fields, electrons and energy levels, have become the objects of much of scientific inquiry. So the objects of scientific inquiry are of a very special sort: intellectually constructed objects.

Scientists can regard theory in one of two ways. They can see it as an organising structure with **explanatory** and **predictive** power, or they can use it as a convenient device for **prediction only**, rejecting any explanation of reality. The former approach is taken by the **realist**, the latter by the **instrumentalist**.

The chief aim of this chapter will be to show that instrumentalism is a form of anti-realism, and has several important philosophical weaknesses. A secondary aim is to investigate whether constructivist educational psychology may be used to off-set these instrumentalist weaknesses.

The differences between realism and intrumentalism and their attitudes to the role of theory in science, will be explored. The origin of instrumentalism in the history of science and its attempt to "save the appearances" without getting involved in metaphysical speculations about a possible underlying reality will be examined. From this historical treatment, the characteristics of instrumentalism will be elaborated, as well as its philosophical implications. A critique of instrumentalism, based mainly on that of Popper, will be given.

Finally, it will be contended that the philosophical drawbacks of instrumentalism may be remedied by a constructivist approach, and the relationship between instrumentalism and constructivism will be discussed. Both instrumentalism and constructivism are rooted in pragmatism, and so share its weaknesses of arbitrariness, relativism and subjectivism. It will be shown that only a **critical** constructivist approach can lead to full-blooded realism.

2.2 What is instrumentalism?

Instrumentalism is a way of going about scientific inquiry which is more concerned with **relating observations**, usually in a mathematical and operational way, and being able to make accurate **predictions** from them, than with the real existence of the entity under study.

Because it ignores questions about reality, instrumentalism tends to be superficial and pragmatic. It is a useful way of saving the appearances without getting involved in explanatory speculations which, it holds, go beyond the facts. For instrumentalism is **rooted in the empiricist tradition** which accepts only sensory experience as the source of valid knowledge. It rejects realism for two reasons: firstly, **realists go beyond the facts** when they try to explain phenomena; secondly, whether or not there is indeed an underlying reality behind phenomena, science works very successfully when treated instrumentally. The postulating of a supposed reality underlying appearance is a superfluous hypothesis.

Realist scientists are interested in whether their theories are true or false, that is, whether there is some sort of correspondence between their theories and the natural world. Instrumentalist scientists are not particularly interested in whether their theories are true or not. They are mainly interested in whether they work or not. Their aims are **pragmatic**.

Instrumentalist scientists pursue their activity by emphasising (a) **operational definitions;** (b) **rules** and **calculative predictions**; (c) **theories** as **useful fictions**. They prefer to **describe** rather than **explain.**

For example, resistance R is operationally defined as the quotient of potential difference and current, or as a volts per ampere (R = V/I). Hence, given potential difference and current strength, the resistance can be predicted by calculation. Whether resistance as the opposition to a flow of charges really exists or not, is beside the point. What matters is that the formula works. It is useful. Therefore it is pointless calling upon the possible existence of something if it does not add to its usefulness: keep the whole inquiry process as simple and as non-metaphysical as possible.

Although instrumentalist science works, it is a very limited way to knowledge. In trying to save the appearances, it is reluctant to commit itself to deeper, more satisfying explanations. This leads to a tendency not to take the implications of its theories seriously. Theories are not explanations of reality, but only fictions devised to account for the facts. Hence they can be arbitrarily changed to suit the facts. This arbitrariness leads to relativism, scepticism and pragmatism.

2.3 The importance of scientific theory

The controversy about realism and instrumentalism is centred on the different ways they interpret the role of theory in science.

2.3.1 The role of scientific theory

A scientific theory is an **intellectual construct** which uses a set of logical rules which serve to link the theory with the world, and to relate observations with each other. It is an invented **conceptual structure** which stands or falls on its ability to **describe, explain,** and **predict** observable phenomena, without being dependent on any **single falsifying observation.** A theory must lead to fruitful consequences, which can be tested empirically. Its function is to provide a **context** for a variety of facts, to give **intelligible structure** to our experience, and to offer a tentative **explanation** for phenomena. Truth is approached, but never reached. Such is the contemporary notion of scientific theory.

This contrasts sharply with the traditional concept of theory which is still prevalent in school science education. This traditonal, now out-dated, view stated that the theories of science are **derived directly from observations**, and are tentative proposals which stand or fall by their ability to stand up to a **single, crucial** experimental test. Today there is concensus in the scientific community that a theory cannot be refuted by a **single**, crucial experiment. Theories may be retained in spite of falsifying observations. They need time before they are rejected. The traditional view of science said: If a new opposing theory falsifies an older theory, then the older one must (logically) be ruthlessly rejected. The contemporary view holds: If a new opposing theory falsifies an older theory, **both** may be held **simultaneously** (and even illogically) for some time.

The out-dated notion of theory held that a theory is a guess about some aspect of nature which cannot be observed directly, but which can be inferred by indirect evidence. This implies that there is an eternally existing real world out there waiting for scientists to discover. Today there is widespread agreement that the real world is not discovered, but is constructed. Our observations and experiments merely refute or confirm our guesses. According to Popper, almost all the knowledge we acquire is done through guessing, and what we learn from experience is only how wrong many of our guesses unfortunately are. We come to know reality by criticising our theories. Indeed, all we ever know are our theories.

What distinguishes scientific knowledge from other forms of human knowledge is, amongst other things, its built-in mechanisms of self-regulation. All science is directed towards the growth of objective knowledge. This is achieved through **critical preference of theories:** some conjectures are better than others.

> "Objectivity rests on criticism, on critical discussion, and on the **critical examination of experiments**." (Popper in Miller 1983, p.84)
>
> "So long as a theory withstands detailed and severe tests and is not superceded by another theory in the course of scientific progress, we may say that it has 'proved its mettle' or that it is **corroborated** by past experience." (Popper in Miller 1983, p.136)

The chief role of scientific theory is to **explain**. The aim of science, maintains Popper, is to find **satisfactory explanations**. What kind of explanation may be satisfactory? The answer is (says Popper): an explanation in terms of testable and falsfiable universal laws and initial conditions. Instrumentalists interpret scientific theories as having little or no explanatory power. But this, maintains Popper, is not so. Every time we proceed to explain some conjectural theory by a new conjectural theory of a higher degree of universality, we are discovering more about the world, trying to penetrate more deeply into its secrets. And, says Popper, every time we succeed in falsifying a theory, we make a new important discovery. For these falsifications teach us the unexpected. And theories reassure us that, although they are our own inventions, they are none the less genuine assertions about the world, for they can **clash** with something we never made. Our theories enable us "to meddle effectively in the working of the world". (Miller 1983, p.11) Our theories do affect nature in some way.

Our theories make assertions about structural or relational properties of the world. The properties described by an explanatory theory must be, in some sense or other, **deeper** than those to be explained. Although (says Popper in Miller 1983, p.167) this word 'deeper' eludes logical analysis, the 'depth' of a scientific theory seems to be most closely related to its simplicity and so to the wealth of its content.

As Hodson (1986c, p.220) points out, an individual practitioner may have confidence in his theory, but it must stand up to the severe criticism of his fellow scientists, and be **accepted by the scientific community**. As communal confidence in a theory grows, it acquires its own observation language with its own built-in assumptions. This allows scientists to say, for example, that, in terms of solubility theory, they "**see** sugar **dissolving**" rather than that they "**see** sugar **disappearing**", or that, in terms of the theory of particle physics, they "**see** the track of an **electron** in a cloud chamber", and not just "a thin, white line". In other words, theoretical ideas acquire a reality status.

2.3.2 The status of scientific theory

The status of scientific theory has two extreme positions: that of **naive realism** and of **instrumentalism**. Naive realists hold that scientific theories provide a true description of the world. Naive realists hold that all entities postulated by scientific theories (eg electrons, atoms, photons, etc) have a real existence. However, because our senses and observational equipment are imperfect, our theories are incomplete and subject to revision. So if a naive realist states that a theory is tentative, he means that, one day in the future, when laboratory techniques and measuring procedures are perfected, absolute truth will be attained.

Instrumentalists, on the other hand, maintain that theories do not refer to existing entities. Theoretical entities such as electrons are simply convenient fictions which are useful in making predictions. For instrumentalists, theory is not an intellectual **structure**, but only an intellectual device or **functional instrument** for relating observations. The real world is described by imaginary models which have no ontological counterpart. Observations are hard and factual, and completely distinct from theoretical entities, which are figments of the imagination.

2.3.3 Instrumentalist theories are immature theories

Science is more than an accumulation of facts. It is a synthetic, constructive activity. Thus when the early astronomers tried to 'save the appearances', or account for the facts concerning planetary motion, they were not simply collecting facts or telling a new tale for each fact. Rather, this was an intellectual advance, the beginning of a scientific theory. By coordinating information, they began to see that there were patterns in the phenomena which enabled them to predict future events. And they obviously took delight in this. (Rogers 1977, p.223) But although their theories were able very successfully to predict planetary events, they lacked physical, bodily explanations. They tried to improve, not by simplifying, but by adding further *ad hoc* riders. They were intellectually satisfying, but lacked simplicity and fruitfulness.

In his wonderful book *Physics for the Inquiring Mind*, Eric Rogers (1977, p.341) discusses the role of scientific theories in some detail. He begins by presenting "The fable of the Plogglies" in order to illustrate the way scientific theories operate. This fable tells of a land in which men constantly found, to their perplexity, that whenever anyone wanted a pencil, one could never be found; and that whenever someone did find one and wanted to sharpen it, the pencil sharpener was always found to be full of pencil shavings. After investigations, a magnificent theory was put forward to account for these two phenomena. It suggested that, beneath the ground, lived a great number of little people called Plogglies, who at night would find any pencils, grind them up, and stuff the shavings into the pencil sharpener. This was a brilliant theory, for in one stroke, it accounted for both mysteries.

This is an example of a prescientific theory. The work of nature is explained by invoking unpredictable gods or demons. The overall objection to the plogglies theory is simply that there are not any plogglies. There (says Rogers) is where many modern physicists would disagree. They would not mind the plogglies being a fiction (like any model in science) but they would call it bad theory because it was too expensive. The plogglies were invented and endowed with two special behaviours to explain two sets of events, and they do not explain anything else. They are an *ad hoc* theory, a theory concocted just 'for this purpose'. There is nothing wrong with *ad hoc* theories - they may even turn out to be true - but they are weak, usually little more than narrow hypotheses born in faith. They may be useful, but we do not place much trust in them. The prescientific theory has much in common with instrumentalist interpretation of theory.

The case against demons is: they are **arbitrary**, **unreasonable**, **multitudinous**, and **overdressed**. We need a special demon with special attributes to account for each fact. We prefer something simpler, more economical: a consistent body of knowledge, with strong ties to experiment, and with cross-checks and interlinkages to assure us of its validity.

So, for Rogers, the test of a good theory is not success versus failure but remains simplicity and economy versus increasing complexity or clumsiness. The best theory is the one that is most fruitful, economical, comprehensive, and intellectually satisfying.

Then, as theory grows from a single speculative guess to a general form of knowledge that fits many observed effects, we trust it more and more. We are so pleased with its consistency and fruitfulness that we say: 'The entities implied by our theories must exist.' The realist takes his theories and their implications seriously, whereas the instrumentalist regards them as fictions and useful tools. The realist tends to hold on to his theories, and will change them only if they continually fail severe tests, whereas the instrumentalist is quite content to change theories with minimal empirical evidence. So it seems that instrumentalism is an immature form of realism. Hodson (1982, p.26) rightly states that it is the **path of science** to proceed **towards a realist theory by way of instrumentalist theories** (or models). Contemporary theories are instrumental, but are **moving towards realism.**

The task of science can hardly be understood if we are not realists. If our theories, that is, our scientific conjectures, can conflict with the facts, then these facts must somehow reflect an external real world.

However, naive realism also has its problems, for it does not take the constructivist nature of scientific theory into account. Thus a compromise view between the extremes of naive realism and naive instrumentalism, but which also accommodates constructivist psychology, will be sought. Such a view is called **critical realism.**

2.3.4 Theories and models

A model may be regarded as a simplified structural representation of a theory. It should not be identified with the theory. Models may be used to connect theory and experience, experience with imagination, theories with other theories, imaginative creations with formal theories. A model is an analogy or metaphor for the real situation. It may take various forms: hardware, pictorial, word-metaphorical, mathematical.

The critical realist uses a model in an instrumentalist way. It may be useful even if it is not true. The scientist uses it **as if** it is true. For no model corresponds in every way with the phenomenon it is representing. Thus the critical realist distinguishes clearly between a model and its broader theory. The model is instrumental and useful, whereas the theory is explanatory and more fully real. The instrumentalist, however, makes no distinction between theory and model.

Science often approaches a realist theory by way of tentative instrumentalist models. The distinction between model and theory is therefore made in terms of 'degree of uncertainty'. A theory is a more certain structure than a model.

2.3.5 Experiments and theory

Experiments are conducted within a particular theoretical matrix, which governs the choice of a problem, the experimental design, interpretation of the results, and so on. No theory-independent experiments are possible. Science is theory-driven, rather than experiment-driven. Pre-existing theoretical understanding gives purpose and meaning to experiments. Yet it is still a widely-held view that all science results from experimentation.

The view is now out-dated that theory-generation is little more than "a process of looking for regularity in nature" and that theories are "simple guesses about nature, of the kind that children produce for themselves after a few moments of laboratory experience". (Hodson 1989, p.55) Theories, in this now-abandoned view, are subordinated to the facts, and easily validated by observation.

Another prevalent myth, says Hodson (1989), is that scientists can establish 'truth' by means of crucial experiments. A hypothesis can be rejected, and another accepted, on the evidence provided by a simple experimental test. This kind of naive interpretation of the Popperian notion of falsification carries with it the assumption that theory-independent evidence is available. If rival theories are incommensurable, there can be no crucial experiment that can decide between them. Such experiments (continues Hodson) would require competing theories to make opposing predictions regarding the same events. In practice, competing theories address the world in different ways (often using different concepts) and, therefore, make different kinds of predictions about observable phenomena. Therefore, it is usually only possible to provide an experimental evaluation of a theory on its own terms.

Experimental testing of theories is not, therefore, an infallible, single-step but a multi-step decision-making process monitored and validated by the scientific community. Scientists who accept a particular theoretical structure may find it difficult to recognise deficiencies in that structure, because theoretical biases blind them to the theory's shortcomings and prevent them from obtaining suitable counter-evidence. According to Feyerabend (1977), a theory's success in explaining facts is guaranteed, because the theory creates its own supporting evidence and excludes facts which would refute it. So a new theory is often needed to show up errors in the old one by providing an alternative perspective. The new theory may be supported by a test which was not even possible within the context of its predecessor, and the earlier theory may be rejected on the basis of an observational test that would have been quite inconceivable within the conceptual framework of the old theory. Thus it may be necessary, on occasions, to introduce theories that are inconsistent with the existing theory. As Hodson (1989) points out, whether or not we accept Feyerabend's claim, it is clear that correspondence with the experimentally gathered facts does not necessarily afford any increased truth status on a theory. It simply means that it **may** be true.

2.3.6 Theory is part of reality

Scientists often treat some theories as real, but others as instrumental models. If so, which theoretical entities are, in fact, real, and which are useful fictions? How do we decide? Hodson (1982b, p.27) suggests that we should perhaps follow Dewey's distinction between the statements 'theoretical entities are real' and 'theoretical entities exist'. The physical world is real and scientific theories are real, but they are not identical. There is an ontological distinction between them. 'Dragons' and 'phlogiston' are real, but they do not exist. Similarly, 'electron' and 'magnetic field' are real concepts, having an existence independent of individuals. But we do not know whether they actually exist or not. We **believe** that they do, but a change in theory may lead us to change our opinion in the same way that a change in theory led us to change our views regarding the existence of dragons and phlogiston.

Both Hodson (1982a,b) and Selley (1981) advocate realism, but their views of reality are significantly different (Hodson 1985, p.33). Selley's view is that reality is best represented as a **continuum** from direct sense experience to pure conjecture. The reality of an entity depends on the immediacy of our experience of it, which may be a mixture of direct observation and theoretical inference. There are degrees of reality. Some things are more real than others, but even the least real are nevertheless real. Hence electrons and photons are real.

My own view is that there is a continuum from direct observation to pure conjecture. There are **levels of reality**. Even direct observation is, to some extent, theory-laden. So as Popper said, all we know are our theories. But I do agree with Hodson that there must be a distinction between conceptual reality and ontological reality. Although we may not have direct, untainted access to the existing world, our great confidence in our cognitive faculties enables us to cope very well with our world of theories.

2.3.7 Summary

Scientific theories are not simply inductive generalisations rigorously obtained from observational data, and able to be falsified by observational evidence. Rather, theories are complex structures produced by the human mind, which may be retained in spite of falsifying observations. They need time to grow before being severely tested. A new theory may have to be introduced to provide evidence for the rejection of an old theory.

2.4 Origins of instrumentalism

2.4.1 Saving the appearances

Instrumentalism has its origins in the compartmentalised thinking, the "controlled schizophrenia", as Koestler put it, which began to emerge with the Greek astronomers around the 2nd century A.D.

In order to account for the retrograde loopings of planetary paths, Ptolemy devised a complex system of forty wheels-within-wheels or epicycles. He clearly never believed that there really were wheels out there, but they did 'save the appearances' and provide a mechanism for accurately predicting the position of any planet. He therefore 'saved the phenomena' by inventing a suitable hypothesis, regardless of whether the hypothesis was true or not, that is, whether it was physically possible or not. As Koestler (1959, p.74) pointed out,

> "astronomy, after Aristotle, becomes an abstract sky-geometry, divorced from physical reality. ...It serves a practical purpose as a method for computing tables of the motions of the sun, moon and planets; but as to the real nature of the universe, it has nothing to say."

Ptolemy's theory was concerned only with predicting, and not with a true description of the universe. Copernicus, however, put forward a theory which not only **predicted**, but also **explained**. The Copernican theory provided a more comprehensive conceptual structure, which had a much greater power for promoting **understanding**. It revealed a **physical** link between planetary motion and theory. Copernicus believed that his heliocentric theory was a true description of external reality. Kepler (quoted by Koestler 1959, p.169) verifies this:

> "He (Copernicus) thought his hypotheses were true."

Kepler was commenting on the famous Preface to Copernicus's book "*De Revolutionibus*", which was written by Osiander, a friend who tried to protect Copernicus from Aristotelians. Osiander had written:

> "For these hypotheses need not be true..."

It seems that Copernicus was shocked by this insertion. Yet there can be no doubt that Osiander was acting with the best of intentions, for two years earlier, when Copernicus had been hesitating about publishing his book, Osiander had written a letter to him, saying:

> "For my part I have always felt about hypotheses that they are not articles of faith but bases of computation, so that even if they are false, it does not matter, provided that they exactly represent the phenomena..." (in Koestler 1959, p.167)

Osiander was obviously aware that the Copernican theory was more than a sky-geometry: it was a true physical description. However, by presenting it as a hypothetical device for prediction rather than a description of how things are, the problems of theological confrontation were skirted.

Thus, even though Copernicus still resorted to the use of epicycles, his heliocentric theory was not a mere fictional hypothesis, like Ptolemy's. It did not matter whether you believed Ptolemy's epicycles or not. All that mattered was that his theory worked. However, the Copernican theory had to be taken seriously, for it attempted to describe what was physically really out there. Copernicus's sun-centred system was far more than only a computational device.

This concern with the results of observations from instruments in order to predict, without any attempt at **physical** explanation, is typical of what is now called **instrumentalism.**

2.4.2 Nominalism and phenomenalism

Common-sense tells us that there is something behind the surface view of the objects we see. We can treat a computer as a black box, and work it quite efficiently without knowing how it works. But at the back of our minds we are aware that there is something at work deep down. The superficial, sensed experience is called the **phenomenon.** It is what **appears** directly to the senses.

Classical realists held that there is a reality behind appearance. They held that there is a real 'substance' of 'computer-ness' within any particular computer which gives this machine the form of a computer. The trouble with this type of realism is that the existence of such real 'substances' cannot be verified by the senses. **Phenomenalists**, on the other hand, say that there is no reality behind appearance.

William of Occam (1290-1350) severely criticised the Scholastic tendency to create unnecessary metaphysical entities behind appearance. Reality, said Occam, is precisely what appears to the sense. All our knowledge about the world comes through our senses. All being is thus reduced to what is perceived.

Occam's desire to get rid of any superfluous principles became known as 'Occam's Razor'. His philosophy was the first formal emergence of **empiricism**, a theory of knowledge which based itself on pure sensory experience. It regarded classical realism as too metaphysical, for there is no evidence that something lies beyond phenomena. Empiricism, therefore, tends to be phenomenalist.

Occam's contention that concepts were only words gave rise to the term **nominalism**. The chief argument against nominalism is that it is arbitrary and subjective. It leads to a theory of knowledge which concentrates its attention on language and the meanings of words. Concepts are merely tools of thought. Similarly, scientific theory, for nominalists, is only an instrument for organising our thoughts. Theory is not explanatory, nor is it informative about the world. Hence nominalism ends up by becoming too inward-looking, too caught up in word games, instead of coming to grips with the real physical world.

Theologians were quick to realise that Occam's radical empiricism meant that spiritual beings, and in particular God, were threatened. Naive nominalism propagated a phenomenalism which endangered the whole structure of religion, and was understandably regarded with suspicion by the Church of its day.

2.4.3 Galileo's realism

Galileo accepted the Copernican heliocentric theory as a true description of the real physical world. Because this seemed to conflict with Aristotelian cosmological views, as well as certain aspects of Scripture, Cardinal Bellarmine objected to this realist interpretation. However, he informed Galileo that it was permissable, from the Church's standpoint, to believe in the Copernican system as a mathematical device for saving the appearances. To quote Bellarmine (Koestler 1959, p.447):

> "For to say that the assumptions that the Earth moves and the Sun stands still saves all the celestial appearances better than do eccentrics and epicycles, is to speak with excellent good sense and to run no risk whatever."

In other words, realism can be set against intrumentalism. The Church, which usually held a strong realist standpoint, was willing temporarily to accept Galileo's theory in a phenomenalist, instrumentalist sense. This neatly sidestepped theological problems. Ironically, today it is science, rather than the Church, which accepts instrumentalism. Instrumentalism is thus a convenient, safe retreat from any metaphysical issue.

2.4.4 Newton: Instrumentalist or realist?

Newton's formulation of the Law of Universal Gravitation and his three laws of motion is still regarded as one of the greatest scientific achievements of all time . Historically, Newton's theory was the first really successful **physical** theory. The seeds of a physical theory were present in Copernicus's system, and these seeds germinated and bore fruit in Kepler's work. When Kepler looked for a mathematical relation between a planet's distance from the sun and its period, he came up with his Third Law, which was no more than an empirical law to fit the observational facts. But then Kepler asked himself **why** the planets moved in this way. Koestler (1959, p.258) explains it thus:

> "Nobody before Kepler had asked the question **why** this should be so. ... Kepler's answer was, that there must be **a force emanating from the sun** which drives the planets round their orbits. ... It would be difficult to over-estimate the revolutionary significance of this proposal. For the first time since antiquity, an attempt was made not only to **describe** heavenly motions in geometrical terms, but to assign them a **physical cause.**"

Kepler did not use the word "force"; he spoke of a "moving soul" of the sun which drove the planets, like rotating, sweeping brooms: his ideas were still primitive and partial.

Newton addressed himself to solving the problem of planetary motion. He brought the works of Galileo and Kepler together in a powerful, unifying theory. The key pieces of the puzzle were Kepler's laws of planetary motion, Galileo's laws of falling bodies and projectiles, and Descartes's notion that inertia made bodies persist not in circular (as Galileo suggested) but in straight line motion.

Kepler had toyed with the idea of "weight" as the mutual attraction between two bodies, but he shrank from the fantastic notion of a gravitational *anima mundi*. Newton applied Kepler's Laws to the orbit of the Moon. At the same time, he drew on Galileo's laws of projectiles. He then identified the Keplerian orbit of the Moon with the Galilean orbit of a projectile, which he postulated was continually falling towards the Earth, but was unable to reach it because of its rapid forward motion. The paths of planetary motion were the resultant of the interaction between the force of gravity, which was inherent in any mass, and centrifugal force, which was not a force at all, but simply a special case of Newton's First Law of Motion. Gravity fills the universe, according to Newton, with interlocking forces of attraction, issuing from all particles of matter and acting on all particles of matter.

Newton was aware of the metaphysical problems of his concept of gravitation. He did not easily accept the idea of action at a distance. He wrote (quoted in Koestler 1959, p.503):

"It is inconceivable that inanimate brute matter should, without the mediation of something else, which is not material, operate on, and affect other matter without mutual contact."

He went on to say that it seemed to him to be an absurdity that the innate gravity of one body should act upon another at a distance through a vacuum. Gravity, he said, must be caused by an "agent", but he did not explain what he meant by this "agent". Yet,in spite of this, our textbooks do not hesitate to attribute to Newton the idea of gravitational attraction as an intrinsic characteristic of matter, as Powers (1982, p.45) points out.

Similarly, in order to describe "true motions" of bodies, Newton postulated the existence of Absolute Space. Although he contended that there was observational evidence (for example, in his famous bucket experiment) that absolute motion could be distinguished from relative motion, it is clear that there is a difference in what we see (the concavity of the water surface), and our interpretation of it (absolute motion). In other words, says the intstrumentalist, absolute space is a metaphysical concept.

The same could be said of Newton's First Law of Motion. It would seem that it is impossible to test it, for can a body ever be completely free of external forces acting on it? Thus the law is purely axiomatic, speculative and metaphysical in nature.

Newton assumed that matter was made up of particles. Atomism is a very appealing scheme for making 'change' intelligible. Change or motion can be explained in terms of the geometrical rearrangements of fundamental particles. However, as Powers (1982, p.33) notes, once we are committed to this atomistic approach we are bound to distinguish between two sorts of properties: (a) **primary qualities**, those properties actually possessed by the real object; and (b) **secondary qualities**, those properties produced by interaction with our sense organs. This distinction between primary and secondary qualities was first postulated by Galileo, and later expanded upon by Locke. Not only is it non-empirical (that is, not given in immediate experience), but it has led to the reduction of the real physical world into a dualism of mathematical entities on the one hand, and a set of irrelevant characteristics on the other. Galileo, and later Newton and Locke,

"banished the qualities which are the very essence of the sensual world - colour and sound, heat, odour, and taste - from the realm of physics to that of subjective illusion." (Koestler 1959, p.529)

Doubtlessly, this enabled science to progress with unprecedented speed and success, but, as Koestler pointed out, the price was high. Without a supportive, all-embracing, unifying explanation; without a full-blooded theory (even bordering on the metaphysical), science has carried man to the brink of self-destruction. Today, science is "sailing without ballast", in Koestler's words, and reality is gradually dissolving between the physicist's hands.

Was Newton a realist, or an instrumentalist? So much of his theory relies upon axiomatic deductions and rationalist schemes, that one is tempted to say "instrumentalist". If he was merely instrumentalist, then his theory would not really be novel and informative about the world. For example, does his substitution of *gravitatio mundi* for *anima mundi* add to our knowledge? Does "gravity" explain any further than "soul"? Is it more informative about the physical world? It seems that only the name has changed. Yet I believe that, in the Newton's mathematical formulation of the idea, we have learned something new about the world. The metaphysical concept of gravity (and it is metaphysical, for it cannot itself be observed, but only its effects), **together with** the mathematical formulation, point to a realist explanation.

The mathematical formalism by which Newton related mass, force and acceleration, in order to yield reliable predictions, suggests that his empiricism was instrumentalist in orientation. But the very fact that he was knowingly willing to adopt a metaphysical **explanation,** such as the notion of universal gravitation, to explain **why** his formulas worked, is convincingly realist.

To sum up, then, it is clear that Newton was securely empirically based, both in his mechanics and his optics. He drew on the empirical data of both Galileo and Kepler. He maintained a strong link with the real physical world. He consistently followed a strict inductive, scientific method, as Losee (1980, p.81) noted. His mathematical formalism enabled computative predictions to be made. In this regard, his theory was positivist and instrumentalist. However, Newton's theory not only **predicted**, but it **explained.** It provided a unifying, satisfying intelligibility, precisely because Newton was courageous enough to risk his intellectual integrity on metaphysical concepts like gravity. Newton was a scientific realist. Instrumentalists are far too cautious, and therefore their theories remain sterile.

2.4.5 British empiricism reinforces instrumentalism

Empiricism, as a philosophy of science, holds the apparently down-to-earth, common-sense view that all our knowledge comes through our sensory experience. At first sight, this seems undeniably and obviously true. Empiricism emerged during the great rise in science following Galileo and Newton. Physics rapidly became the model of how knowledge was obtained. The rationalism of Descartes had been fashionable, but now was superceded by the certainty of the inductive, empirical approach. Observations and measurements, obtained under specified conditions, emphasised that reliable knowledge was gained only through our senses. These ideas were taken up by John Locke, George Berkeley, and David Hume. Immanuel Kant later further elaborated and criticised these views.

It is necessary to distinguish between empiricism as a philosophy of science, and empirical scientific method. The latter is a well-known procedure in scientific inquiry. Its emphasis on sensory observation is a factor in its success. But it easily leads to the attitude that only knowledge obtained by sensory observation is valid. That is, it is but a short step from empirical method to empiricism.

2.4.5.1 Locke's empiricism

John Locke (1632-1704) may be regarded as the founder of empiricism as a theory of knowledge. He maintained that all our knowledge is derived from experience. At birth, the mind is a *tabula rasa*. Our ideas are obtained from two sources: sensation, and reflection on other ideas. So all our ideas originate in sensation. Knowledge gained in this way seemed to Locke to be far more sound and certain than the rationalist approach of Descartes.

Locke distinguished between our **ideas** and the **things** of the external world. It is the action of things upon our senses that gives rise to our ideas of things and their qualities. Things are not in our minds: ideas are. Locke, therefore, was a **realist** insofar as he held that an external world exists apart from our minds. He also held a **causal theory of perception**, that is, the view that our sense-perceptions are the mental effects of the actions of things upon our senses.

The notion of the mind as a blank slate has overtones of **passivity**: the mind simply absorbs impressions from the senses. However, to form complex ideas, the mind must actively join together simple ideas.

Locke distinguished between **primary** and **secondary** qualities. Primary qualities are those that are inseparable from the object, such as solidity, extension, mass, and motion. Secondary qualities are those that do not belong of necessity to the object, such as colour, sound and smell. The primary qualities, he maintained, are in the object; the secondary, however, are only in the observer. Without the eye, there would be no colour.

For Locke, there is a reality behind these qualities, but we can never sense it directly. Thus, we can never know the real substance of things. All we perceive are their qualities. Reality, for Locke, is purely **phenomenal**.

It is important to note that Locke's empiricism has, pragmatically, been useful. The strength of the empirical method lies in its attempt to be precise and objective; its weakness, in that it does not go far enough. Sensory experience is only part of scientific insight, as Bernard Lonergan (1957) correctly pointed out. The tendency of science to remain fixated on sensory experience alone (that is, so-called objective observation and measurement), has been problematic for science.

Locke's empiricism leads us to a serious problem, namely, that if sensations are caused by things outside of us, how can we know this? For we experience the sensations, not their causes. Our experience would be exactly the same if our sensations were to come about spontaneously. Open-brain stimulation by probes can trigger off the sensation of taste, even though the tastebuds are not themselves used. In other words, if we hold a naive empiricism, we cannot say with any certainty that an external world exists apart from us. It may, but all we can say for sure is that we experience sensations. We become locked within ourselves, and end in a "forlorn scepticism", or even idealism.

Locke's contention that without the eye there would be no colour seems to be on firm ground, because the observer does "add to" the thing observed, much as sun-glasses "add to" the incoming light. But Berkeley (see section 2.4.5.2 below) pointed out that the same argument would also apply to the primary qualities. All qualities, maintained Berkeley, are in some way secondary.

Locke's distinction between primary and secondary qualities is the source of the current debate about the theory-dependence of observation. There is much truth in Berkeley's criticism, for all observations are interpretations. Although Locke assumes an external reality, he concludes that we cannot know it, because it is not accessible to sensory experience. We can only know phenomena, not the reality beyond them. Since all we know are our sensations, we remain trapped within our own experience, and end up in either **scepticism** or **idealism.**

It is the intriguing paradox of empiricism that, on the one hand, it has produced the most powerful and reliable body of knowledge the world has ever known, namely, scientific knowledge, and on the other, if followed to its logical conclusions, we paint ourselves into a corner and end in doubt and a sense of unreality. This brings us to Berkeley.

2.4.5.2 Berkeley's Instrumentalism

George Berkeley (1685-1753) was also an empiricist. He, too, held that we can have no knowledge of anything that does not first come through the senses. However, he rejected Locke's conclusion that we cannot know true reality. He refused to wallow in the scepticism of Locke. After all, empiricism was the basis of physical science. To end in scepticism was to undermine science. Berkeley suggested that scepticism arose only because Locke's assumptions were not sound. Locke had assumed that there was a reality behind appearance, but that we could not have knowledge of it because it was not directly available to the senses. Berkeley questioned the existence of this world beyond the phenomenon. To assume a mysterious, unknowable substance behind appearance merely creates unnecessary problems. Said Berkeley: "We have first raised a dust and then complain that we cannot see." He contended that we can know all that there is to know about things, for there is nothing more to know about things than we can observe by our senses. Reality is what appears to the senses. Phenomenal reality is the only reality.

It is important to understand correctly what Berkeley meant. The belief that there is something "deep down things", as the poet Gerard Manley Hopkins put it, to preserve the regularities of things, is a widely-held common-sense conviction. Berkeley never doubted this. What he opposed was the view that the reality behind appearance was in some way **material** or **substantial.** For him, it was more like an idea, or something spiritual. Modern physics, according to Gardner (1983) supports his view, for the quantum mechanical view of matter is that it can be regarded as a form of energy with wave properties. Berkeley would have said that an electron, for example, may (or may not) exist, but because it is directly unobservable by the senses, it cannot exist without a mind to support it. "To be, is to be perceived", said

Berkeley. Indeed, according to Berkeley, nothing can exist without a mind to perceive it. Gardner (1983, p.15) summarises Berkeley's views as follows:

> "If we cannot observe it, we cannot know it. In other words, if no mind existed in the universe and a single object were suspended in space-time, it is meaningless to say that the object exists. To claim existence, matter needs to be perceived by a mind."

Now, this smacks of idealism, or, as Berkeley preferred to call it, "immaterialism". Yet he was not denying that stones resist kicks. Something **is** out there, independent of ourselves. For classical realists, it was a real "substance" behind the phenomenon. For Berkeley, it was God.

Berkeley assumed that a material "something" to explain reality is unnecessary. For this alleged hidden substance behind reality adds nothing to our knowledge. We can get along very well without it, for it performs no explanatory function whatsoever. Therefore it is a useless hypothesis, and, according to Berkeley, we should get rid of it. Let reality be simply what appears to the senses.

Berkeley's brand of empiricism is known as instrumentalism. An instrumentalist approach to science is thoroughly phenomenalist. That is, it assumes (and it **is** an assumption!) that reality is fully perceived by observation. Some instrumentalist scientists might say that there **may** be something more to reality than what appears, but there are no grounds for assuming this. Therefore, look only at **regularities** in **phenomena**, so that **rules** can be made in order to **predict**. Scientific theory is not informative about the physical world. Rather, it is but a **useful fiction** or **tool** to aid prediction.

What brought Berkeley to this philosophy was his criticism of Newton's theory. Newton himself had distinguished between treating "forces" as formal mathematical correlations, and as really existing. Berkeley held that Newton was correct to hold this distinction. But what upset Berkeley was that Newton talked about forces as if they were something more than terms in an equation. As Losee (1980, p.160) points out, Berkeley maintained that forces in mechanics were analogous to epicycles in astronomy. These mathematical devices were useful in calculating the motion of bodies. But, according to Berkeley, it is a mistake to attribute a real existence to these constructions. Newton's reference to "attractive forces" is misleading, for they are mathematical entities only.

The point is that we do not directly perceive "force" by sensory experience. What we observe are the effects of the motions of bodies under certain conditions. In Berkeley's own words:

> "In this as in other instances, I do not perceive that anything is signified besides the effect itself." (in Burtt 1939, p.558)

Empirically, we can have no knowledge of forces. They are mental constructions to account for the cause of motion. Minds are the only causal agents, not forces. Causality is imputed to things by the mind. Forces do not exist in themselves. They are purely useful book-keeping tools. Newton's Laws are nothing but computational devices for the description and prediction of phenomena. The terms expressed in the laws need not refer to anything that really exists in nature. Nevertheless, Berkeley conceded that such terms as "force", and "impetus", do have an important use in mechanics.

As for "gravitation" and "absolute space", they are unnecessary metaphysical entities, mysteriously lying behind the phenomenon. Newton's attempt to explain "true motions" in terms of absolute space was invalid, because absolute space did not exist. It was only a metaphysical invention. Hence science could deal only with relative motions.

Similarly, the notion of "mass", so important to Newton's theory, was simply a mental construct. Locke had suggested that mass was a primary quality, inherent in an object. But Berkeley's insistence that all qualities were secondary and existed only in the perceptual experience of the subject, meant that mass was in the mind. In my view, this was a fore-runner of our contemporary notion that all observation is theory-laden.

Berkeley's criticism of Newton's theory is consistent with his instrumentalist emphasis. Berkeley was anxious to defuse any materialist implications of the new science, as Powers (1982, p.109) notes. But in doing so, he argued his way from a radical empiricism to an idealist metaphysics. Only ideas and mind exist. Ultimately, the external world is simply a collection of perceptions maintained in existence by the mind of God.

2.4.5.3 Hume's views on Causality and Induction

David Hume (1711-1776) also shared (with Locke and Berkeley) the empiricist assumption that we never perceive anything except our own ideas. All our knowledge comes from experience. We can know only what we directly perceive. But what we directly perceive is only our own sensory impressions. We remain trapped within ourselves. We cannot know the true nature of things, because these lie beyond our experience. We can continue to do empirical science; but the conclusions drawn from science never attain the status of genuine knowledge. Thus Hume's empiricism led him to **scepticism**.

Induction is the mental process of making generalisations from a number of particular observations. Aristotle advocated its use in finding general laws. Induction, says Magee (1973, p.19), "is seen as the hallmark of science". Hume raised some awkward questions about induction. He postulated that no number of particular observations, however large, could logically lead to a universal general statement. We may have made a thousand observations of the sun rising, but that does not guarantee that it will rise tomorrow. No number of observations of white swans allows us **logically** to conclude that "All swans are white". In scientific inquiry, scientists usually conclude, from a large number of experiments, that **all** cases hold under certain conditions. For example, "Water, at a certain pressure, always boils at 100^{o} C", or "All copper objects are good conductors of electricity". Such generalisations go far beyond the evidence. For we have never seen all copper objects, nor tested all water. This "going beyond empirical evidence" is at variance with the empiricist doctrine.

The problem of induction has baffled philosophers of science for centuries. That the whole of scientific knowledge should rest on such apparently shaky foundations is, as Magee says, "uniquely embarrassing". It turned many into sceptics, or irrationalists. In practice, scientists are aware that scientific laws cannot be proved with certainty. However, every confirming instance increases the degree of probability of the law. The important thing is that science works; it delivers the goods. But this is like building a house on a foundation known to be insecure.

Hume also addressed the problem of **causality**. What do we mean, when we say that A causes B? If billiard ball A collides with billiard ball B, can we say "A caused the motion of B"? For we cannot empirically experience "cause". There is nothing more than the contiguity and succession of events. From many prior experiences, we learn that event B always follows event A. We recall their constant conjunction in all past instances. So we call the first the "cause", and the second the "effect". The important point to note is that, according to Hume, this is simply a psychological conjunction.

Having started from the sensible and empirical, Hume arrived at the disastrous conclusion that nothing is to be learned from experience and observation. Such is the paradox of empiricism. Empiricism is a common-sense theory of knowledge, yet, as Popper (in Miller 1983, p.106) rightly states, "the common-sense theory of knowledge is liable to lead to a kind of anti-realism".

2.4.5.4 Kant's reply to empiricism

Hume's arguments awoke Immanuel Kant (1724-1804) from his "dogmatic slumbers". Instead of empiricism leading to knowledge which was certain, it ended in uncertainty. Rationalists such as Descartes had held that rationalism was a much better way to certainty. But Hume's analysis of cause and effect challenged reason. He demonstrated, said Kant, that it was impossible to gain knowledge by pure reason alone.

Kant attempted to marry rationalism with empiricism. He agreed with the empiricists that all our knowledge begins with experience, but he rejected the empiricist thesis that it all arises out of experience. He contended that some of our ideas are contributed by the mind itself. The mind **structures** knowledge. Experience is not simply an unstructured stream of consciousness, but rather a unified, organised whole. The mind is not the passive copier of impressions that the empiricists maintained it was. Rather, it **actively** structures experience. Order is imposed on the world by our minds.

In order for appearances to be understood at all, they must be structured in terms of the categories of the understanding. Experience involves the ordering of our impressions in a regular and ordered way, according to certain rules. If it were simply random, we would be left with only an unstructured stream of impressions.

Our minds add to our sensory experience. Our knowledge of the world is, so to speak, filtered through our mental categories. Concepts such as "cause", "space", "time", and "substance", are categories of our minds. Our minds impose these concepts on the sensory impressions gained from phenomena. But we should not extend the application of these concepts beyond the objects of possible experience, that is, beyond empirical reality. They have **objective** validity within the realm of phenomenal experience, but not beyond. Thus they are objective, and not merely subjective, as Hume had suggested.

For Kant, empirical reality is phenomenal reality. Our perceptions represent appearances only. As appearances, they cannot exist in themselves, but only in us. What objects may be in themselves, remains completely unknown to us. We can know phenomena, but not the reality behind phenomena. Kant thus held a phenomenalist position, while acknowledging the existence of a hidden reality behind appearance.

Kant regarded himself as a realist, and attempted to refute idealism. He could be classified as a realist, because he held that there is an external (but knowable, phenomenal) reality, which causes our sensory impressions. Kant thus subscribed to a causal theory of perception. But because true reality is, for Kant, ultimately unknowable, he never actually escaped from idealism.

Kant is closer to the realism of Aristotle and Thomas Aquinas, with its emphasis on active intellect, than the cold, passive realism of the empiricists. As Lindsay in *Critique of Pure Reason* (1959, p.xvi) says:

> "There is a halfway house between the realism of ... a passive mind and the idealism of ... a creative mind."

As Schacht (1984, p.247) succinctly puts it, we know less than what the rationalists say we do, and more than the empiricists think we do.

2.4.6 The Inductivism of J.S. Mill

Inductivism is a point of view that emphasises the importance to science of inductive arguments. Scientific inquiry is a matter of inductive **generalisation** from the results of observations and experiments. The philosophy of science of John Stuart Mill (1806-1873) is an example of the inductivist view.

Mill stressed the importance of induction in science. He claimed that every causal law known to science had been discovered by one of four inductive methods. He put forward strict **rules** governing the use of induction in hypothesis-making, and for the verification of hypotheses. Because of his over-emphasis on inductive rules, he has been accused of stifling the role of the imagination in hypothesis-making.

Yet Mill was aware of the importance of deduction in scientific method. Indeed, he was convinced that the great Newtonian synthesis was the fruit of hypothetico-deductive method rather than inductive method. Mill's method was simply a strong endorsement of the scientific method advocated by Bacon, in which **observation** was structured so as to preserve objectivity as far as possible, and **generalisations** were made along inductive lines.

However, as Popper later pointed out, the use of empirical **verification** of many particular cases to confirm a law, merely gives the impression that scientific laws are absolute. In this way, said Popper, inductive verification leads to intellectual stagnation.

Further, Popper maintained that no observation is objective. All observation is saturated in prior theory. Thus observation cannot be separated from theory.

2.4.7 Mach's Instrumentalism

Ernst Mach (1838-1916) developed a critique of Newton's philosophy of science that was strikingly similar to the critique given by Berkeley. Mach shared Berkeley's instrumentalist approach to scientific theories. He declared that

> "it is the object of science to replace, or save, experiences, by the reproduction and anticipation of facts in thought". (Mach in Losee 1972, p.163)

According to Mach, scientific laws and theories are implicit summaries of facts. They enable us to describe and anticipate phenomena, in the most economical way, with the least possible expenditure of thought.

Mach also shared Berkeley's conviction that it is a mistake to assume that the concepts and relations of science correspond to that which exists in nature. Theories about atoms may be **useful** for the description of certain phenomena, but this does not mean that atoms really exist.

Like Berkeley, Mach also refused to posit a realm of reality behind the realm of appearance. He was a thorough-going **phenomenalist**. Mach himself stated that

> "What we represent to ourselves behind the appearances exists only in our understanding, and has for us **only** the value of a *memoria technica* or formula, whose form, because it is arbitrary and irrelevant, varies very easily with the standpoint of our culture". (Mach in Losee 1972, p.163)

Mach attempted to reformulate Newtonian mechanics from a phenomenalist standpoint. He hoped to show that mechanics could be divested of "metaphysical" concepts such as atomism, force, gravitation, mass, absolute space and time. He used a procedure called **operationalism**. For example, he attempted to give an "operational definition" of "mass". This meant defining mass in terms of the procedures by which it is measured, preferably in mathematical terms. As Powers (1983, p.35) notes,

> "His operational definition for 'mass' made use of Newton's Third Law of Motion and is often cited as a fine example of a positivist clarification of a scientific concept."

By combining the Second and Third Laws, we can deduce the law of conservation of momentum. Since momentum is defined as the product of mass and velocity, Mach argued that we can define the ratio of the masses of two interacting bodies in terms of the ratios of their changes in their velocities. In this way we are defining mass in terms of measurable quantities. Similarly, we can eliminate the metaphysical element of 'force' by defining it as the product of mass and acceleration.

Mach's refinements certainly clarify Newton's ideas. By ignoring metaphysical concepts, the theory becomes much more clean-cut. Unfortunately, however, operational definitions of mass violate some of the essential mathematical characteristics implicit in Newton's idea of the quantity of matter. As Powers (1983, p.37) points out, operational definitions

> "severely restricted the range of ideas that Mach was prepared to countenance, and he questioned not only absolute space and time, but also the existence of atoms and, later, the theory of relativity as well."

2.4.8 Positivism

Positivism is a tough-minded empiricism which holds that nothing can be known to be real except what might be observed. It is an anti-realist approach to science which is not interested in whether theoretical entities, such as electrons and photons, really exist or not.

Hacking (1983, p.41) lists six characteristics of positivism:
(1) An emphasis on **verification**.
(2) An emphasis on **observation**.
(3) Against the idea of **causality**.
(4) Downplaying **explanations**.
(5) Against **theoretical entities**.
(6) Against **metaphysics**.

Positivist scientists emphasise verification. Significant propositions are those whose truth or falsehood can be settled in some way, usually by evidence gained by observation. Observation is impersonal and objective. There is no causality in nature, only constant regularities. One event simply follows another. Explanations may help organise phenomena, but do not provide any deeper answer to "Why" questions except to say that the phenomena regularly occur in such-and-such a way. Entities referred to in theories may or may not exist. Positivists tend to be non-realists, not only because they restrict reality to the observable, but also because they are against causes and are dubious about explanations. Finally, they are opposed to anything metaphysical. Untestable propositions, unobservable entities, causes, deep explanations: these, says the positivist, are the stuff of metaphysics and must be eliminated.

Instrumentalism is closely related to positivism. It also has all of the above six properties, but emphasises the one concerning theories. Theories are not true descriptions of reality, but rather only fictions to assist computational predictions. So, in addition to the above six characteristics of positivism, we can add "emphasis on rules and computational predictions".

For example, a positivist view of Newton's gravitational 'field' states that it is simply a calculating device. A field cannot have real existence. For in Newton's theory, a change in the position of one object would register **instantaneously** at the other. This is impossible. Therefore, say the positivists, gravitational field is not physically real, but only a theoretical **fiction** for coordinating our predictions.

In contrast, Faraday believed that fields were real because iron filings sprinkled around a magnet fall into curved patterns. Also, Faraday's concept of field implied that it carried energy, which seems a strong reason for thinking of his field as real, as Powers (1983, p.47) correctly points out. The positivist, instrumentalist view cannot properly account for the concept of field. Indeed, the experimental success of Faraday with his idea of field meant that it had to be taken seriously. There is some truth in Hacking's (1983) contention that scientific realism wins the battle with instrumentalism when it comes to experimental **intervention**.

Positivism regards both realist theories and instrumentalist theories as valid working hypotheses. Both work in practice, but instrumentalism is more convenient, and this is all that matters.

2.4.9 Logical positivism

In the 1920's, a group of physicists and philosophers, called the Vienna Circle, proposed a **strict form of positivist empiricism**, with a strong emphasis on language and the logical meaning of scientific statements. This came to be known as logical positivism. It reinforced the **inductivist** view, and held that it is meaningless to talk about things that cannot be observed. There is, therefore, nothing behind or beyond experience. For logical positivists, such as Rudolf Carnap, phenomenalism is an adequate approach to science, just as realism is. Both yield successful results. Both work in practice. However, the language of phenomenalism is more **convenient**.

For logical positivists, **verification** and **operationalism** are central techniques. Verification is strongly empiricist, based on objective observation and inductive generalisation. Operationalism concentrates on defining concepts in terms of measuring procedures. This leads to a definite instrumentalist view of theory. Theories are logical constructs.

Logical positivism has profoundly influenced the philosophical attitude of modern science and in particular physics. It advocates a pruning process in order to eliminate metaphysics from science as much as possible. Only statements which are observationally verifiable should be taken as significant. How then can we speak about unobservables such as electrons and photons? Bertrand Russell held that unobservables are inferred entities, and should be linked to direct observation statements by logic.

The chief criticism of the verification principle is that it relies strongly on induction. As we have seen, inductive statements go beyond the facts. They contain more information than the evidence warrants. Also, causality is seen in a very restricted light. Physics today plays down causal talk. As Hanson (1971, p.34) observes, physics today is concerned with

> "only earlier and later states of affairs, theoretically construed".

This last point is becoming increasingly noticeable in contemporary science, namely, the awareness that science is theory-laden. As for operationalism, in spite of the fact that "it works" very well, it reduces science to "a kind of bookkeeping", as Medawar (1967, p.137) puts it.

So, today, logical positivism has fallen from favour. No one today wants to be called a positivist. Positivism is now regarded as too impersonal and anti-social, and as having been a factor in creating the technological ogre. Unfortunately, its influence lingers, especially in school science. Science is still seen as a body of proven knowledge which can provide absolute certainty about the world.

2.4.10 Dewey's instrumentalist pragmatism

A pragmatic approach to knowledge developed as the result of the American frontier experience, in the light of which

> "Americans came to measure success in terms of the consequences which accrued from harnessing the environment for human purposes." (Gutek 1974, p.106)

The pragmatism propounded by John Dewey (1929) has many similarities with logical positivism. It sought to avoid the metaphysical question of realism by denying that there is a dualism of reality and phenomenon. Dewey argued that classical realism was a metaphysical ploy to seek stability in a changing, uncertain world. It tended to promote theoretical, academic speculation rather than practical activity. Children learn through active reconstruction of their experience. Theory is tested in experience. Mind is a social process of solving problems. Questions of real existence are irrelevant. What matters is, not man's quest for certainty, but how he copes with and controls the processes of an imperfect, changing world. Ideas are tentative, instrumental plans of action designed to achieve human ends.

Dewey called his pragmatism **instrumentalism.** For Dewey, language and theories are instruments that mould our experiences to suit our purposes. Our world, and our representation of it, is a social construct. An instrumentalist approach to scientific inquiry tends to be pragmatic and utilitarian.

Dewey's phenomenalist standpoint affected his notion of truth. For most realists, truth is the correspondence between an assertion and reality. For Dewey, truth is that which is confirmed by testing. It is that which works. Truth is created when an assertion is confirmed. This can be illustrated by an example given by Gardner (1983). Suppose there is a penny in a box. The realist says "There is a penny in the box", whether or not the assertion is verified. The pragmatist says "There is a penny in the box", only when, on opening the box, he sees the penny. Truth is instrumental and expedient. Theories are not

> "judged in terms of truth or falsity but rather in terms of their usefulness as instruments". (Chalmers 1986, p.147)

Karl Popper rejects this notion of truth, for it is relativistic. Popper is a "common-sense realist", who holds that the world exists out there independently of whether we believe it or not. A theory can be true even if nobody believes it. By refusing to commit himself to a scientific realism, Dewey has jeopardised scientific knowledge, and risked bringing it to the brink of idealism and a superficial utilitarianism.

2.4.11 Relativity and instrumentalism

Einstein's Special Theory of Relativity of 1905 suggested the idea that simultaneity is relative to a frame of reference. Simultaneity involves measuring times and time intervals. The fundamental problem in measuring time intervals is that, two events that appear simultaneous in one frame of reference do not appear simultaneous in a second frame of reference that is moving relative to the first, even if both are inertial frames. Consider a long train moving at constant velocity. Two bolts of lightning strike the train, one at each end (A and B). An observer on the ground is located midway between A and B. An observer on the moving train is also midway between its ends. Suppose the two light signals reach the observer on the ground simultaneously. He concludes that the two events took place simultaneously. But the observer on the moving train receives the light signal from the front of the train before the other. He concludes that the event at the front of the train took place earlier than the one at the rear. Hence simultaneity depends on the state of motion of the observer, provided that it is assumed that the speed of light does not change.

Neither length nor time can be regarded as absolute: the measures of each will always have to be related to a frame of reference. This preserves Einstein's Light Postulate, namely, that the speed of light is invariant.

These are strange ideas. Even more strange is the fact that Einstein gave them a physical interpretation. However, positivists have urged that they must be interpreted instrumentally: the theory is merely a mathematical device, with no reference to reality. They argue that Einstein's procedure for synchronising clocks in different locations is an operational definition. Hard-line operationalism seems to be arbitrary, dependent on the choice of experimental technique.

Berkeley had long before rejected the idea of true proper motion. He maintained that only relative motion was possible and that absolute space and time were simply fictions. So Einstein's theory was well-received by instrumentalists.

The most disturbing implication of Einstein's theory seemed to be the threat it offered to the notion of 'an independent physical reality'. As Powers (1982, p.87) points out:

> "Classical physics seemed to have a grip on a picture of the physical world as it really is; 'relativity' seems to suggest that this 'real physical world' must forever elude our grasp and that we ought to reconcile ourselves to merely describing the results of measurements - 'saving the appearances' as it was once called."

The instrumentalist interpretation given to relativity theory is part of the "slippery slope from positivism to idealism", as Powers puts it. This seems to give rise to a world of fictions, a case of mathematics putting common-sense to flight. We appear to be back to a new kind of scholasticism, where belief in abstruse calculations takes priority over the evidence of one's senses.

And yet, from the fantasy there emerges a ray of light, which brings us back to earth. For the theory of relativity reveals quantities which are invariant, which - even in common-sense terms - is the best possible reason for saying that it has 'a grip on reality'. (Powers 1982, p.97) The chief among these is the concept of "mass-energy", the idea of energy that converts into mass, and *vice versa* in a magnificent conservation law. Whereas in Newtonian mechanics there are two conservation laws, one for energy and one for momentum, in relativity theory they can be replaced by a single conservation law. And whereas in classical mechanics mass was a conserved quantity, in special relativity the quantity that is conserved is the sum of the masses and their relativistic kinetic energies. This new concept **subsumes** that of mass in an overarching conservation law. Far from sounding the death-knell of the real physical world, Einstein's theory revives it.

2.4.12 Quantum theory and instrumentalism

In 1927 Niels Bohr put forward his famous 'Principle of Complementarity' to account for the puzzle of wave-particle duality. The critical point is that the complementary descriptions are **mutually exclusive**. If a theory purports to describe reality (as a realist would believe it does), then an ambiguous reality is suggested. Which one is true, wave reality, or particle reality? Therefore a realist interpretation of the wave-particle duality seems to fall, and an instrumentalist interpretation seems the only sane alternative. Instrumentalists hold that any difficulties in making sense of this duality arise from a misguided desire to 'look behind' the experimental results for a 'metaphysical' explanation.

Bohr believed that there was 'something' physically real there, but that we can never penetrate behind the experimental arrangements to reach this 'something'. In other words, to escape from the 'metaphysical' problems, he shelved any attempt to apply the theory to the real physical world. He adopted an instrumentalist standpoint.

Popper (1956, p.361) regards Bohr's Principle as a

> "'renunciation' of the attempt to interpret atomic theory as a description of anything".

Bohr's Principle simply avoided certain contradictions by adopting a self-consistent formalism. Thus the result of every single experiment was consistent with the theory. This, said Popper, is all we could ever get, and all we could ever hope for.

Bohr used scientific theory in an instrumentalist way. He used it *ad hoc* in order to escape from contradictions. Popper regards instrumentalist theory as obscurantist and fruitless. He says

"... the principle of complementarity has ... remained sterile within physics. In twenty-seven years it has produced nothing except some philosophical discussions..." (Popper 1956, p.362)

Einstein himself found the implications of quantum theory very troubling. He rejected Heisenberg's Uncertainty Principle, a stategy modelled on the operationalist analysis of simultaneity which Einstein himself had proposed twenty years earlier. Positivists accepted Heisenberg's idea, because they held that it was meaningless to talk of physical quantities which could not actually be measured. Einstein opposed the implicit positivism in Heisenberg's Principle, and continued to do so until the end of his life.

In 1935, Einstein, together with associates Podolsky and Rosen, had set out a thought-experiment, the so-called EPR Paradox. If two isolated particles interact and then separate again, by measuring the momentum of one, we can infer the momentum of the other, even though we did not observe it. We can infer that it has this momentum independently of the fact that we made an observation on the other particle. Now, according to Powers (1982, p.148) a theory is said to imply that a physical property of a system is real if it allows us to predict its value without our interacting with the system. Therefore, said Einstein, the momentum is real.

Bohr, however, interpreted the EPR experiment in a **holistic** way. Particles which were once together in an interaction remain in some sense part of a single system. Einstein felt that this was a further retreat from reality.

In 1982 Alain Aspect and his associates at the University of Paris-South, performed an experiment involving measuring the direction of polarisation of a rapidly switched beam of light. The polarisers were randomly changed while a pair of photons was in flight. The switching was so fast, that measurement of one photon could not affect the other. The point was that it was thought that the experimental design would affect the photon. The photon remains in an indeterminate state until it is observed. The very act of measuring its direction of polarisation brings it from its indeterminate state to a real state of polarisation. The experiment was, in a way, a test to find the underlying reality below the unreal world of the quantum. According to quantum theory, polarisation does not exist until it is measured. According to realists, each photon has a real, intrinsic polarisation from the moment it is created. The result of this crucial experient showed that polarisation does not exist until it is measured. As Gribbin (1984) puts it, "Nothing is real unless it is observed." The experiment seemed to prove that there is no underlying reality to the world. Even though this experiment was performed after Einstein's death, the idea would have been anathema to him. Instrumentalism seems to have won the battle with realism.

We can never recover the world-picture of classical physics. The EPR experiment implies that there is **instantaneous** action at a distance in the underlying field. Richard Feynman in his *Lectures on Physics*, cited by Gribbin (1984, p. 231), summed up the paradox as follows: "The 'paradox' is only a conflict between reality and your feeling of what reality 'ought to be'."

Perhaps this means that we should revise our notion of reality. Perhaps we could return to the 'holistic agnosticism' of Bohr. Or we could accept a reality in which 'action-at-a-distance' occurs. Yet one is left with the feeling that a theoretical realist like Einstein would somehow find this an unsatisfactory solution.

2.4.13 Summary

From this survey of the origins of instrumentalism, several points relevent to this study come to light:

(1) 'Saving the appearances' is **arbitrary**. It does not matter what theory is invented, provided it works.

(2) Instrumentalists hold **theories in low regard**. Theories are simply fictions.

(3) Instrumentalism is **a stage on the way toward realism**

.

(4) Instrumentalism is **phenomenalist**.

(5) There are two types of instrumentalism: **strong** and **weak**.

Strong instrumentalism refers to those scientists (eg Bohr) who brought forward experimental results which were incompatible with a realist interpretation. Weak instrumentalists accept that theoretical entities may exist, but they are not interested in them. Their published material may be read from either a realist or an instrumentalist point of view. This study is more concerned with weak instrumentalism.

Classical instrumentalism, which denies any kind of ontological status to the theoretical entities of science, is sometimes called 'strong' instrumentalism. Many of the recent critics of scientific realism are 'weak 'instrumentalists. These allow that theoretical entities have an everyday existence of the 'chairs and goldfish' kind, but reject that there is any deeper sense of the really real. Their rhetoric is antirealist in tone, but their position often seems compatible with scientific realism. They seem to have the best of both worlds. As McMullin (in Leplin 1984, p.26) says, "I am inclined to think that their effort to have it both ways must in the end fail." It is as dangerous to 'hedge one's bets' in the scientific enterprise as it is in anything else.

2.5 Characteristics of instrumentalism

Using Hacking's six characteristics of positivism discussed above, the chief characterstics of instrumentalism can be listed as:

(a) Emphasis on **observation**: What we can see, touch, taste, smell and hear, provides the best foundation for knowledge. Observation is objective and impersonal.

(b) Opposition to **causality**: There is no cause in nature. What we observe are simply constant regularities.

(c) Downplaying of **explanations**: Explanations may help organise phenomena, but do not provide any deeper knowledge.

(d) Rejection of **theoretical entities**: Reality is phenomenal only, and is restricted to what can be observed.
(e) Downplaying of **theories**: Theories have no correspondence to reality apart from their usefulness as tools for thought.

In addition to these positivist characteristics, the instrumentalist makes great use of **operational definitions** and **calculations** for **predictive** purposes.

2.6 Implications of instrumentalism

The indisputable success of science is no doubt due in part to the clean-cut, 'no-frills' instrumentalist method, which serves to clarify concepts and tighten arguments. However, instrumentalism can easily lead to idealism, phenomenalism, agnosticism, relativism, gamesmanship, a spectator attitude, and pragmatism.

2.6.1. Idealism: If only sensory knowledge is valid, then all we ever know is the experience of our sense impressions. We can never be sure that an independant world lies outside of ourselves. For example, in open-brain surgery, a touch of a probe on a particular part of the brain can trigger off a sensation of smell, even though no external smell is there. To postulate the existence of something outside us is a metaphysical jump, which is not allowed by empiricist philosophy. So we remain forever trapped within ourselves, and our thoughts are the only things we know. Reality is in the mind. We become idealists, or, at very least, sceptics.

2.6.2. Phenomenalism: Our senses experience phenomena directly. What we see is what we get. For the empiricist, the directly observed thing is reality. There is no underlying reality behind appearance. The surface view is all that there is. Things are exactly what they seem. Thus an empiricist/instrumentalist view is superficial.

2.6.3. Agnosticism: If only sensory knowledge is valid, then the notion of God is seriously undermined. Scepticism and atheism follow.

2.6.4. Relativism: If theoretical knowledge is downgraded into a fiction which has no necessary physical counterpart, it need not be taken seriously, for it can be as arbitrary as another cog in the wheel of Ptolemy's epicycles. For most people, truth is a correspondence to reality, but for an instrumentalist, truth is what works. Truth is relative. It depends on the result of inquiry. A statement is not true in itself. It is only true if found to be so.

2.6.5. Gamesmanship: Because an instrumentalist scientist does not take his theories seriously and regards them only as useful devices for prediction, the whole scientific enterprise becomes a game. It is not interested in explanation, but simply that it works. If this is all that science is, then it is dishonest. As Powers (1982, p.164) has commented, it may be viewed as a costly hoax we have played on ourselves.

Pirsig (1974, p.24) distinguishes between **scientists** and **technologists**. Whereas the scientist **thinks** about what he is doing, the technologist performs a job mechanically. The scientist is committed to seeking out the implications of his research; the technologist remains **uninvolved**. The scientist is passionately caught up in his work; the technologist is a **spectator**. The scientist does the research for its own sake; the technologist is only interested in whether it **works** or not. The scientist's results may or may not be useful; the technologist's are **useful**.

Of course the above assertions are blatant generalisations. But the point is that the scientist should have a much deeper perspective than the technologist. His interest should penetrate reality. He should be a realist, who cares about research for its own sake without any regard for its usefulness. He should be willing to stick his neck out and confidentally say, "Electrons do exist!". He should be prepared to make bold conjectures, and not be immersed in the wishy-washy attitude of instrumentalist science. He should be committed to realism, and not play games.

A similar phenomenon occurs in the field of computers, and particularly computer games. How easily youngsters become addicted to computer games! They seem to be thoroughly involved. But are they really? For those asteroids hurtling across their monitor screens, and the laser beams flashing their destructive paths, are mere simulations, flickering images, obediently following their programmed coordinates. The eye predicts, the hand presses a button, a high-speed digital calculation occurs, and the asteroid is destroyed in a gigantic explosion. But the pieces of shrapnel whizzing past are not real. It is only a game. And as such, it is passive, and the player is essentially uninvolved. As a game, it is good and useful, as far as it goes. But it is not real life.

I contend that computer games are prime examples of the instrumentalist attitude. This struck me one evening in 1986 when I was using a BASIC program I had written to predict the position of Halley's Comet on a given night. It was only a calculus for prediction, like Ptolemy's. Data and images could be manipulated in a purely geometric way, with little or no reference to physical reality. The computer was isolated in time and space from everything else in the universe. It had no relationship with the user, or the Cosmos, except in a superficial, instrumental way. It was not interested in the real physical gravitational forces pulling on real masses. It merely computed the mathematical models of Newton's Laws, and came up with the right answer. It was a spectator, and it made the user a passive spectator as well. For instead of going out and observing the night sky for oneself, one tended to become an armchair astronomer. And therein lay its danger.

Powers (1982) encourages us to take a realist stance in science, for we can easily be deceived by the escapism and superficiality of the instrumentalist approach. Realism

> "requires us to take very seriously the question of the consistency of the assumptions our theories make. A recipe-book instrumentalism carries with it no such injunction. Phenomenalism (or sub- microscopic phe-

nomenalism) provides a way of brushing problems of intelligibility aside, but if the implication is that we are simply investigating experimental effects we produce in our apparatus and that these can tell us nothing about 'what is there', then the whole enterprise may seem like a costly hoax we have played on ourselves; and it will be hard to believe a positivist who claims that this makes no difference. When experimentalists 'bombard' protons with electrons they have to 'believe' in both their missiles and their targets; though it seems 'hard-headed', phenomenalism is a theory for spectators rather than actors." (Powers 1982, p.164)

The deliberate lack of commitment to a serious realism suggests that instrumentalists are playing games. For Berne (1964, p.44),

> "A game is an ongoing series of complementary ulterior transactions progressing to a well-defined, predictable outcome."

Games are substitutes for real living. They are governed by rules, and involve activity and fantasy. Games are directed towards the manipulation of reality, and are evaluated by their effectiveness or payoff. Games may not be intended to convey information, but merely to follow a predetermined course to an expected conclusion. Games are basically dishonest, for they tend to be cosmetic and superficial, shelving the important issues of life. They can be manoeuvres to attain pragmatic, utilitarian goals.

The parallel of games with instrumentalism is more than mere coincidence. For, like games, instrumentalism is a substitute for commitment to realism. Instrumentalists are concerned only with manipulation and control of the natural world, and are more interested in the practical pay-off than constructing intelligible explanations of the natural world. Their procedures follow a predetermined course and yield expected conclusions. Finally, like games, instrumentalism is also basically dishonest, for it deliberately ignores whole areas of non-empirical reality in order to achieve a type of knowledge which is as objective and as theory-free as possible. This is a pretence, for it goes on to imply that non-empirical reality does not exist.

This pretence is nothing new. It can be traced back to the early Greeks, who put forward elaborate cosmological theories to account for certain observations in spite of the fact that the theory completely contradicted other known facts. Koestler (1959, p.65) notes that there was "a certain dishonesty" about this. Yet this developed into the "controlled schizophrenia" of "saving the appearances" at all costs.

> "Their (the Greek astronomers) main concern was to 'save the appearances'. The original meaning of this ominous phrase was that a theory must do justice to the observed phenomena, or 'appearances'; in plain words, that it must agree with the facts. But gradually, the phrase came to mean something different. The astronomer 'saved' the phenomena if he succeeded in inventing a hypothesis which resolved the irregular motions of the planets along irregularly shaped orbits into regular motions along circular orbits - **regardless whether the hypothesis was**

true or not, ie. whether it was physically possible or not." (Koestler 1959, p.73)

Ptolemy made it quite clear why astronomy must renounce all attempts to explain the physical reality behind phenomena; because the heavenly bodies, being of a divine nature, obey laws different from those found on Earth. Ptolemy was a whole-hearted Platonist. He divorced sky-geometry from physics, astronomy from reality. The split world, says Koestler (1959, p.74), is reflected in the split mind. It knows that **in reality** the sun has a physical influence on the planets; but reality is no longer its concern.

2.6.6.Spectatorship: If scientific theories are mere fictions with no reference to reality, then science has no sense of commitment. It is content to remain passive and uninvolved. It prefers technology to front-line research, for there is no incentive. It simply becomes isolated in time and space, and has no relationship to the user, who is therefore tempted to remain a passive and uninvolved spectator.

2.6.7. Pragmatism: Instrumentalism emphasises utility: the purpose of science is not to explain but to provide useful predictions. Hence nothing is worth doing unless it is useful. So Space Shuttles are preferable to Voyager probes, because the former have important military and economic spin-offs, whereas there is little obvious use in taking a few pictures of distant planet Neptune. Instrumentalism does not encourage the search for truly new knowledge. It appeals to the "instant success" attitude of modern man.

Dewey's pragmatic thesis that if a hypothesis works, it is true, is a dangerous one, for it easily leads to relativism of the following type: It does not matter whether God exists or not; what is important is that the hypothesis works. Similarly, it does not matter whether there is a reality behind the phenomenon; the phenomenon is sufficient in itself, for it works. It does not matter whether an electron or a photon exists or not, as long as the fictitious concept works. But, of course, it **does** matter. For how can any physicist aim a beam of electrons at a cathode-ray screen, and not believe that electrons actually exist? Not to do so is essentially dishonest.

Commenting on the recent cut-backs in the American space-research programme, Lago (1983) observes that contemporary Western society's emphasis on practicality and financial success has led to utilitarian values. Nothing is worth doing unless it is useful. Since space-probes to the planets have no obvious, direct usefulness, funding for such projects has been considerably reduced. The proposed probe by the United States to Comet Halley was cancelled, and America is the poorer for this. The entire American exploratory space programme has languished, because of pragmatic values. The very frontier mentality of pragmatism which created America has sadly blinded that country to any enterprise which is not pragmatic. According to a comment in *Sky and Telescope* (October 1988, p.332), most Americans do not think that the space programme is as important as, say, crime, or drugs, or AIDS, or even garbage collection.

> "Practicality has created America's greatness, but we have paid a dear price for it - and in the space age, that price is paralysis." (Lago 1983, p.28)

That this is true was borne out by the tragic Space Shuttle Challenger disaster in January 1986. The practical success of the space programme was seriously wounded, and Americans lost their self-confidence. All major space exploration in the United States ceased until September 1988, when Discovery went into orbit. During those two years, paralysis set in. Not only did NASA miss a golden opportunity to send a probe to Halley's Comet, but the unique encounter of Voyager 2 with planet Uranus was mentioned in passing, as it were, by the media.

Knowledge for its own sake has a low value in contemporary Western society. This materialistic, utilitarian philosophy has spread to all highly technological countries. It is reflected in the instrumentalist attitude. This, in turn, is entrenched in our high school science textbooks.

We must break out of this vicious circle, for there are unquestionably certain human enterprises which are justifiable **in themselves**, without having to be obviously useful. But the instrumentalist attitude tends to blind us to this, and encourages the passivity syndrome which permeates so much of modern society.

Commenting on Dewey's instrumentalist pragmatism, Bertrand Russell (1979, p.782) wrote:

> "In all this I feel a grave danger, the danger of what might be called cosmic impiety."

For Russell, the instrumentalist view of truth about the world lacks the necessary element of humility. It is a step

> "on the road towards a certain kind of madness... I am persuaded that this intoxication is the greatest danger of our time, and that any philosophy which, however unintentionally, contributes to it is increasing the danger of vast social disaster." (Russell 1979, p.782)

2.7 Popper's critique of Instrumentalism

Popper maintains that instrumentalists have no reason to take pride in their apparent victory. For although

> "science is valued, admittedly, for its practical achievements; but it is even more highly valued for its informative content, and for its ability to free our minds from old beliefs, old prejudices, and old certainties, and to offer us in their stead new conjectures and daring hypotheses. Science is valued for its liberalising influence." (Popper 1956, p.363)

Scientists have dared to create theories, or conjectures, which are in striking contrast to the everyday world of our senses. Aristarchus and Copernicus conceived the heliocentric theory, and held it to be true, in violation of the evidence of their own senses. Such theories would be important even if they were only exercises of the imagination. But they are more than this. We submit them to severe tests. We try to explain the regularities we observe. And so we reach out to **new** knowledge. Our theories are **informative** about the physical world.

Those who regard science as nothing more than glorified plumbing, and scientists as only technicians, see it as useful, but of little cultural worth. It does not reveal new worlds. The physical world is just surface: it has no depth. The world is just what it appears to be. The instrumentalist attitude prevents fruitfull questions from being asked.

The issue, therefore, lies between a **critical and adventurous rationalism and a narrow and defensive belief according to which we cannot and need not learn and understand more about our world than we know already**. The latter creed is incompatible with the appreciation of science as one of the greatest achievements of the human spirit.

Popper's criticism of instrumentalism runs as follows: Instrumentalists hold that scientific theories are nothing but technological computational rules. There is a big difference between pure theories (in the realist sense) and instrumentalist theories.

Firstly, computational rules (such as navigational rules) are **tried out** rather than **rigorously tested by attempts to refute them**. Computational rules are tested by applying them. But proper theories are tested by **selecting for our tests those crucial cases in which we expect the theory to fail if it is not true**. The expectation is much different from that of computational rules. A theory can be falsified by an attempt to refute it. If not, it is confirmed. An instrument can break down, or be outmoded. But it does not make sense to say that we submit an instrument to the most severe test we can design, in order to reject it if it does not stand up to them. Instruments cannot be refuted.

The point is, that the instrumentalist interpretation will say that different theories have different applications. But it cannot account for scientific progress.

This brings us to Popper's second point, namely, the question of new theories. Instrumentalist theory is **not informative** about the world. It does not lead to **novel** facts or new theories. It is just as obscurantist as essentialism. Instrumentalists have a **cautious** attitude which encourages them to assert nothing other than can safely be derived from the sure basis of observation. Insofar as the realist is prepared to stick his neck out and conjecture that the theoretical entities suggested by his theory really do exist, he is much bolder than the instrumentalist. And history has shown the realist stance to be more productive and fruitful. For example, Cardinal Bellarmine's instrumentalist standpoint avoided problems but led to scientific sterility in astronomy for centuries, whereas the realist position taken by Galileo posed many problems, but was more fruitful. It was precisely those problems that provided the incentive for further development.

> "There is an important distinction which we can make between two kinds of scientific prediction and which instrumentalists cannot make; a distinction which is connected with the problem of scientific discovery. I have in mind the distinction between the prediction of **events of a kind**

which is known, such as eclipses, or thunderstorms, on the one hand, and, on the other hand, the prediction of **new kinds of events** (which the physicist calls 'new effects') such as the prediction which led to the discovery of wireless waves, or of zero-point energy, or to the artificial building up of new elements, not previously found in nature.

It seems to me clear that instrumentalism can only account for the first kind of prediction..." (Popper 1956, p.385)

Popper concludes by saying that the search for a reality behind appearance has to be discarded once we become conscious of the fact that the world of each of our theories may be explained, in its turn, by further theories - theories of a higher level of abstraction. We are led to take all these worlds, including our ordinary world, as equally real. It is a mistake, says Popper, to regard the phenomenon of my piano as real, while its alleged molecules and atoms are mere 'logical constructions'. There are levels of reality, or levels of conjecture. All these theories are real, from the one of direct phenomenal observation, down to the most abstract theory of quantised field of forces. Note that, for Popper, all observation is theory-laden, the result of interpretation. He states (1956, p.386):

> "It is my belief that our discoveries are guided ... by theory, rather than that theories are the result of discoveries 'due to observation'; for observation itself tends to be guided by theory. ...I cannot but think that it is a mistake to denounce Newtonian forces (the 'cause of acceleration') as occult, and try to discard them ... in favour of accelerations. For accelerations cannot be observed any more directly than forces."

In other words, the directly-observed phenomenon is just as theory-dependent as the unobservable. There are degrees of conjecture.

Thus the distinction between Locke's **primary** and **secondary** qualities falls away. Both qualities are equally real, and equally theory-dependent and in the perceiver. Appearance is part of reality, not reality itself. To quote Popper again:

> "There is a reality behind the world as it appears to us, possibly a many-layered reality, of which the appearances are the outermost layers. What the great scientist does is boldly to guess, daringly to conjecture, what these inner realities are like. This is akin to myth making." (in Miller 1983, p.122)

Popper states that we should hold a state of affairs as real if, and only if, the statement describing it is true. But, he notes, it would be a grave mistake to conclude from this that the uncertainty of a theory, that is, its conjectural character, diminishes in any way its claim to be real. We are not omniscient, and no doubt much of what is real is still unknown to us. It is thus indeed the old Berkeleyian mistake (in the form 'to be is to be known') which still underlies instrumentalism.

The fact that some of our theories clash with reality, tells us that there is a reality. And this, says Popper, is why the realist is right.

Summary of Popper's critique:

Popper rejects instrumentalism on three grounds:

(1) Realist theories can be falsified by a crucial test, whereas instrumentalist theories are neither true nor false, only useful.

(2) Realist theories are informative about the world; instrumentalist theories yield 'expected' predictions.

(3) Realist theories accept levels of reality from direct appearance to abstract theory, each level being theory-laden; instrumentalists separate observation from theory, and hold that appearance is the only reality.

In my judgement, Popper's notion that theories should be truly **informative**, and that there are **levels of reality**, is correct. However, according to most contemporary philosophers of science, Popper errs in (1). No theory is refutable by a single test. For rival theories are often held simultaneously. Therefore a more complete critique of instrumentalism needs to take the views of other comtemporary philosophers of science into account. This will be done in the following section.

2.8 Instrumentalism and constructivism relativist?

Both instrumentalism and constructivism stem from the pragmatic notion of coping with the environment. Pragmatism is rooted in empiricism, as the historical survey above has shown. Yet in spite of this common heritage, I contend that it is possible that a constructivist approach in science education may be a way of off-setting some of the empiricist problems inherent in the instrumentalist position.

Constructivism is a theory of knowledge which holds that human beings build up their notion of reality. Knowledge of the real word is an intellectual construct, or a theoretical structure. From the point of view of this study, its chief characteristics are that the construction of theories involves the **creative imagination**, and is **active** rather than passive, as empiricist theories of knowlege tend to be.

Therefore, what is now needed is a brief outline of how instrumentalism and constructivism are seen in terms of contemporary thinking. Contemporary philosophy of science is chiefly concerned with **theory** as an over-riding **structure**. This section will look at the part played by theory in both instrumentalism and constructivism.

Theoretical constructs arise through the interaction between present experience and previous knowledge. Theories are invented to make experience viable and hence meaningful. Constructivism involves a choice between rival theories. The instrumentalist approach to science involves the arbitrary and free interchange of theories for the sake of greater convenience. Because theories are held in low esteem by both instrumentalists and constructivists, this free interchange is possible with little need for inductive testing.

The questions this section addresses are: Is constructivism to be preferred to instrumentalism? Can constructivism overcome the weaknesses of instrumentalism? Is choice between theories a matter of whim? Are instrumentalism and constructivism relativist?

2.8.1 Conventionalism

When rival theories are to be compared, the scientific community must decide which to accept. Such decisions take on the role of conventions, and are left to the good judgement of scientists. This approach to science is known as **conventionalism.** For a conventionalist, the question of truth or falsity does not arise. A theory is not 'provenly true' but only 'true by convention'. The long-term practice of the scientific community agrees on a theory's truth status.

If a conventionalist wishes to retain the idea that science has anything to do with objective, factual truth, he must devise some independent metaphysical principle. If he does not, he cannot escape from scepticism, or, at least, some radical form of instrumentalism. Instrumentalism is a form of conventionalism. So too is constructivism.

Conventionalism rests on the conviction that "false assumptions may have true consequences; therefore false theories may have great predictive power." (Lakatos in Hacking, 1981, p.111) For example, Ptolemy's theory, while wrong, had great predictive power. But conventionalists had to face the problem of comparing rival false theories. Most of them identified truth with what conventionally is true and found themselves holding some version of pragmatism.

In instrumentalist forms of conventionalism, one does not have to adhere forever to a given theory. One may abandon it if it becomes unbearably clumsy and if a simpler one is offered to replace it. It is in no need of valid inductive inferences. The changes on the theoretical level are only instrumental. Theoretical progress is only in convenience, not in truth content. Theory replacement becomes a matter of whim.

2.8.2 Bold and cautious conjectures

Popper maintains that science progresses by making bold conjectures, and then thinking up ways of refuting them. A bold conjecture is one which involves a risk, one which contradicts the accepted scientific view or the evidence of our senses. For example, the Copernican theory was a bold conjecture, because it both went against the geocentric theory of Ptolemy and contradicted our sensory experience that the sun travels across the sky. It must yield novel information. Predictions are novel if they involve some phenomenon that does not figure in, or is perhaps explicitly ruled out by, the background knowledge of the time.

Significant advances are made by the **confirmation of bold conjectures**, or the **falsification of cautious conjectures**. The former case is informative because it marks the discovery of something previously considered unlikely. For example, Eddington confirmed Einstein's risky prediction that light rays bend in strong gravitational fields, thereby contributing to our knowledge. The information gained was novel. On the other hand, the falsification of cautious conjectures is also informative because it establishes that what was regarded as unproblematically true is in fact false. For example, the prediction that Mars will be in a certain position in the sky on a given date is a cautious prediction, for it is easy to do. Yet if, for some reason, this was observationally refuted, the theoretical repercussions would be enormous. We would have learned something new.

In contrast, if a **bold conjecture is falsified**, then all that is learnt is that yet another eccentric idea has been proved wrong. For example, Kepler's theory that the spacing of the orbits of the planets was related to Plato's five regular solids, was a bold idea. Yet its refutation was not a significant landmark in the progress of knowledge. Similarly, the **confirmation of cautious hypotheses is uninformative**. Such confirmations merely indicate that some theory that was well-established and regarded as unproblematic has been successfully applied once again. For example, if our prediction of the celestial position of Mars turned out correctly, this would not be new knowledge in the profound sense. It is only an expected prediction. To take another example from Chalmers (1986, p.55), the confirmation of the conjecture that samples of iron extracted from its ore by some new process will, like other iron, expand when heated, would be of little consequence. Instrumentalist science usually falls into this latter category of cautious hypotheses. Constructivism usually involves the falsification of bold conjectures.

The trouble with Popper's falsificationism is that it relies on observation which, being fallible, does not provide the decisive logical rigor that Popper desired.

2.8.3 Sophisticated falsificationism

Conventionalism was criticised on the grounds that comparison of theories is too **subjective** and **arbitrary**. Popper's falsificationism gave a firmer, more objective foundation to conventionalism. However, its weakness is that it allows singular, rather than universal, theories to be accepted by convention. That is, a theory can be refuted by a single, crucial experiment. Lakatos (1970), however, denied this. His more sophisticated falsificationism stated that science has a 'hard core' which cannot be modified or rejected. It is the decision of the scientific community to decide what is unfalsifiable in the hard core. If an anomaly occurs between observation and theory, it is dealt with by modifying the 'protective belt' of auxiliary hypotheses which surround the hard core. A young theory grows in spite of many falsifying observations.

Thus no single experiment alone can lead to falsification. There is no falsification before the emergence of a better theory. Hence falsification is not just a relation between a theory and an observation, but a multiple relation between competing theories.

Moreover, some of the theories which bring about falsification are frequently proposed **after** the counterevidence. Crucial counterevidence can be recognised as such among all the anomalies **only with hindsight**, in the light of some superceding theory. Thus the crucial element in falsification is whether the new theory offers any **novel** information compared with its predecessor. In spite of many anomalies, we do not consider a theory as falsified until we have a better one. Thus science grows by a proliferation of rival theories rather than by counterexamples or anomalies.

For Popper, an old theory is refuted, then a new one proposed. For Lakatos, an old theory cannot be refuted until a new one is proposed.

2.8.4 Ad hoc hypotheses

An *ad hoc* hypothesis usually involves the addition of an extra postulate to an existing theory to protect it from falsification. The modification has **no testable consequences** that were not already testable consequences of the unmodified theory. To use an example given by Chalmers, the generalisation "Bread nourishes" is a low-level theory. Suppose people from a particular village ate bread and died. The theory that "Bread nourishes" is now falsified. To protect it from falsification, the theory can be given an ad hoc modification: "Bread, with the exception of bread produced in the particular village, nourishes". It is ad hoc because it cannot be tested in any way that was not also a test of the original theory.

Another example of an *ad hoc* theory is the addition of another epicycle into a planetary orbit, to make that observation fit the theory. Instrumentalists willingly accept *ad hoc* theories.

Popper accepted saving a theory with the help of auxiliary hypotheses as long as it can be tested in a way that is not also a test in the original theory. Otherwise the auxiliary theory is *ad hoc*, and is to be rejected.

2.8.5 Proliferation of theories

Proliferation of theories is important for **constructivists.** Instrumentalists discard theories with little regard for their truth status. The criterion of theory choice is simply convenience. This is characteristic of pragmatism. Constructivists are inclined to choose theories they prefer, with little regard to logic or rational grounds. This is characteristic of voluntarism. This needs to be tempered by a severe critical attitude. Lakatos (in Lakatos & Musgrave 1970, p.187) said:

> "**Scientists dream up phantasies** and then pursue a **highly selective hunt for new facts which fit** these phantasies. This process may be described as 'science creating its own universe' ... The dogmatic falsificationist will throw up his hands in horror at this approach. He will see the spectre of Bellarmino's **instrumentalism** arising ... He may even brand it as a revival of the unholy irrationalist alliance of James's crude **pragmatism** and of Bergson's **voluntarism** ... But our sophisticated falsificationism combines 'instrumentalism' (or 'conventionalism') with a **strong empiricist requirement**, ... the requirement that **the - well-planned - building of pigeonholes must proceed much faster than the recording of facts which are to be housed in them.** ... Sophisticated falsificationism thus combines the best elements of voluntarism, pragmatism and of the realist theories of empirical growth." (in Lakatos & Musgrave 1970, p.188)

In other words, a research programme is said to be progressing as long as its theoretical growth anticipates its empirical growth, that is, as long as it keeps predicting novel facts with some success.

So it may well be that the introduction of a new theory is needed **before** falsifying observations can be made. So long as we think within the confines of a particular conceptual framework we may be unable to unearth the evidence that would falsify that theory. An alternative perspective is needed to highlight the shortcomings of the existing theoretical system.

This brings us back to Rogers's 'plogglies' theory. The arbitrary nature of the 'plogglies' theory reveals it as too wild, too unscientific. Popper would regard it as unfalsifiable. It is a bold conjecture, but if it could be falsified, all we would learn is that yet another way-out theory has been proved wrong. Yet Feyerabend would regard it as the result of the pre-scientific, uninhibited, proliferation of ideas. It was, perhaps, a first step on the road towards scientific realism.

Are instrumentalist theories, as fictions, the theories of cranks? Feyerabend (1981, p.199) distinguishes between the respectable scientist and the crank. How can we tell if a proposed theory is reasonable or absurd? The answer is that the crank is **content** with defending his theory in its original, undeveloped, metaphysical form, and he is not **prepared to test it**, or even admit that there is a problem. However, if he tries to adapt his theory to the accepted theory, and look at old problems from a new point of view, then he is progressing. In order to avoid being a crank, **one must know one's subject**. As Chalmers (1986, p.136) says, commenting about this, it is not sufficient merely to follow one's whims and inclinations in an uninformed way.

2.8.6 The principle of tenacity

When a scientist is confronted by a number of theories, he must select the one that promises to lead to the most fruitful results. He should "stick to this one theory even if the actual difficulties it encounters are considerable." (Feyerabend in Lakatos & Musgrave 1970, p.203).

When eliminating conjectures, we must use a principle of tenacity together with a principle of proliferation. We must be allowed to **retain** ideas in the face of difficulties; and we must be allowed to introduce **new ideas** even if the popular views should appear fully justified.

2.8.7 The need for an empirical base

Popper asserts that one theory may be closer to the truth than another, whether a particular individual or group of individuals thinks so or not. The approximation to the truth is termed by Popper the verisimilitude of the theory and, as science progresses, so the verisimilitude of its theories increases.

Therefore we need to posit some inductive principle to relate - even if tenuously - the scientific gambit of pragmatic acceptances and rejections to verisimilitude. Only such an 'inductive principle' (says Lakatos) can turn science from a mere game into an epistemologically rational exercise.

Feyerabend follows Popper in holding that theories are not confirmable by observation, but at best falsifiable. Scientific knowledge grows through the proliferation of theories, which can then be exposed to potential falsifiability **through the editing effects of the world.** (Petrie 1981, p.33)

2.8.8 The critical attitude

Theories cannot be refuted except with the help of alternatives. But before we accept an alternative theory, we must be strongly based in our present one. A critical attitude ensures that we do not take on new theories too arbitrarily. Scientists should not construct theories at random. Rather they must subject them to criticism in order to obtain better theories.

> "Proliferation means that there is no need to suppress even the most outlandish product of the human brain. **Everyone may follow his inclinations** and science, conceived as a critical enterprise, will profit from such an activity. Tenacity: this means that one is encouraged not just to follow one's inclinations, but to develop them further, to raise them, with the help of criticism (which involves a comparison of the existing alternatives) to a higher level of articulation **and thereby to raise their defence to a higher level of consciousness.**" (Feyerabend in Lakatos & Musgrave 1970, p.210)

Popper insists on ruthless rejection of an old theory if severe criticism refutes it. Yet he also advises scientists not to let go of old theories uncritically.

> "He who gives up his theory too easily in the face of apparent refutations will never discover the possibilities inherent in his theory. ... Do not give up your theories too easily - not, at any rate, before you have critically examined your criticism." (Popper in Miller 1983, pp.126 and 127)

Instrumentalists tend to release their theories too easily. As Popper suggests, we must not let go of our theories too readily. We must be very critical. The instrumentalist is not critical enough. Perhaps the same charge can be brought against the constructivist. It is this persistent critical attitude, together with the stringent editing effects of the world, which bolster both instrumentalism and constructivism against relativism.

2.8.9 Constructivism on the way to instrumentalism

Instrumentalism is a form of pragmatism, and so also is constructivism, but in different ways. They both are concerned with the purely pragmatic aim of coping with life. In order to cope, outmoded theories must be replaced by newer, more useful ones.

Instrumentalism changes its theories too easily without sufficient regard to self-testing against reality. It is more concerned with internal consistency than whether it describes physical reality. If instrumentalism is uncritical (in Popper's and Lakatos's sense), it may end in scepticism or idealism.

Constructivism psychologically precedes instrumentalism. Constructivist theory holds that the person constructs a variety of theories to account for observations, then chooses the best. This is achieved by testing the implications of each possible theory against each other and against reality. If this is done uncritically, then it may lead to an instrumentalist approach. If, however, it is done in a truly critical way, then it may go further and lead to full-blooded realism. For, as Popper rightly says, we approach reality through severe criticism of the consequences of our theories.

2.8.10 Instrumentalism on the way to realism

Instrumentalism is the first stage on the way towards realism. This can be seen both in the history of science as well as in the child's learning process. At first, we are likely to construct fictional theories without too much regard for testing their consequences. Through repetitive criticisms, we reject the more outlandish theories, and come to accept those that are reliable and fruitful. Eventually, our confidence in our theoretical constructions entitles us to regard them as true descriptions and explanations of reality.

2.8.11 Summary

Several points arise from the above discussion. Firstly, instrumentalist theories are arbitrary. Therefore, uncritical instrumentalists may let go of their theories far too readily. Secondly, constructivist theories are also arbitrary and imaginative, bordering on unreason. Uncritical constructivists may invent theories too readily. So there must be two important controls in operation here: (a) the critical guidance of the scientific community; and (b) a strong empirical base. Thirdly, uncontrolled constructivist theories may lead only to naive instrumentalism, but highly critical constructivism may lead, through instrumentalism, to full-blooded critical realism.

2.9 Conclusions

(1) Saving the appearances may involve concocting suitable theories at whim, from plogglies, through epicycles, to other fictions.
Imaginative theory creation needs to take place within certain parameters laid down by prior theory.

(2) Instrumentalism has the following characteristics:
(a) Observation is objective.
(b) Observation refers to phenomenal reality only.
(c) Computative predictions are 'expected'.
(d) Rules and calculations are recipe-like.
(e) Definitions are nominalist.
(f) Definitions are operational.
(g) Theories are mere fictions.
(h) Theories are useful devices for predicting.
(i) Theories are not truly informative (ie novel).

(3) Instrumentalism tends to lead to:
(a) Idealism
(b) Scepticism
(c) Relativism
(d) Agnosticism
(e) Phenomenalism
(f) Regarding science as a game
(g) Spectatorship
(h) Pragmatism

(4) Its chief weakness is that, of its very nature, it does not lead to novel information. It is too cautious, and therefore unfruitful. It is only partially scientific.

(5) Instrumentalism is a very shallow realism which is arbitrary, but it works in practice. Hence it is a useful starting-point for a realist view of science. Instrumentalism is a stage on the way toward realism.

(6) Central to constructivism is the notion of proliferation of theories and theory choice. Both instrumentalism and constructivism have low regard for the status of theory. This is why they can discard theories so easily.

(7) However, constructivism and instrumentalism, while similar, are not the same. Constructivism has the edge on instrumentalism. For, being prior, it encourages imagination. It is therefore open to fruitful growth, whereas instrumentalism in itself is sterile.

(8) However, constructivism, like instrumentalism, should not be retained simply because it works. Uncritical constructivism leads to instrumentalism with all its weaknesses. By restricting our thinking to instrumentalist thinking, we stifle growth and intellectual satisfaction. By opting for constructivism, we leave ourselves open to pragmatic relativism. The best way out of this impasse is to complement instrumentalism with **critical** constructivism. This will give rise to a full-blooded critical realism.

These last three points will be explored in greater detail in the next chapter.

Chapter 3

CRITICAL REALISM: TOWARDS A CONSTRUCTIVIST REALISM

3.1 Introduction

One of the most important themes running through contemporary philosophy of science is the well-founded contention that all observations are theory-laden: no observation is completely objective and impersonal. The observer's prior knowledge, his presuppositions and prejudices, his unique point of view, his interpretations, and his very choice of what to observe, all influence, to a greater or smaller degree, what he perceives. All observations are made in the light of pre-existing theoretical structures. Indeed, it seems that scientific inquiry begins with theory rather than observations.

Thus all knowledge is very personal. Each individual person views the natural world through tinted spectacles, as it were. So, in order to make sense of what he or she perceives, each person actively constructs his or her knowledge of reality. There may be a number of possible theoretical explanations for a given sensory-experience. The person constructs, what seems to him or her, the best explanation. With successive experiences, and by a learning process involving iterative trial-and-error, one theory may be rejected and another accepted, or two apparently contradictory theories may even be held illogically for some time until the first is superceded. In this way, conceptual structures of the real world grow. We construct our own knowledge of reality.

The crucial question which must be asked is, to what extent is the individual's knowledge of reality objective? If all observation is saturated in theoretical presuppositions, then surely we live in a world of our own making? If, as Piaget and other constructivists hold, we construct our knowledge of reality, then surely such knowledge is subjective and exists only in the mind? We are cognitively isolated from reality. As Hacking (1984, p.130) puts it,

> "When philosophers begin to teach that all observation is loaded with theory, we seem completely locked into representation, and hence into some version of idealism".

Constructivist epistemolgy is, with good reason, currently highly esteemed by researchers in science education. Almost every journal article mentions some aspect of constructivism, especially those dealing with misconceptions and alternative conceptual frameworks. Apart from contemporary philosophy of science, there is considerable psychological evidence for constructivism in recent science education studies, based on work done originally by Jean Piaget. Constructivist psychology is the accepted view today in science education.

Yet if scientific knowledge is created by our mental operations, and if such conceptual constructs are indeed subjective and lead to idealism, then obviously a very strong warning must be given to science educators not to rush unthinkingly down the road to constructivism. The philosophical implications of constructivist psychology must be thought through before accepting it. Otherwise science education may be careering headlong into the absurdity of Hegelian idealism and all its consequences. The notion that truth is relative is one of these consequences. For the relativist, there is no one-to-one correspondence between our knowledge and the objects in the real world. Truth is what works for me. I construct my own truth. So constructivism is a form of pragmatism (Von Glasersfeld 1989, p.124). As Ortony (1979, p.1) points out, the constructivist approach to knowledge is "the hallmark of the relativist view". Indeed, some constructivists are even encouraging science educators to accept relativism. For example, Pope and Gilbert (1983, p.259) urge that the constructivist view must find "an epistemological base which acknowledges such relativity". Such an exhortation as this must be examined very critically.

Similarly, the contemporary anti-positivist movements in the philosophy of science (represented especially by Kuhn and Feyerabend) may be characterised as **idealist** and **relativist.** That is, they are anti-realist. Kuhn rightly emphasised the social aspect of scientific inquiry and practice. But if a theory is accepted by the scientific community as true, then its truth value will change if and when the theory is superceded by another better one. Truth is therefore relative to the scientific community. However, if a realist stance is adopted, then truth cannot be relative. For the realist, truth is some type of correspondence of thought with an external world. Truth exercises a regulating effect on thought. However, the regulative role of the social community cannot be ignored. Consequently, the type of realism chosen must take into account the **social** characteristics of scientific practice **without** ending in a **relativist** view of truth.

If a constructivist approach may lead to the notion that scientific knowledge is subjective and unreal, then scientific theories would be just as fictitious as those of instrumentalists. Instrumentalists can change theories fairly arbitrarily because they regard them as convenient devices. Constructivists rely on a choice of the best of several theories, unwanted ones being rejected. However, it is very important not to do this arbitrarily. The constructivist calls on the scientific community to help him decide objectively. But it is also necessary to have a strong empirical base, a toehold in reality. We need to show that, by our construction of reality, we achieve a richer view of the world than instrumentalism gives. This may require a **revision of our notions of reality and objectivity**.

The chief aim of this chapter is to explore some of the various types of realism and try to find a way of accommodating current constructivist thinking in science education to realism. For science is essentially a form of realism. Scientific inquiry assumes that there is a real physical world which exists independently of our minds. Yet science must also acknowledge its constructivist (and hence relativist) character. So it is very important, from a philosophical point of view, to secure constructivism on a firm and objective, non-relativist, empirical foundation.

This chapter will therefore seek for a type of realism which will take into account (a) constructivist psychology, and (b) the social character of the scientific enterprise. This type of realism must be empirically grounded, so that knowledge is objective and truth not relative. At the same time, it must allow for the fact that science is a very human thing, a product of the creative imagination. It will be seen that a realism known as **critical realism**, and especially that of the Canadian philosopher-theologian Bernard Lonergan, will satisfy these demands.

3.2 Constructivism

3.2.1 Definition

Constructivism is a philosophy of education whose central theme is that learning is an active process

> "by means of which we, individually, literally construct the form and substance of our own world out of our experiences." (Gruender 1989, p.170)

Ortony (1979) states that knowledge of reality, whether it is occasioned by perception, language, memory, or anything else, is a result of going beyond the information given. It arises through the interaction of that information with the context in which it is presented, and with the knower's preexisting knowledge.

In contrast with the empiricist view, in which absolute truth is attainable, the constructivist approach is one in which direct access to the existing world is denied. As Ortony (1979, p.1) says, the objective world is not directly accessible, but is constructed on the basis of the constraining influences of human knowledge and language. Its chief characteristic is a relativist notion of truth. In the constructivist view, there is no rigid differentiation between scientific language and other kinds. Language, perception, and knowledge are inextricably interdependent.

According to Piaget, knowledge is an operation that constructs its objects. The child constructs his notion of reality. Knowledge is a set of conceptual constructs which the child invents in order to help him adapt to the environment. For constructivists, therefore,

> "knowledge refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable." (Von Glasersfeld 1989, p.124)

Constructivism is therefore a form of pragmatism. Piaget never held that knowledge is a representation of the real world. Rather it is the collection of conceptual constructs which help a person to cope.

3.2 2 The philosophical underpinnings of constructivism

There are signs of a constructivist theory of knowledge in the classical realism of Plato and Aristotle. This was further elaborated by Thomas Aquinas in the 12th century. However, this type of realism dealt with such universal concepts as necessity, essences, and absolute truth. Such static concepts led to the stagnation of critical thought and tended to stifle inquiry. So metaphysical speculation flourished. In the 15th century, a movement opposing metaphysical speculation arose. Known as empiricism, this theory of knowledge was strongly against any form of constructivism. Kant criticised empiricism, arguing that some of our knowledge is indeed constructed.

We must be careful to distinguish realism (ontology) from our knowledge of reality (epistemology). The two are closely linked, but if we confuse the two, we fall into what Bhaskar (1975) calls the 'epistemic fallacy'.

An exposition of classical realism and its epistemology, empiricist theory of knowledge, and Kant's theory of knowledge follows. The epistemology behind classical realism will be treated in some detail, because it is my contention that the Aristotelian notion of **natural light** helps explain Piaget's notion of functional representation, as well as Lonergan's view of human knowing.

(1) Classical realism

Since early Greek times, there has been a division of opinion as to how our knowledge of reality is acquired. These can be broadly distinguished into two camps: Platonic and Aristotelian.

Plato held that this world of sensory phenomena is but a shadow of the real world of Ideas or Forms. Only the mind can have true knowledge of these Forms. The dualism between the world of Appearance and that of true Reality can thus be traced right back to Plato.

Aristotle, on the other hand, was a common-sense realist. He believed that this world is fully real, and that we can have true knowledge of it. For Aristotle, the mind is a *tabula rasa*, a blank slate, and there is nothing in the mind which was not first in the senses. All our knowledge comes through our senses. Aristotle rejected Plato's notion of innate ideas. Our mind, said Aristotle, abstracts the common features from many real examples. This common feature is called the **essence** of the object, and has a real existence within the object itself. For example, the essence of 'tableness' really exists within the form of this particular table. Many prominent scholars (Guthrie 1978, p.129; Knowles 1962, p.209; Copleston 1955, p.175; Dondeyne 1958, p.144) hold that Aristotle believed that the intellect is an **active** agent. Intellection requires an active operation of the mind.

The epistemology of the 12th century philosopher-theologian Thomas Aquinas is that of a **moderate realism**, situated between the rationalism of Plato and the empiricism of the Nominalists.

Aquinas held that knowledge **intends** reality. This means that, of its very nature, our mind knows being.

> "A thing is knowable because existence is pointed to. Therefore being is the proper object of mind." (Aquinas in Gilby 1956, p.217)

In other words, the mind is open to reality, ready to grasp its depth and fullness, and **confident** that what it apprehends conforms to reality as it is. Knowledge is, by nature, directed to reality as a whole, not to just a part of it (such as the sensory).

For Aquinas, the formation of concepts occurs as Aristotle had suggested, as follows. External signals impinge on the senses, which present the individual, particular object to the mind. The mind actively strips off all that is individual and accidental, and grasps the essence or substance. The essence of the individual object is reached by a process called 'abstraction'.

Whereas sense perception is purely receptive, intellection demands both an active (abstractive) and a receptive faculty. To supply this need, Aquinas followed Aristotle by introducing the 'active', or as it was later called, 'constructive' intellect, the *intellectus agens*.

Copleston (1955, p.173) observed that Aquinas insisted that the work of **synthesis** goes on in cognition. It takes place at the level of sensory experience. Discrete sense impressions are subconsciously brought together into a unified experience. However, these sensory images of particular objects are still disorganised and particular. The mind now, in a further stage of the process of synthesis, **actively** abstracts the essence and produces an impression in the passive intellect. The passive intellect reacts to the active intellect by forming the universal concept.

The universal concept is the modification of the intellect by the essence of a particular object, the essence residing in the real object. Hence abstraction, for Aquinas, does not cut off the mind from reality. The mind is not enclosed in its own ideas, as it is for the Empiricists.

For Aquinas, 'nature' is 'substance' considered as an activity, whereas 'essence' is 'substance' considered as definable. Substance belongs necessarily to an object, whereas there are properties which need not. Such changeable qualities are called 'accidents'. Aquinas's 'substance' is not the same as that of Locke. Locke's substance is an unknowable substratum. For Aquinas,

> "the distinction between substance and accident is a distinction, not between an unknowable substratum and knowable modifications, but between that which exists, if it does exist, as a subject and that which exists only as a modification of a subject". (Copleston 1955, p.82)

That is, for Aquinas, an object's substance is not an unknowable substratum hidden under its accidents. Substance is not situated behind or underneath the manifestations of the existing thing, but saturates and envelops them. In knowing the object's accidents we know something about its substance. A substance is **not** a phenomenon. When I look at a tree, I do not and cannot see the substance of the tree apart from the tree's colours and so on. But insofar as the colours of the tree manifest the substance, I can properly be said to perceive the substance. What I perceive is neither an unattached accident nor an unmodified substance. I perceive a modified thing.

Abstraction is the opposite of the Empiricist's associationist doctrine. As Dondeyne (1958, p.142) notes,

> "Our ideas are not the product of a process of addition, but rather of an illuminating analysis of the perceived datum."

In other words, the datum is a structured whole and has significance. There is in man, not an *a priori* knowledge of the world, but a *lumen naturale*, a natural light or source of understanding capable of illuminating our perceptive experience.

As Dondeyne (1958, p.145) points out, the Thomist view is "worlds away from empiricism". The Thomist theory of knowledge is not a representationalist one, based on passive copies or mental images. It is not associationist. Nor is it an intellectualist *a priorism*. Aquinas refused to admit any innate ideas. Further, he did not end in the scepticism of the later British Empiricists. He maintained a strong link with the world. For Aquinas, the natural source of our understanding wakens and gives rise to knowledge only by a living contact with the world. Our intellectual apparatus does not simply copy reality: it modifies, or constructs, reality. Aquinas made use of Aristotle's 'natural light' precisely because he denied that we have innate or *a priori* ideas. Rather, the 'natural light' makes its presence felt only in the gaining of knowledge. It is in uncovering the world that cognitive life and all that it implies are revealed to us.

In my view, therefore, Aquinas is, in a mild way, a constructivist. According to Aquinas we do not have direct intuitions of essences or substances of things. But this does not mean that they are unknowable. They are knowable in and through their activities. I come to know another person by listening to his words and observing his actions, for his words and actions reveal him in different ways.

Although Aquinas rejected the notion of innate ideas, he did admit self-evident principles which in some way give information about reality. Now, if the doctrine that all our knowledge depends on sense experience meant that the process of acquiring knowledge about reality was simply a passive process of receiving sense-impressions and that the mind was simply a passive recipient, these self-evident principles would be unnecessary. But Aquinas did not think that the mind is purely passive. On the cognitive level, a mental activity, a process of active synthesis, is involved. Thus, as Copleston (1955, p.30) says:

> "Aquinas could well have endorsed Kant's famous statement that 'though all our knowledge begins with experience, it by no means follows that all arises out of experience'".

That is, Aquinas's epistemology agrees well with Kant's, provided that Kant's phenomenalism is excluded.

The essence of the classical realist position can be briefly summarised as follows:

(a) A real world exists independently of our knowledge of it.
(b) This real world is knowable.
(c) Knowledge is gained by an **active** intellectual process, in which conceptual construction, or at least modification, occurs.
(d) Knowledge is of essences or substances, which are far more than Kant's lifeless, unknowable noumena hidden behind phenomena.

Thus classical realism does not agree with the passive representationist theory of knowledge of Empiricism, nor with its phenomenalism. Classical realism had a distinct constructivist leaning.

(2) Empiricist realism

Empiricism is a theory of knowledge which holds that all our knowledge comes through the senses. It is sometimes called **empirical realism** and **naive realism** by contemporary philosophers of science.

Empiricism has been discussed at length in Chapter 2 above. To summarise, empiricists hold that an external real world exists, and is known by sensory experience. The objects of the real world impinge on the senses, and the sense-impressions give rise to ideas in the mind which are copies of real objects. Knowledge is a passive process, and reality is there waiting to be discovered. Such knowledge of reality is cumulative and eventually will lead to absolute truth.

(3) Kant's transcendental idealism

Between the classical realist view and that of the empiricists, there lies a third standpoint, that of *a priorism*, a view held by Kant. Kant stated that

> "Although all our knowledge begins with experience, it by no means follows that all arises out of experience." (Kant 1959, p.25)

Kant held that the mind actively structures our experience. The immediate objects of our perception are due partly to external things and partly to our own perceptive apparatus. Locke had stated that secondary qualities (colours, sounds, smells) are subjective, and do not belong in the object itself. Kant, like Berkeley and Hume, went further, and made the primary qualities also subjective. Thus what appears to us in perception, the phenomenon, consists (said Kant) of two parts: that due to the object, which he called 'sensation', and that part contributed by our mental apparatus, which orders plurality into a unity.

Kant held that there are aspects of our knowledge which are not supplied immediately by the senses. We are born with certain *a priori* concepts, such as space and time and substance, which impose form on phenomena. The *a priori* categories are applied to sensory data. They provide a kind of screening function, as Pirsig (1974, p.126) described it. We see the world through the tinted spectacles of the *a priori* concepts. The mind changes, or adds to, our sensory input. We build up our own concept of reality, a concept which is being continually modified by fresh inputs.

If, as Kant suggests, the *a priori* concepts in our minds are independent of what we sense, and if they actually filter what we sense, then the empiricist view of the scientist as a passive observer is wrong. As Pirsig (1974, p.129) rightly observes, this aspect of Kant's metaphysics led to a "much more satisfying understanding of how we know things". The chief criticism of Kant's theory of knowledge is that only knowledge of phenomena is possible. The world of underlying reality is not able to be known. Thus Kant ends in phenomenalism. Cognitive isolation from reality makes his theory a form of idealism, but the constructivist notion of *a priorism*, a notion which allows sensory experience to go beyond the facts, transforms this into what is often called **transcendental idealism**.

3.2.3 Piaget's constructivism

Jean Piaget approached the epistemological question of constructivism from the standpoint of experimental psychology. Piaget (1954) showed that children actually create their own concept of reality. Piaget believed that it is our prior knowledge, our previously elaborated understanding, that enables us to make sense of what we perceive. Thus it is not through direct observation alone, but through the actions that we carry out upon our perceptions, that is, mental operations, that we come to know the world. As Popper says (1983, p.48), our observations are always interpretations.

The central idea behind Piaget's constructivism is that of **equilibration** between assimilation and accommodation. Equilibration is a self-regulating mechanism which governs the development of intelligence (Furth 1969, p.206). When the individual perceives some anomaly, cognitive conflict is set up, and various alternative concepts are constructed in order to adapt to the new situation. Rowell (1989, p.142) describes it thus:

> "The mechanisms of equilibration in the individual are triggered by the disturbance of a knowledge system when a 'gap' or conflict is recognised by matching an anticipation, generated by the application of it ... against an interpretation of what occurs. In response ... compensatory (regulatory) constructions are produced in a (typically) multi-step process involving feedback loops - feedback from the effect of an action provokes a reassessment of the situation resulting in a continuation of the action in a modified form, which is followed by feedback ...and so on."

Assimilation is the process by which the environment becomes incorporated into the organism's cognitive structures. Furth (1969, p.14) describes it as

> "the psychological relation of a stimulus to a reacting organism and expresses an inner correspondence or sameness between an environmental phenomenon and the structure within the organism".

When the knowing organism is able satisfactorily to accept an anomalous situation in terms of its existing cognitive schemes (theories), the anomaly is readily integrated. However, if the anomaly cannot be satisfactorily interpreted in terms of its existing cognitive schemes, those schemes themselves are rejected and new ones are constructed. **Accommodation**, then, is an organism-outward tendency of the inner structure to adapt itself to a particular environmental event. A **scheme** for Piaget is the coordination and organisation of adaptive action, considered as a behavioural structure within the organism, such that the organism can transfer or generalise the action to similar and analogous circumstances. (Furth 1969, p.44) A scheme is a network of concepts or a theoretical structure.

According to Rowell (1989), Piaget postulated a series of levels of compensatory constructions. Alpha behaviour is an attempt to neutralise a disturbance by ignoring it, by regarding it as anomalous, by inventing a separate theory to account for it, or by deforming it in such a way that it is no longer experienced as a disturbance. Alpha behaviour is, in other words, a conservative response. However, this response is unstable and fragile. Beta behaviour involves a progressive theory change (accommodation), retaining as much as possible of the original theory while integrating the disturbance as a new variation - hence eliminating it as a disturbance. Finally, in gamma behaviour, the reorganisation begun in the beta phase is completed, and disturbances are now anticipated and not eliminated.

Piaget later complemented his description of levels of compensation in the process of equilibration by a more detailed examination of the mechanisms underlying that sequence (Rowell 1989, p.143) He proposed the interactive functioning of two cognitive systems concerned with **understanding** (System I) and **succeeding** (System II). System I consists of concepts, including the structured aspects of operational schemata. It constitutes what is real for the individual, and is the system to which equilibration applies. System II is geared to bringing about success, and consists of procedures, including the procedural aspects of operational schemata. Its potential for revision makes it a tool for the reequilibration of System I. It is the source of opening up new possibilities in the search for solutions to new problems opened up by the mismatch of anticipation and observables, that is, the facts read off from reality by application of the individual's knowledge framework. The creation of possible solutions, then, essentially falls under the aegis of System II. Possibilities are constructions. And since hit-or-miss tactics and mistakes are intrinsic to the *modus operandi* of System II, the potential for making errors is also evident. Equilibration must, therefore include a selection mechanism for error elimination.

Learning and the knowledge it creates are, therefore, explicitly instrumental. This is the connection between instrumentalism and Piaget. But we must not interpret Piaget too simplistically. His theory of cognition, says Von Glasersfeld (1989, p.128), involves a two-fold instrumentalism. On the sensory-motor level, action schemes are instrumental in helping organisms to achieve goals in their interaction with their experiential world. On the level of reflective abstraction, however, operative schemes are instrumental in helping organisms achieve a coherent conceptual network that reflects paths of acting as well as thinking which are viable. The first instrumentality might be called utilitarian, the second epistemic. The first refers to action skills, the second to understanding. This radical shift in the conception of knowledge, maintains Von Glasersfeld, eliminates the paradoxical conception of truth that requires a forever unattainable ontological test.

If Von Glasersfeld is right in that an ontological test for truth is forever unattainable, then we are once again left in the dubious limbo of relativism. Piaget (1970, p.15) wrote

> "Knowing reality means constructing systems of transformations that correspond, more or less adequately, to reality ... (They) are not copies of the transformations in reality; they are simply possible isomorphic models among which experience can enable us to choose".

Our conceptual systems, according to Piaget, are possible models, from which we choose the most viable. Yet models are testable and hence changeable. They must conform to the facts.

Rowell notes that 'conformity to the facts' again raises the potential problem that observables are actually interpretations. This invests knowledge with a potential incestuousness of its constructs. When this is combined with the inherent conservatism of the operation of equilibration and the investment in constructivism, then it seems very difficult to escape from cognitive isolation from reality. An **independent criterion** is required for theory testing. The closest we can approach this, says Piaget - indeed the only such criterion available to us - is an **intersubjective** one. A social factor is therefore imperative to knowledge construction. This social component to knowledge ensures the rationality and objectivity of the individual's knowledge. However, the importance of the individual mind as the equilibratory seat of novel reorganisations should not be overlooked.

Cognition must be regarded as an **adaptive** function. Adaption is an equilibration between assimilation and accommodation. In order for the individual to be able to cope with his or her environment, knowledge structures are adapted. Knowledge, for Piaget, is the collection of conceptual structures that turn out to be adapted or, as Von Glasersfeld (1989, p.125) says, **viable** within the knowing subject's range of experience. Viability is tied to the concept of equilibrium. In the sphere of cognition, though indirectly linked to survival, equilibrium refers to a state in which the knower's cognitive structures have yielded expected results without revealing conceptual conflicts.

Thinking, for Piaget, is an operation. An operation is an action which is an adaptive, functional behaviour (Furth 1969, p.55). Operations differ from external actions in that they are geared to internal function. The biological function of knowing a thing in the environment is to react to the thing in an adaptive manner. In Piaget's terminology, the assimilation of a sensory-motor scheme is always simultaneous with an accommodation to the external aspects of things. It is commonly held that we think in order to act. We plan a trip, then execute it. Thinking is regarded by many as a prelude to action. This is a Deweyan instrumentalist notion: thinking is **for** acting. Yet Piaget insists that thinking is action, and not merely **for** action. For him, operational thinking is an interiorised or internal action. But is it internal merely in the shallow sense that it does not take place overtly and is not easily observable? Furth says no. It is internal in the more profound sense that the object of thinking is not outside the thinking scheme, as in the case in sensory-motor actions, but remains within and can itself be called a product of thinking. Thinking and its functional object are within the same psychological plane. Interiorisation is more than internalisation. Interiorisation refers to the gradual formation of generalised conceptual schemes from particular content. It leads from practical to operational intelligence, and (states Furth 1969, p.262) is the **precondition for objective knowledge** as well as for symbolic representation. As Furth (1969, p.60) states:

> "This is, no doubt, the profound reason why the one word 'operation' suffices on the operational plane for the two words 'scheme' and 'external action' on the sensory-motor plane."

Piaget rejects the notion of knowledge as a representation of reality. Empiricist theory of knowledge postulates that ideas are images, or copies, or pictures of the external real world, passively acquired, or mirrors of reality. Piaget dispenses with mediational representation. Rather he employs representation in the active sense and relates it to the symbolic function of intelligence. It lies midway between operational activities and motoric output. The product of this activity is a symbol. For Piaget, the operative process by which we construct reality-as-known and the symbolic process by which we re-present known reality are functionally different.

Piaget refers to internal knowing by different terms: **operations** when he emphasises their being part of a reversible structure; **judgement** when he considers the assimilatory activity that assigns an event as belonging to a structure; **concept** when he focuses on the operational scheme as the common source of assimilations. Psychologically all these terms partake of an identical reality status. An active structure, an operation, a concept or judgement are for Piaget one and the same reality, and not different reified entities (Furth 1969, p.76). Moreover, these notions enjoy no reality status of their own. They are merely ways of expressing the only real event which exists, namely the fact that 'a person knows something'. This knowing is one of the modes of existence belonging to the living organism as a whole.

Representation is not passive, but functional. The relationship between symbols (concepts) and reality is not one of causal representation. It is a special relation, corresponding to the philosophical notion of **intentionality** (Furth 1969, p.78), meaning simply, the relation of knowing. Intentionality is an openness to reality, the intellectual grasping of reality with the full confidence that what is apprehended conforms to reality as it is. It corresponds to some extent with the classical notion of **natural light** discussed above in 3.2.2.

Thus representational thinking in the wide sense means simply operative thinking. It is identical with thought, that is, with all intelligence which is not simply based on perceptions, but on systems of concepts or mental schemes. In the narrow sense, representation can be limited to the mental image, that is, to the symbolic evocation of absent realities. The concept is an abstract scheme, and the image a concrete symbol. Furth (1969, p.79) holds that he would not hesitate to call Piaget's distinction between the two meanings of 'representation' ontological, implying different **levels of reality**.

During the past fifteen years, a substantial amount of research in science education has been carried out on 'misconceptions' (Helm 1980), 'preconceptions' (Ausubel 1968), 'children's science' (Gilbert, Osborne and Fensham 1982), 'alternative conceptions' (Driver and Easley 1978), and 'alternative frameworks' (Driver 1981). Although originally based on Piagetian stage theory, the Alternative Conceptions movement is rapidly developing its own paradigm (Gilbert and Swift 1985).

Alternative conceptions are beliefs which children hold about scientific concepts which differ from the currently accepted view. As Driver (1981, p.95) states:

> "Pupils can and do bring alternative frameworks to explain observations which are in keeping with their experience..."

Various researchers have noted over and over again that there is

> "a creative and imaginative element involved on the part of the child in constructing the meaning he imposes on events." (Driver 1981, p.95)

This whole research programme is contributing "to the increasingly constructivist orientations of educational research." (Gilbert and Swift 1985, p.682)

Ausubel, Novak and Hanesian (1968, p.88) substantiate this view:

"Anyone who pauses long enough to give the problem some serious thought cannot escape the conclusion that we live in a world of concepts rather than in a world of objects, events and situations. The reality we experience psychologically is related only indirectly to the physical properties of our environment and to our sensory correlates. Reality, figuratively speaking, is experienced through a conceptual or categorical filter."

Piaget himself had stated that he was not interested in the question of an external reality. All that concerned him was how knowledge is constructed (Gruber and Voneche 1977, p.xxii). Yet, in my view, Piaget maintained a firm foothold in the world. Furth (1969, p.16) rightly noted that Piaget kept a definite link with the real world by holding that the **child is part of it**. Inhelder supported this view. She said (in Furth 1969, p.24):

"It is thus in acting on the external world that, according to Piaget, the child elaborates a more and more adequate knowledge of reality."

Piaget's experimental findings refute, once and for all, the empiricist standpoint. Concepts are not passive copies. They are cognitive constructions. Piaget labelled his own position as **constructivist** or **interactionist**, rather than **a priorist**. For the child invents rather than discovers his ideas. This distinction separates Piaget from empiricism and from pure Kantian *a priorism*. However, as Gruber and Voneche (1977, p.xxxviii) state:

"No one can read Piaget without thinking of Kant. He is not, of course, Kantian in his solutions, but a very considerable portion of his work has gone into studying the development of just those fundamental ideas that Kant identified and claimed were given *a priori*."

Comments on Piaget: Some of the above points are especially relevant to the purposes of this chapter, and need to be highlighted:

(1) The adaptive nature of equilibration involves a coping with the environment. This **implies** realism.
(2) The social factor helps ensure objectivity, but is not fully adequate for avoiding relativism.
(3) Piagets' constructivism is pragmatic and instrumentalist.
(4) Interiorisation is a more profound concept than external action. Thus Piaget's instrumentalism is not superficial.
(5) Representation is functional, therefore 'intentional'. This implies a 'going beyond' or transcendance out of keeping with pragmatic instrumentalism. The 'intentionality' of functional representation means (a) our minds, of their very nature, can get in touch with the external world; and (b) we have the utmost confidence in our cognitive powers.
(6) Piaget's distinction between concrete symbol and abstract scheme implies a hierarchical ontology (levels of reality).

All these points, taken together, indicate that Piaget's theory of knowledge is far more profound than Dewey's

3.2.4 G.A. Kelly's personal construct psychology

Kelly (1955) argues against what he calls 'accumulative fragmentalism', that is, the notion that knowledge is a growing collection of substantiated facts. He rejects an absolutist view of truth, and holds that scientific knowledge is the result of human reconstruction. Scientific knowledge consists of man-made hypotheses which a person may choose to review and revise in the light of what might appear to be a 'better' theory.

Kelly (1966) describes his own philosophy of knowledge as 'constructive alternativism'. He states that constructive alternativism is the view that man understands himself, his surroundings and his potentialities by devising constructions and then testing the tentative utility of these constructions against such criteria as the successful prediction and control of events. Knowledge is seen as being produced by transactions between a person and the environment. The emphasis is placed on **active** reaching out to make sense of events by engaging in the construction and interpretation of individual experiences.

Whereas Piaget regarded learning as evolution through an invariant sequence of stages of intellectual development, Kelly sees no necessary sequence of events for learning. Learning has no particular goal, for each student builds a unique structure of knowledge.

Kelly bases his whole approach to the development of a person on the metaphor of **man-the-scientist**. The Kellyan scientist is a constructivist. People understand themselves, their surroundings, and anticipate future events by constructing tentative models and evaluating these models against personal criteria. For Kelly, any event is open to as many reconstructions of it as our imaginations allow. Each person erects a personal representational model of the world which allows some sense to be made of it and which enables the person to chart a course of behaviour in relation to it. These representational models are composed of a series of interrelated **personal constructs** or tentative hypotheses about the world. Constructs are used by a person to describe present experience and to forecast events (theory building). Constructs also allow assessment of the accuracy of previous forecasts after the events have occurred, thereby testing their predictive efficiency (theory testing). Kelly's main emphasis is on the uniqueness of each person's construction of the world.

For Kelly, successful communication between people depends not so much on commonality of construct systems, but upon the extent to which people can "construe the construct system of the other". That is, communication depends on the degree to which people can have some degree of empathy and understanding of someone else's constructs, while not necessarily holding the same constructs themselves.

In my view, the importance of Kelly lies in his insistence that students recognise their role as theory builders. This aspect cannot be over-emphasised. His idea of constructing reality by means of tentative models comes very close to Selley's type of Critical Realism (see section 3.4.1 below). However, in my opinion, Kelly's personal construct psychology does not provide a strong enough link with the existing world 'out there'. Indeed, like Piaget, he is not particularly interested in whether an external reality exists or not. Rather, he is mainly interested in what man makes of it (Kelly 1969, p.25). This interest in the **individual's** personal construct tends towards relativism.

The similarity between Kelly's constructivism and Dewey's instrumentalist pragmatism (which will be described in section 3.2.5 below) is clear. For Kelly, the person constructs his own reality to help him cope. Thus the goal of learning is purely a pragmatic one. While the pragmatist's emphasis on **activity** should be applauded, it still leaves much to be desired as far as pedagogy is concerned (Pope and Gilbert 1983, 194). For a pupil can be active, but the learning derived from the experience may be limited if the person can see little or no relevant links between the activity and his own life.

3.2.5 Dewey's instrumentalist constructivism

Like Piaget, Dewey held that knowledge has no meaning independently of inquiry. That which satisfactorily terminates inquiry is knowledge. Intelligence is the instrument of action. Thinking is a specific event in the movement of experienced things. Knowing is but a series of organising acts. Ideas are instruments to be used to alter an indeterminate situation. Inquiry is the controlled or directed transformation of an indeterminate situation into one that is determinate. The object of knowledge resides in the consequences of directed action. Scientists accept the consequences of their experimental operations as constituting the known object, and care nothing for reality. Reality is conceived as an unending process of **events**. Reality is purely what is directly experienced.

When the organism is confronted by a conflicting situation or a problem, thinking activity is set up to solve it. Active grappling with the problem leads to a new situation. The thought-situation is only a constant movement towards a defined equilibrium. The role of thinking is instrumental and functional: it brings about the transition from a relatively conflicting situation to a relatively integrated one. Its purpose is to change and control the environment.

In my view, the fact that Dewey's emphasis on activity and experience is based on pragmatism leaves it open to the charge of being superficial. Von Glasersfeld (1989, p.125) notes that constructivism differs from pragmatism in **how** the knowledge that enables us to cope is arrived at. Dewey had correctly maintained that meaningful learning by the child should be carried out by discovery and activity methods. Unfortunately, this was later extrapolated by Dewey's disciples to mean that abstract knowledge of the real world was impossible unless preceded by direct empirical experience. Such a rigid empiricism stifled science. Although Piaget emphasised the importance of learning through activity, he would not have agreed with activity in itself. For all activity requires a prior theoretical structure to organise it. At school level, a naive activity or discovery way of learning science is not nearly enough, as Driver (1981) points out. It is necessary also to have an overall theoretical scheme to guide laboratory work. Prior theory acts as a filter through which sensory experience first passes. Ausubel *et al* (1968, p.530) point out that

> "The very processes of perception and cognition require that the cultural stimulus world must first be filtered through each individual's personal sensory apparatus and cognitive structure before it can have any meaning."

Whereas Dewey ignores reality, or even says it does not exist, Piaget, while holding no interest in its existence, implies a multi-leveled reality. Dewey's phenomenological treatment of knowledge lacks depth, whereas Piaget's cognitive structures provide a sound theoretical explanation. Dewey's philosophy, as Santayana has said, reduces to a 'philosophy of the foreground'. Ultimately, his theory of knowledge is based on an empirical realism.

Dewey had an early interest in Hegelian idealism. He later rejected the idealist notion that the object was subordinate to thought, and turned this around. 'Practice' reveals reality, not cognition. Cognition, for Dewey, depended on its capacity to satisfy non-cognitive demands. Such is the primary basis of instrumentalism. Thought is reduced to events.

3.3 Scientific realism

Realism is the theory that the ultimate objects of scientific inquiry exist and act quite independently of scientists and their activity.

During the 1970's and 1980's, there has been a move away from Kuhnian relativism towards **scientific realism**. In view of the prestige of scientific **theory,** its claims must be taken seriously. In Hesse's (1980, p.xii) opinion, one way of getting round the problems which scientific theory raises is to abandon positivist epistemology rather than the claims of theories. This has led to a metaphysical form of scientific realism, which effectively neglects epistemological questions in favour of analysing the **ontology** of theories as if current science is known to have arrived at or somewhere near the truth. A feature of current scientific realism, says Hesse, is that it still retains the logical presuppositions of empiricism.

Boyd (in Leplin 1984, p.41) states that scientific realism embodies four theses:

(1) Scientific theories should be interpreted realistically.
(2) Scientific theories, interpreted realistically, are confirmable.
(3) Progress in science is due to successively more accurate approximations to the truth.
(4) The reality which scientific theories describe is largely independent of our thoughts and theoretical commitments.

Anti-realists in the constructivist tradition, such as Kuhn, deny 4. However, they may well (maintains Boyd) affirm 1, 2 and 3 on the understanding that the reality which scientists describe is somehow a social and intellectual construct. As Kuhn and Hanson both argue, a constructivist perspective limits the application of 3, since successive theories can be understood as approximating the truth more closely only when they are part of the same general constructive tradition or paradigm.

Critical realism's version of scientific realism generally rejects 2, placing its position as intermediate between empiricist realism and constructivism.

3.3.1 Anti-realism

There are many variations of anti-realism in science. Among them are instrumentalism, pragmatism, constructivism, and idealism. The first two are based on the empiricist theory of knowledge.

(a) Empiricist anti-realism

If the empiricist assertion that the only knowledge which is valid is that based on sensory experience, then knowledge of any object referred to by theory, such as an electron, is impossible. Knowledge cannot extend to unobservables. Scientific realism promises theoretical knowledge of the world, but, at best, it can deliver only computational convenience (Boyd in Leplin 1984, p.42). A reality behind appearances does not exist. Only phenomenal reality exists. If this is so, then theories can be interchanged relatively arbitrarily without resorting to rigorous empirical testing. Theoretical entities become fictions, and the whole scientific enterprise becomes a game.

(b) Polanyi's Platonic realism

Michael Polanyi's (1958) Gestalt-based psychology of discovery rejects the mechanistic approach to science as a system of causes and effects. It also rightly rejects the now orthodox neo-Kantian concept of science as the study of appearances.

Polanyi argues that there is an independent external reality, and that the criterion of truth is whether our claim to have knowledge coincides with that reality. Unfortunately we can never be sure that it does so and therefore we have to rely on our beliefs about it (Brownhill 1983, p.31). We see the world from the perspective of an interpretive framework. In order to understand reality, we must immerse ourselves in it. We do not create reality, but sometimes partially recognise it. Much of our scientific knowledge is tacit. We cannot describe it in words, but we have a feel for it. We learn best by personal experience through activity.

Polanyi's concepts of 'indwelling' and 'tacit knowledge' have Platonic overtones. According to Brownhill (1983, p.45), Polanyi acknowledges that he is a neo-Platonist concerned with essences. These cannot be known through the senses, but only in an intuitive way. We know more than we can describe. This is our 'personal knowledge'. Polanyi's Platonic realism thus comes very close to idealism.

However, Polanyi maintained that this does not jeopardise the validity of our scientific knowledge, for any 'personal knowledge' has to be ratified by the scientific community as a whole. Hence the **objectivity** of our knowledge is guaranteed by the **scientific community**. By entrenching such knowledge in the context of an accepted theory, the objectivity is assured. A theory becomes more objective as it becomes more abstract, as it breaks away from everyday perceptions and prejudices. Theories are subjected to severe tests. Even so, we can never be absolutely certain that our knowledge is truly objective, for such is the human condition. Perhaps it is our notion of reality and objectivity which is wrong.

Polanyi was trying to move away from the notion of objectivity associated with the concept of the cool, detached scientist. For Polanyi, greater objectivity is attributed to theoretical knowledge than knowledge gained through sense experience. The reason for this was that it was revealing a higher level of reality. We move through a hierarchy of levels of reality. We no longer need the two-world theory of appearances and underlying reality. Rather there is a continuum of interpretations of experience, each built on the previous one. The process of indwelling reveals different levels of reality, for one moves from the known reality to the unknown reality. The traditional notion of objectivity as some impersonal method of making judgements is wrong. We need to reappraise our notion of reality.

Some aspects of Polanyi's thought have considerable merit. Firstly, much of our scientific knowledge is far more than the sum of its parts. Secondly, our empiricist-based notion of reality and objectivity needs to be revised. Thirdly, there are levels of reality. Polanyi's weakness, in my view, is his playing down of the empirical basis, a fact which, in spite of his emphasis on the function of the scientific community, leads to a form of anti-realism.

(c) Kuhn's constructivist anti-realism

Thomas Kuhn (1962) was influenced by Polanyi's views (eg Kuhn 1962, p.44), particularly those concerning the role of the scientific community.

Kuhn holds that scientific knowledge is gained in two ways: **normal science**, and **revolutionary science**. Scientists work within a particular theoretical tradition called a **paradigm**. Most of the puzzling problems they encounter can be easily resolved in terms of the existing theories. However, if they come across an **anomaly** which cannot be accounted for in terms of existing paradigm, then the paradigm itself must be overthrown. This involves a radical Gestalt switch of theoretical framework. It may also happen that both the old and the new theories exist side-by-side for some time, until the new one is ratified by the scientific community.

Kuhn maintains that the history of science shows that science is not governed by logic alone. It tends to be irrational in some things. Also, its objectivity is relative to the scientific community. For Kuhn, a scientific statement becomes true if the scientific community as a whole agrees with it. Truth becomes relative to the accepted view.

Popper strongly opposed such relativism, for it leads to anti-realism. If truth is relative to the accepted view, then when one theory is disproved, its truth is falsified, and the succeeding theory is now seen as true. However, it is a historical fact that rival theories (eg Copernican and Newtonian) often coexist for a long time, as Kuhn himself pointed out. If each theory is supposed to offer a true description of reality, do we have a case of multiple realities? As Hacking (1983, p.66) puts it:

> "With each paradigm shift, we come, as Kuhn hints, to see the world differently - perhaps we live in a different world. ... The realist about

> theories cannot welcome this view, in which the aim of discovering the truth about the world is dispersed."

Thus Kuhn's views turn out to be anti-realist.

3.3.2 In defence of scientific realism

Richard Boyd (in Leplin 1984, p.58) argues for scientific realism. His principal concern is to show that the instrumental reliability of the theory-dependent methodology of the mature sciences leads inevitably to realism. His realism holds that scientific theories are at least approximately true and genuinely referential. Thus he argues that neither the empiricist tradition, which invalidates all reference to unobservables, nor the constructivist tradition, which denies the independent reality of the objects of scientific knowledge on the basis of the theory dependence of method, can explain the empirical success of the mature sciences.

Whereas Boyd argues for scientific realism from the viewpoint of **explanation**, Hacking does so using **intervention**. Hacking (1983) holds that reality has to do with our ability to change the world, that is, to intervene. He agrees with Dewey that we must grasp reality as it is. He believes that Popper points in the right direction. Popper (in Hacking 1983, p.146) said that we extend reality to unobservables because

> "the entities which we conjecture to be real should be able to exert a causal effect upon the *prima facie* real things; that is, upon material things of an ordinary size: that we can explain changes in the ordinary material world of things by the causal effects of entities conjectured to be real".

In other words, entities conjectured to be real, such as electrons, can physically affect other more directly observable entities, such as the chemical coating of a TV screen. If they can, then they are real.

I wish to emphasise the importance of this notion of 'acting on the external world', for, in my view, it provides for constructivism the escape route from subjectivism and idealism. Hacking (1983, p.130), for example, maintained that if we hold that all observation is interpretive and influenced by prior theory, then we can never escape from the mind. He rejected the contention that all observation is theory-laden, and insisted that by intervening and doing we keep in touch with the real world. While disagreeing with his view that some observations are theory-free, I agree with him on intervening. I hold with Popper that there are degrees of theory-ladenness, and with Grove Maxwell (in Hacking 1983, p.170) that there is a **continuum** in observation from direct observation through to theoretical entities. The point is that, although a constructivist approach is to a large extent intra-mental, it retains a foothold on objectivity and realism by **activity in the world**. Petrie (1981, 200) supports this view:

> "...we triangulate on reality with our representational schemes, and some of these representational schemes require activity in the world... If all we had to do was think about the world, then, indeed, we might fear for objectivity, but since we must act in the world and coordinate our activity with our thought so that activity and thought triangulate on

nodes of stability in the world, objectivity and conceptual change are possible at the same time."

3.3.3 Varieties of scientific realism

(1) Popper's common-sense realism

Popper is a common-sense realist, a realist not in the classical sense of believing in real essences, but in the sense that an independent external world exists. Common-sense distinguishes between appearance and reality. But common-sense also realises that appearances have a sort of reality. If an unobservable entity such as the molecular structure of this typewriter is meaningful because it is theory-laden, then so also is its surface appearance theory-laden. Popper (1956, p.383) holds that there are degrees of theory-ladenness. Some objects are more conjectural than others. But even direct sensory observation of surface appearances has some minimal degree of interpretation in terms of prior theory. In other words, for Popper (1983, p.220) there is a surface reality and a depth reality, rather than a real essence behind the phenomenon. And every level of conjecture, whether surface or depth, is just as real as any other.

Popper contends that realism is neither demonstrable nor refutable. But it is arguable, and the weight of the argument is overwhelmingly in favour of realism and against idealism. Popper holds that:
(1) Realism is a matter of common-sense.
(2) All physical, chemical, biological, and other sciences, imply realism, because they investigate the objects of the physical world.
(3) Human language is essentially descriptive, and description is always realistic: it is of something.
(4) Idealism is simply absurd. It is inconceivable that my mind could have dreamed up the beauty of Rembrandt's paintings or Bach's music.
(5) Our subjective knowledge consists of dispositions to act on and adapt to external reality.

Popper's criticism of instrumentalism (see section 2.7 above) is that it is basically dishonest. Instrumentalism starts by acknowledging that it is interested only in phenomena, but ends in saying that phenomena are the **only** reality. It ignores, or gives weak arguments for, the existence of non-observable theoretical entities, such as electrons and photons. By deliberately ignoring whole realms of reality, it becomes a sham. It is basically dishonest, as Koestler (1959, p.65) noted in the instrumentalism of Ptolemy's astronomy.

Popper (1983, p.59) postulates "like a naive realist" that there are three worlds: Firstly, there is a physical world (world 1); then there is a world of states of consciousness and subjective experience (world 2). These two interact with each other. Finally there is a third world (world 3), the world of theoretical systems, problems, critical arguments, and the contents of journals, books, libraries and data bases. The knowledge of world 3 is objective knowledge, because it is public. It is knowledge without a knower. So Popper claims to be a common-sense realist, but he rejects the common-sense theory of knowledge as a blunder. Instead, he prefers an objective theory of conjectural knowledge.

(2) Hesse's moderate inductive realism

Hesse (1974) holds that realist hypotheses do not explain the empirical success of science. She proposes, at odds with current fashion, an **inductive** model of science. This model is intended to be a *via media* between the extremes of formal logical science and historical realism.

> "In contrast to the non-inductive Popperian tradition, it defines the goals of science primarily in terms of expectations of successful prediction, rather than in terms of the search for more and more powerful testable theories." (Hesse 1974, p.284)

Popperians reject induction, but, as has been pointed out above, Hanson believed that induction can be justified precisely because it too is theory-laden. Hanson (1971) noted that induction is rarely undertaken aimlessly, without some theoretically determind goal. It is built on experience which is itself already highly selective.

Hesse's scientific realism is therefore grounded in solid inductive foundations, which links knowledge firmly to the real world. Her scientific realism is a truth realism.

(3) Harre's referential scientific realism

Harre (1986) holds that we should create a form of realism that is close to scientific practice, and try to establish that existence is prior to theory. Most realist approaches, including those of Popper, Hesse and Einstein, are based on the truth-falsity idea. A realism to suit contemporary needs must be wider than this. It must not depend, in any essential way, on the strict concepts of truth and falsity. Harre (1986, p.65) calls this **referential realism**.

The demonstration of the existence of a real examplar is at once cognitive and a material practice. An object is located in the grid of space-time, and we point to it. We draw our attention to the presence of the object. Then there is the cognitive act of describing it. The classical formulation of the referential position is Sellars's remark that, to have good reason for holding a theory, is to have good reason for holding that the entities postulated by the theory exist.

This is not new, says Harre. St Thomas Aquinas used it, in the sense that all scientific propositions have their term in natural matter. However,

> "a truth realism based on propositions has proved vulnerable to sceptical assaults. I hope to create a referential realism based on things. Instead of asking 'Are the statements of this theory true or false?' ... I believe scientists actually ask 'Do things, properties, processes of this sort exist?' and do their best within human limitations to find exemplars. Realism is grounded in material practice." (Harre 1986, p.97)

Three scientific methodologies: Harre's scientific realism states that science has three methodologies:

(a) The first is directed at **normal experience of cognitive objects with pragmatic properties**, for example, Newton's Laws. This involves a realist metaphysics, with a Kantian way of experiencing the world.

(b) The second embraces **unobservable entities**, for example, electrons and photons. Here theories are treated as real and objective.

(c) The third is **analogical**, using mathematical principles, statistical models, and other highly-abstract concepts, for example, the strange world of particle physics, dealing with quarks, charms, and so on.

Each of the three different methodologies is appropriate to the study of a specific domain of beings, both natural and cultural.

There are three **levels (or realms) of reality**. The referents of type 1 theories belong to Realm 1, the realm of the actual and possible objects of experience. The moon and Pluto, the Grand Canyon, the tongue, and goldfish, belong to Realm 1. For type 2 theories, we, the users, are committed, not only to the ontology of Realm 1, but also to beings which, if real, would be available to the amplified human senses. These are objects of possible experience, and their certification as part of the real furniture of the world depends on the availability of the necessary technology. Micro-organisms and X-ray stars belong in Realm 2. For type 3 theories, we, the users, are committed, not only to the ontologies of Realms 1 and 2, but also to beings which, if real, could not become phenomena for human observers, however well-equipped with devices to amplfy and extend the senses. Realm 3 is a domain of beings beyond all possible experience. Quantum states and naked singularities are denizens of Realm 3.

Thus Harre's multi-leveled reality ends in a Kantian transcendental idealism. For Harre, ultimate reality is unknowable.

3.3.4 Some comments about today's scientific realism

An important theme common to most of the above philosophies of science is the notion that there are **levels of reality**. It can be seen, to greater or lesser degrees, in Piaget, Polanyi, Popper and Harre. For all of these, theoretical structures are part of reality, and the more theoretical, the more objective they are.

3.4 Critical realism

Man's quest for certainty gives rise to a desire for an absolutist view of truth. Man wishes for a direct one-to-one correspondence with reality. He wants to feel that his knowledge corresponds exactly with the world he knows, that electrons and photons exist just as surely as the water he observes boiling in a kettle. Yet there is a subjective element in all our knowledge.

We live in a world of concepts. So we need to revise our concept of reality to take this subjective element into account. For we, the knowing subjects, are part of the objective world we know. The organism is part of the environment. We are part of reality itself, immersed in it. We therefore are compelled to reject an absolutist view of truth, for scientific knowledge consists of tentative hypotheses and trial-and-error gropings towards truth, without ever reaching absolute truth. Each person constructs his own representational model of the world. G.A. Kelly (1955), the personal construct psychologist, proposed a model of 'man-as-a-scientist', a model which breaks down the distinction between observer and observed. The observer is caught up by his immersion in his environment, whether he likes it or not. Piaget had a similar view, namely, that the organism is part of the environment and interacts with it. So did Dewey. Reality does not cause experience: it is itself part of the experience. All our observations are saturated in our theoretical presuppositions.

For Kelly and Piaget, the question of the existence of an external reality is not important. Kelly is quoted by Pope and Gilbert (1983a, p.197) as saying that

> "the open question for man is not whether reality exists or not but what he can make of it".

On the other hand, Gruender (1989, p.175) makes the point that, if conceptual construction of reality is a way of coping with or adapting to the environment, or surviving, then surely this is a realist stance?

However, an honest discussion of the question reveals an important fact: our concept of reality as completely independent of us is outmoded. We therefore need to review our notion of reality.

3.4.1 Historical overview of critical realism

The naive empirical realist view of truth holds that there exists 'out there' a real world which it is the task of scientists to discover. According to this view, absolute truth about nature can be attained, and nature is eternally waiting to be uncovered. Many of our current scientific theories may be true and will never be disproved. Hence scientific knowledge is cumulative.

According to classical empiricism, represented by John Locke and David Hume, the ultimate objects of knowledge are atomistic events. Such events constitute given facts. Knowledge and the world may be viewed as **surfaces**. On this conception, science is conceived as a kind of behavioural response to the stimulus of given facts. Even if, as in positivism, such a behaviourism is rejected as an account of how science originated, its valid content can still be reduced to such facts.

An alternative classical philosophy of science is Kant's transcendental idealism. This teaches that the objects of scientific knowledge are models, ideals of natural order. Such objects are artificial constructs and though they may be independent of individual men, they are not independent of human activity in general. On this conception, knowledge is seen as a structure rather than a surface. But the natural world becomes a construction of the human mind, or, in its modern version, of the scientific community.

A third position is that of **Critical Realism**, or, as Bhaskar (1975, p.25) calls it, transcendental realism. It regards the objects of knowledge as structures. These objects are neither phenomena (empiricism), nor human constructs imposed on the phenomena (idealism), but real structures which endure and operate independently of our knowledge. According to this view, both knowledge and the world are structured; both are differentiated and changing.

Critical realism, then, must be distinguished from, and is in direct opposition to, **empirical realism.** Both classical empiricism and transcendental idealism subscribe to empirical realism. For empirical realists, a real entity is a particular object of perception. For classical realists, a real entity is some general feature or property of the world (universals). For the critical realist, a real entity is an object of scientific discovery and investigation, such as causal laws. Realism about such entities entails a particular realist position in the theory of perception and universals.

Whereas naive constructivism is reluctant to acknowlege that the knowing subject has access to the external word and therefore tends to end in relativism, critical realism can sustain the idea of a world independent of man, and is able to uphold the objectivity of facts.

Selley (1981, p.253) maintains that critical realism is more consistent with the historical development of science. Critical realism teaches that theories are attempts at representing the regularities in natural phenomena, through suggested pictures of what the natural world **might be like** in order that it should give rise to the observable effects. According to Selley, the subtle difference in this critical realism is that although a real world exists out there independently of human thought, there is no possibility of our ever knowing just what it is like. We can only hypothesise, examine our hypotheses for self-consistency, and devise experimental tests. In recognition of this change in meaning, the word 'theory' is often replaced by 'model'.

Figure 3.1: **A critical realist interpretation of scientific knowledge (after Selley 1981, p.253).**

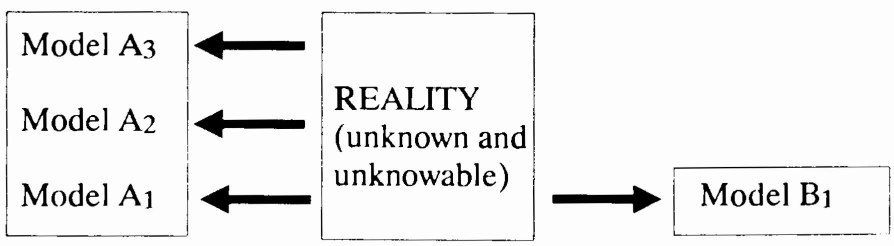


Figure 3.1 depicts a critical realist interpretation of scientific knowledge, showing two different models for some limited aspect of the world. Of these, Model A is shown as having greater explanatory scope than Model B, though the latter may have some merits, such as greater simplicity or familiarity, which makes it worth retaining. The arrows represent observable facts which are the data base for each model. Models A_1 and B_1 (and perhaps also C_1,...) explain the same observable phenomena, while Models A_2 and A_3 are elaborations of A_1, able to explain a wider range of phenomena. (The observable phenomena, or 'facts', are not necessarily theory-free sense data, but may be interpretations based on some taken-for-granted theory.)

British critical realism emerged in Scotland in the last quarter of the nineteenth century (Passmore 1986, pp.279-297). Andrew Seth tried to be a realist without ceasing to be a Kantian. There is both an empirical and an intellectual component to our knowledge. Our knowledge of reality transcends the empirical experience.

Although what we are aware of is in our minds, it points to a world independent of ourselves. Seth held that, whereas Locke had thought that knowledge is **of** ideas, in fact it takes place **through** ideas. Seth's main critical attack was directed against phenomenalism. If our experience is not of objects themselves (as opposed to appearances), our knowledge would be merely an incoherent succession of transitory states.

Another 19th century Scot, Robert Adamson, maintained that experience does not at first contain any clear-cut distinction between mind and its objects. Yet experience is not intrinsically indifferent to this distinction. We gradually come to realise that our experience has two components: the inner and outer. We must not say that all our knowledge is of the inner, as the subjectivist maintains, or that what we know is independent of the inner, as the naive realist maintains. Thus critical realism, for Adamson, is a compromise between naive realism and subjectivism.

G.Dawes Hicks published his philosophy in *Critical Realism* (1938). Perception, he said, contains three contents: the content of the object, the content we immediately apprehend, and the content of the perceiving act. Perception is an act of selection from the complexity of our environment. Different observers will pick out different sets of qualities from the same scene. A naive realist would say that one perception is as good as another. Thus there is no positive reason for believing that what we immediately apprehend is a sense-datum. Dawes Hicks's critical realism, says Passmore (1986, p.283), rests on a sharp distinction between qualities and objects: the quality is what we immediately apprehend, the object is what stimulates us to that apprehension.

American critical realists (G. Santayana, R.W. Sellars, C.A. Strong) opposed any sort of naive realism as well as idealism. They agreed that there are three distinct ingredients in perception: the perceiving act, something given (the datum) and the object perceived. The perceived phenomenon is apprehended **from the very beginning** as pointing beyond itself to a physical object.

The critical realist position may be summarised as follows: Scientists aim at a true description of the world and a true explanation of observable events. A description of these events must be deducible from the theory. But scientists cannot know for certain that their findings **are** true. Theories are conjectures, which are subjected to tests; they are guesses about reality, which may be wrong. Theories **are** instruments for calculating and predicting, but scientists hope that they are also descriptions and explanations of reality - though they may subsequently find that they are not. Critical realists can be realist about some theories (those they believe to be true) and instrumentalist about others, which they find useful but not true (ie. theoretical models). Instrumentalists, however, are always instrumentalist. For a critical realist, it is not illogical to retain a falsified theory in an instrumentalist capacity, provided that its status is acknowledged. The fact that it is useful does not mean that it is true. It may be that within a restricted domain of application a falsified theory is more useful than a true one because it is simpler to use. In other words, it has instrumental value. Science often approaches a realist theory by way of tentative instrumentalist models.

While critical realism has many advantages over naive empirical realism, it still seems to end in relativism. For critical realists hold that we can never know the world out there. How does this Kantian position affect the validity and objectivity of human knowledge? Are we back to square one?

Not if we accept the critical realism of Roy Bhaskar (1975) and Bernard Lonergan (1957), which will now be presented in greater detail.

3.4.2 Two significant critical realists

(a) Bhaskar's critical realism

Roy Bhaskar (1989) is a contemporary British critical realist. He shows how the critical realist account of natural science can be derived by a critique of the main contemporary philosophies of science.

Bhaskar notes that, during the 1980's, scientific realism has become fashionable in the philosophy of science. This is a reaction to post-Kuhnian relativism. This new scientific realism is, however, actually empiricist. Bhaskar calls it 'empirical realism', which is:

> "a form of realism which fails to recognise that there are enduring structures and generative mechanisms underlying and producing observable phenomena and events. In other words its realism is of the most superficial sort." (Bhaskar 1989, p.2)

So contemporary scientific realism turns out to be wanting. For, being basically empiricist, it still cannot satisfactorily account for theoretical entities.

The empiricist tradition holds that scientific knowledge grows linearly and cumulatively until absolute truth is attained. As Bhaskar observes, there is some merit to this view. It is a historical fact that the fund of scientific knowledge **has** grown over the years. This fact must be acknowledged. Yet, as Kuhn pointed out, science grows by rejecting old theories and accepting new. Plurality of theories, even incommensurable theories, is what counts.

Only critical realism (maintains Bhaskar) can sustain the intelligibility of both the **experimental** and **theoretical** work of science. Only critical realism is able to save the **cumulative** character of science withour resorting to empiricism, and at the same time account for **pluralism of scientific theories** without plunging into subjectivism.

Critical realism is, for Bhaskar, far more than the 'internal' realism of those scientists (like Kuhn) who **believe** in a socially-constructed reality. Rather, it is a metaphysical realism, holding that there is an independent world prior to scientific investigation. Critical realism conceives the world as being structured, differentiated and changing. It is opposed to empiricism, pragmatism and idealism alike.

There are two sides of knowledge: the **social**, and the **objective**. Knowledge is a **social** product. Human beings in their social activity produce knowledge. It is as much a cultural product as a motor car, chair or book. The other side of knowledge is that knowledge is **of things which are not produced by men** at all: the density of mercury, electrolysis, the mechanism of light propagation. None of these objects depend on human activity. If men ceased to exist sound would continue to travel and heavy bodies fall to earth. These are, says Bhaskar, the **intransitive** objects of knowledge. The intransitive objects of inquiry are the mechanisms of the production of phenomena in nature. Science must be seen as a social process whose aim is the production of the knowledge of these mechanisms. The transitive objects of knowledge are Aristotelian material causes. They are the raw materials of science - the artificial objects fashioned into items of knowledge by the science of the day. They include the antecedently established facts and theories, paradigms and models, available methods and techniques of inquiry.

Classical empiricism can sustain neither the transitive nor the intransitive dimensions. For empiricists, events must be analysed in terms of sensations. Kant's transcendental idealism tries to uphold the objectivity of facts. However, it cannot sustain the intransitive dimension. For its objects of knowledge do not exist independently of the human mind. Transcendental idealism holds that the order in nature is imposed by the mind. Critical realism holds that order in nature exists independently of humans. If there were no science, there would still be a nature. Whatever is discovered in nature must be expressed in thought, but the structures and causal laws discovered in nature do not depend upon thought.

Experience presupposes the intransitive and structured character of objects. Epistemic access to independent objects is possible, but they must be structured. The intelligibility of experiments presupposes the structured character of objects. **Explanation** is the production of the knowledge of the mechanisms of the production of some phenomenon. The construction of an explanation will involve the building of a **model**, using antecedently existing cognitive resources and operating under the control of analogy and metaphor.

The world consists of mechanisms, not events. Mechanisms and structures are real and distinct from the events that they generate. Also, events must occur independently of the experiences in which they are apprehended. Mechanisms, events and experiences thus constitute three overlapping **domains of reality**, namely, the domain of the **real**, the **actual**, and the **empirical**. For empiricism, all three domains are identical. For critical realism, the domain of the real is greater than that of the actual, which in turn is greater than that of the empirical. Empirical realism depends on a reduction of the real to the actual. And in doing so it presupposes a closed world and a completed science.

Bhaskar (1975, p.58) emphasises that he is not saying that experiences are less real than events, or events less real than structures. This is the kind of mistake Eddington (1928) encouraged with his 'two table' problem. Every object has two faces, its familiar face, and its scientific face. Which is real? For the instrumentalist, the scientific object is an artificial construct; for the naive realist, the familiar object an illusion. For the critical realist, however, the question is a pseudo-problem. The relationship is not between a real and imaginary object, but between **two kinds of real object**. Thus our knowledge is set in the context of the ongoing activity of scientific practice.

The process occurs in three phases as follows: Science identifies a phenomenon, constructs explanations for it and empirically tests its explanations, leading to the identification of the generative mechanism at work. The classical empiricist tradition restricts itself to the first phase, the neo-Kantian tradition sees the need for the second, but it either denies the need for, or does not draw the full implications of, the third. Critical realism differentiates itself from empirical realism in interpreting the first phase as the **invariance of a result** rather than a **regularity**, and from transcendental idealism in allowing that what is **imagined** at the second phase need not be imaginary but may be **real**. Now in this continuing process (says Bhaskar 1989, p.20), as deeper **levels or strata of reality** are successively unfolded, scientists must construct and test their explanations.

On the critical realist view, the essence of science is the **movement** at any one level from knowledge of manifest phenomena to knowledge, produced by means of antecedent knowledge, of the structures that generate them. Now knowledge of deeper levels may correct, as well as explain, knowledge of more superficial ones. As Bhaskar (1989, p.20) says:

> "But only a concept of ontological depth (depending upon the concept of real strata apart from our knowledge of strata) enables us to reconcile the twin aspects of scientific development: growth and change."

It is clear that for an adequate account of scientific development, both the concepts of a **stratified and differentiated reality** and of knowledge as a **produced means of production** must be sustained.

Bhaskar points out that realism involves an ontology which is distinct from epistemology. However, the two are closely connected. The type of epistemology we hold affects the type of realism we choose. If we hold constructivism, then we must choose critical realism.

For **empiricism**, the natural order is what is given in experience; for **idealism**, it is what we make or construct; for **critical realism**, it is given as a presupposition of our causal investigations of nature, but our knowledge of it is socially constructed. For critical realism, it is the nature of objects that determines their cognitive possibilities for us; it is humanity that is the contingent phenomenon in nature.

In science humans come to know human-independent nature, fallibly and variously. Only critical realism, by setting humanity in nature, is consistent with the historical emergence, and causal investigation, of science itself. Now such an investigation presupposes an intransitive (and so non-human) ontology. This ontology is realism. And it is (says Bhaskar) a necessary presupposition of natural science.

Critical realism, for Bhaskar, is an attempt to re-orient the sciences away from the positivist and instrumentalist goals of prediction and control to the realist ones of depth explanation and intellectual emancipation.

Summary of Bhaskar's critical realism:
(1) It is grounded in the objects of the world.
(2) It takes constructivism into account.

(3) It regards theory as part of reality.
(4) It gives theory a high status.
(5) It guarantees objectivity.
(6) It avoids relativism.
(7) It holds that reality has levels.
(8) It takes pluralism of theories into account.

(b) Lonergan's critical realism

Bernard Lonergan was born in Canada in 1904, and lectured theology students in Montreal (1940-46), Toronto (1946-53) and Rome (1953-65).His main work, *Insight*, published in 1957, was written with theological method in mind, but treated epistemological questions in some detail. Lonergan put forward a type of critical realism which leaned heavily on the philosophies of St Thomas Aquinas and Kant.

Lonergan (1957) believed that the mistake of naive empiricists is that they regard only sensory experience as knowledge, and this leads to all the Humean problems about induction and causation. Kantian phenomenalism is also a direct result of this empiricist view that the real world is the object of sensation only. However, said Lonergan, the thinking subject **actively** brings to bear on the real world more than pure observation . For Lonergan,

> "the real world is not that which is apprehended by mere observation; but ... the real world is that which is known through the three-fold process of experience, understanding and judgement." (Meynell 1976, p.7)

The process of knowing, says Lonergan, is a cognitively structured whole, consisting of sensory experience, an intelligibly constructed theory, and an assessment of the truth of the theory. In Lonergan's words:

> "Now, human knowing involves many distinct and irreducible activities: seeing, hearing, smelling, touching, tasting, inquiring, imagining, understanding, reflecting, weighing the evidence, judging. No one of these activities, alone and by itself, may be named human knowing." (Lonergan in McShane (ed.) 1973, p.16)

Human knowing is, therefore, not this or that operation, but a whole whose parts are operations. It is a dynamic **structure**.

> "Human knowing is also formally dynamic. It is self-assembling, self-constituting. It puts itself together. ...It leads from experience through imagination to insight ... In turn, concepts stimulate reflection, and reflection is the conscious exigence of rationality." (ibid., p.17)

It is a mistake to compare one cognitive operation with another. For example, knowing is not ocular vision, that is, looking.

Experience is of the given: we can have experience of sensing (eg hearing, seeing), or experience of intellectual activities (eg thinking, inquiring, understanding), or experience of reflecting (eg judging, assessing). That is, there are external and internal experiences.

According to Meynell (1976), Lonergan distinguished between two types of knowing: **direct observations**, and **theoretical constructions**. He called the first 'experiential conjugates', and the second 'explanatory or pure conjugates'. Experiential conjugates appeal directly to sensory experience for verification. Pure conjugates, on the other hand, are defined not by direct appeal to experience, but by appeal to empirically established laws and theories. That is, they are verified by **insights** into series of experiences. An example of a pure conjugate is 'mass': one does not have direct experience of mass.

Unfortunately, Galileo (and Locke) distinguished between primary and secondary qualities, instead of between pure and experiential conjugates. This gave a one-sided view to scientific method, because it gave a special privilege to experiential conjugates. This is the basis of modern materialism, which regards the very essence of scientific explanation to be the reduction of all phenomena to that of matter in motion. Lonergan objected strongly to this, for it involves **either** the postulation of what is entirely beyond our experience, **or** the uncritical according of special privilege to one kind of experience over another, that is, that a directly observed object is more real than a theoretical entity.

Knowledge in the proper sense is knowledge of reality. Of its very nature, knowledge is directed towards reality. When we know, we have **confidence** that our judgements about the real are in full accord with the real as it is. So knowledge 'intends' reality. That is, knowledge is **intrinsically** objective.

> "The instrinsic objectivity of human cognitional activity is its **intentionality**. Human intelligence actively greets every content of experience with the perplexity, the wonder, the drive, the intention, that may be characterised by such questions as, What is it? Why is it so?" (ibid., p. 22)

Of its very nature, human knowing goes beyond data to intelligibility, beyond intelligibility to truth, and through truth to reality. But though **it goes beyond**, it does not leave behind. It unites what is beyond with what is behind.

> "From the partial knowledge we have reached it sends us back to fuller experiencing, fuller understanding, broader and deeper judements, for what it intends includes far more than we succeed in knowing. It is all-inclusive, but the knowing we achieve is always limited." (ibid., p.23)

Objectivity is grounded in the totality of the knowing process. It does not reside in a single operation but in a structured manifold of operations.

> "Empiricists have tried to find the ground of objectivity in experience, rationalists have tried to place it in necessity, idealists have had recourse to coherence. All are partly right and partly wrong, right in their affirmation, wrong in their exclusion. For the objectivity of human knowing is a triple cord: there is an experiential component that resides in the givenness of relevant data; there is a normative component that resides in the exigences of intelligence and rationality guiding the process of knowing from data to judging; there finally is an absolute component that is reached when reflective understanding combines

with the normative and the experiential elements into a virtually unconditioned." (ibid., p.24)

Because human knowing reaches such an unconditioned, it transcends itself. And so we distinguish between **what is**, and **what appears**. When we say that something is, we mean that its reality does not depend upon our cognitional activity. In what appears, what seems to be, what is imagined or thought, the object is still tied down by relativity to the subject. Human knowing, then, intends the transcendant. A grasp of the dynamic structure of human knowing is therefore essential to a grasp of the objectivity of our knowing.

Meynell (1976) notes that Lonergan's distinction between the thing-for-us and the thing-in-itself, between the thing-as-described and the thing-as-explained, seems to have something to do with Kant's distinction between phenomenon and noumenon. Exactly what Kant meant by this distinction is disputed; it seems likely to be derived, through successive alterations, from the Galilean and Lockean distinction between primary and secondary qualities. But Lonergan's distinction is not identical either with the Galilean/Lockean, nor with the Kantian. It is simply between things-as-described and things-as-explained. Kant's unknowable things-in-themselves are the residue of real things as constituted by their primary qualities, subjected to a criticism which is not quite thorough enough. Kant did not go far enough into the cognitional process. Part of the cognitional process involves **reflection** and **insight.**

For Lonergan, scientific knowledge is what is derived from inquiry into and reflection on experience. Materialistic philosophy results from the notion that scientific knowledge is obtained by unreflective affirmation of the reality which it immediately confronts. A materialist (positivist) is just critical enough to see the reason for saying that sensation pertains to the perceiver rather than the object perceived; hence, what exists is not the direct object of sensation, but is something which somehow gives rise to sensations in us. Phenomenalism, said Lonergan, is more sophisticated. Phenomenalism is the inevitable result of consistent application of the principle that the real world is the object simply of sensation. It holds that the real world is nothing more than what is known by the senses. Lonergan rejected this, saying that the real world is that which is known by the fullness of sensory and reflective experience. Phenomenalism errs in mistaking one part of the process of knowing for the whole.

Lonergan rejected the phenomenalism of Kant. Yet he acknowledged that reality, for Kant, was not the direct object of experience, as it had been for the empiricists. Kant held that we can know only **phenomenal reality,** and that this knowledge is a compound of **sensation** and the *a priori* categories of our thought. The phenomenal world, for Kant, is partly **sensed**, and partly **constructed**. But we could not know the reality behind phenomena.

According to Meynell (1976) Lonergan took Kant's approach further. He maintained that we can know reality itself as well as phenomena. The real world is that which is known by the three-fold process of **sensation, understanding**, and **judgement.** Reality is constructed as well as sensed. Many scientific objects (eg electrons, photons) are not directly observable. However, the understanding grasps by insight the intelligible unity in the data in the act of constructing a theory to account for them. Hence electrons and photons are real objects with an existence independent of the thinking subject. **Theory is part of reality.**

> "The **naive realist** correctly asserts the validity of human knowing, but mistakenly attributes the objectivity of human knowing not to human knowing, but to some component in human knowing. The **idealist,** on the other hand, correctly refutes the naive realist claim that the whole objectivity of human knowing is found in some component of human knowing, but mistakenly concludes that human knowing does not yield valid knowledge of reality."(ibid., p.25)

For the naive realist, the starting point of this confusion is the myth that knowing is analogous to looking. The eye sees what is to be seen. That is objectivity for the naive realist. He assumes that knowing, if objective, is like seeing. He places the ground for objectivity in the notion that there is direct access to things as they are.

The idealist distinguishes between appearance and reality. By appearance he means precisely what the observer sees or even feels. He may report that a green field is green or that it looks green. The latter does not involve any commitment about its objective properties. Knowledge of appearance is one thing, knowledge of reality another.

However, as Lonergan comments, whether one is knowing what is, or knowing what appears, the act of knowing is more than mere seeing. A judgement is also involved. Higher cognitional operations are involved at any level of knowing. There is no such thing as pure sensory experience. As Lonergan puts it:

> "An act of ocular vision may be perfect as ocular vision; yet if it occurs without any accompanying glimmer of understanding, it is mere gaping." (ibid., p.16)

The **critical realist**, unlike the naive realist, does not hold that human knowing consists in any one single cognitional operation. Also, the critical realist contends that intellectual operations are not necessarily similar to sensitive operations.

Against the idealist, the critical realist maintains that sense does not know appearances. It is just as much a matter of judgement to know that an object is not real but apparent, as it is to know that an object is not apparent but real. Sense does not know appearances, because sense alone is not human knowing, and because sense alone does not possess the full objectivity of human knowing. In Lonergan's words:

> "By our senses we are given, not appearance, not reality, but data. By our consciousness, which is not an inner sense, we are given, not appearance, not reality, but data. Further, while it is true enough that data of sense result in us from the action of external objects, it is not true that we know this by sense alone; we know it as we know anything else, by experiencing, understanding, and judging. Again, it is not true that it is from sense that our cognitional activities derive their immediate relationship to real objects; that relationship is immediate in the intention of being; it is mediate in the data of sense and in the data of

consciousness inasmuch as the intention of being makes use of data in promoting cognitional process to knowlege of being." (ibid., p.30)

Finally, against both the naive realist and the idealist, the critical realist brings the charge of **picture thinking**. The naive realist seeks the ground of objective knowledge of reality in looking and perceiving. The idealist asserts that it is by perceiving that our cognitional activities have their immediate relationship to objects. For both, their world is a picture world. If their world were the universe of being, they would agree that the original relationship of cognitional activity to the universe of being must lie in the intention of being. They forget about being.

Subjectivity was once a pejorative term. It denoted a violation of the normative exigences of intelligence and rationality. But it has come to denote a rejection of misconceived objectivity and a reaffirmation of man's right to be himself. So conceived, the problem of objectivity tends to vanish. It is more acceptable today to revise our notions of reality and objectivity, and describe them in terms of our understanding and judgements. However, even though subjectivity has gained ground in recent philosophy, and rightly so, to condemn objectivity outright undermines authentic human existence. Lonergan puts it thus:

"It is quite true that objective knowing is not yet authentic human living; but without objective knowing there is no authentic living." (ibid., p.32)

A real exclusion of objective knowing destroys personalist values. We **need** objective knowing.

Lonergan distinguishes between "the subject's world" and "the world". The latter is what is there to be known and that is unchanged by its being known. But the subject's world is correlative to the subject: it may be a world that is mostly fantasy; it may be the real world; but, either way, it is the world in which the subject actually lives.

There are therefore **different worlds**. The **first world** is the world of **immediacy.** This is the world of the infant, the world of immediate experience, of the given as given. A **second world** is this world **mediated by meaning**, and it has two forms. Initially it is an extension of the world of immediacy, but gradually, through active involvement with the world, the distinction between subject and object grows. The world mediated by meaning is far more than the sum of all the worlds of immediacy. It is the whole of the worlds of literature and science, of history and philosophy and art. It is a universe of being, that is known not just by experience, but by the conjunction of experience, understanding and judgement.

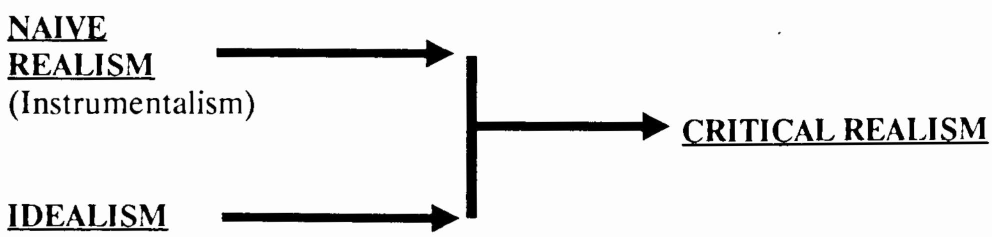
"The difference between the world of immediacy and the world mediated by meaning is the source of the critical problem of philosophers. The world mediated by meaning is for the naive realist just an abstraction; for the idealist it is the only world we know intelligently and rationally, and it is not real but ideal; for the critical realist it is the world we know intelligently and rationally, and it is not ideal but real. The world of immediacy is but a fraction of the real world."(ibid. p. 38)

A **third world** is not only mediated but also **constituted by meaning**. Language is constituted by meaning. But not only language is constituted by meaning. So also are human acts. These include acts of the will. Human acts occur in a socio-cultural context. Human institutions and mores and values have a determination from meaning. Hence the third world is a world of **community**. Common meanings have histories. They become common only through communication, clarification. It is through the available common meanings of community that the individual becomes himself.

This world mediated by meaning is the domain of **theory**. It is far more than the sum of the previous worlds. For meaning goes beyond experiencing. What is meant is not only experienced but also somehow understood and, commonly, also affirmed. It is this larger world mediated by meaning that we refer to when we speak of the real world, and in it we live our lives.

For Lonergan, there are **levels of reality**. At each level of reality, there are things judgements about which may be more or less verified in experience. One rises from the level of direct observation and description, to that of explanation and theory. Dynamic trolleys on a laboratory bench are real, just as are the unobservable forces which give rise to their accelerations. Theories like Newton's mechanics or Einstein's relativity are forms of explanation which have not been achieved simply by looking at the external world. They have been achieved by reiterated putting of questions to experience, and by multiple verifications or falsifications couched in terms of their underlying theories.

Thus critical realism bridges the gap between naive realism (empiricism) and idealism. It accounts for both empirical realities as well as theoretical.



Comments on Lonergan's critical realism: Lonergan manages to keep a firm toehold on the world of empirical objects. The component of sensory experience is one of the three components of human knowing, and must be present together with the other two. This ensures an objectivity which rests on rationality and avoids falling into the relativism that infects Selley's brand of critical realism. And, regarding what Von Glasersfeld calls "the organism's cognitive isolation from reality", Lonergan's levels of reality more than adequately avoids Hegelian idealism.

Also, Lonergan goes much further in his realism than do pragmatists such as John Dewey. Dewey's constructivism ends when knowing successfully achieves its goal: coping with real life. For Lonergan, this pragmatic goal is also important, but it does not end with an understanding only. It must end with full-blooded judgement, so that the learner can become fully human.

Lonergan's critical realism is, in my view, a superb synthesis of the best in the epistemologies of Aristotle, Thomas Aquinas, Kant, Popper, Kuhn and Harre. It also agrees well with Piaget's constructivism, for insight is an active, creative, Gestalt-type process. Lonergan has redefined reality in a wider way, and has moved away from the effete notion of reality which we have inherited from empiricism. His idea of 'levels of reality' is similar to Popper's 'degrees of conjecture'. Indeed, it is the concept of 'levels of reality' and 'degrees of conjecture' which enables us to escape from the **impasse** of instrumentalism.

Summing up: Lonergan's critical realist philosophy emphasises several important points.
(1) All observation is theory-laden.
(2) There are levels of reality.
(3) There are levels of cognitive operations.
(4) These are, broadly, sensory experience, understanding, judgement.
(5) Human knowing is not one single operation alone, but a totality of all three.
(6) Knowledge and reality are not the same.
(7) Knowledge, by its very nature, is open to reality.
(8) Reality is more than the sum of the empirical and the theoretical.
(9) Theoretical entities are part of reality.
(10) Objectivity is not grounded in sense experience alone, but also in understanding and judgement.
(11) A new notion of reality and objectivity allows problems about reality and observation to vanish.
(12) Modern man tends to sense and understand, but not to judge, thus remaining superficial.

3.5 Instrumentalism and Constructivism

Piaget held that thinking is internalised in a profound way. An operation, for Piaget, is not just an external action or event. Dewey, on the other hand, held that thinking is an event. Piaget's notion of interiorisation involves the movement from surface experience to theoretical knowledge, from practical knowing to operational schematic knowing. It is the precondition for objective knowledge. Dewey's theory of knowing remains at the surface.

Piaget's use of structures, and the equilibration between assimilation and accommodation, provides a far more satisfying account of cognition than does Dewey's interactionism.

Althouth Piaget was not interested in questions of reality, his distinction between the wide and narrow senses of representation implies that there are levels of ontological reality. For Dewey, reality is superficial, a kaleidoscope of actions and events.

Both Dewey and Piaget proposed views which were constructivist. Thus whether the learner takes the pragmatist (that is, instrumentalist) route, or the assimilation-accommodation route, he will still construct his reality. However, the Deweyan version cannot account for the construction of unobservables. Although not **passively** representational, its theory of knowledge is still empiricist. The activity advocated by Dewey results in a purely instrumental success. Piaget's constructivism also provides **understanding** as well as instrumental success.

Finally, the role of scientific theory is regarded by each approach in a subtly different but important way. Both constructivism and instrumentalism are forms of pragmatism. Therefore both hold theory in low regard. For the constructivist, a theory is easily rejected in favour of another better one. This is the whole idea behind plurality of theories. For the instrumentalist, a theory is arbitrary and fictional, and therefore can be discarded if it is more convenient. From a pedagogical point of view, this has its merits. But there must come a time when arbitrary swopping of theories must stop, and one theory chosen which conforms to the objective norms of the scientific community. It must be tested against reality.

3.6 Discussion and conclusion

Reality is not 'already out there now'. What is 'out there' is the existing physical object. In the process of acquiring knowledge of the object, reality is created. The objectivity of this reality is guaranteed, not by sense alone, but by the totality of cognitive operations, including sense.

Hence it is important to distinguish between: (1) the existing physical object; (2) the act of knowing; and (3) the real world. Reality and knowledge are distinct, but are closely related. Knowledge is knowledge of reality more than of the physical object. But because objectivity is grounded in the whole dynamic structure of knowing operations (and not sensory experience alone), and is ratified by the community, our knowledge of reality is well-founded.

By revising our notions of reality and objectivity, we have not bowed down to relativism. Indeed, all we have done is to reclaim a more correct, fully human notion. The notions of reality and objectivity based on out-moded empiricist theory of knowledge, were incomplete and misleading.

Since reality has a hierarchy of levels, and since our knowledge of reality is obtained by sensory as well as theoretical experience, theoretical entities are part of reality. Therefore a critical realist takes his theories seriously.

In my opinion, Popper's 'degrees of conjecture' and Lonergan's 'levels of reality' overcome the problems of crass phenomenalism found in the instrumentalist approach. The implication is that instrumentalism is itself a degree of conjecture. For there is a certain truth and value in the instrumentalist view. But it chooses to ignore the fact that there are other deeper levels of reality which also matter.

The many-world reality suggested by Popper and Lonergan is also found in many of the other philosophers examined: Polanyi, Harre, Bhaskar, and possibly even in Piaget. It is a useful concept, enabling the notion of reality and objectivity to be broadened.

The chief point made by critical realism is that theoretical entities are as real as those directly observed: **theory is part of reality.**

In conclusion, we can say:

(1) Constructivism is a well-established theory of education.
(2) Constructivism is relativist.
(3) Constructivism is a form of instrumentalism.
(4) Piagetian constructivism is better than Deweyan.
(5) Piaget's reality is constructed.
(6) Piaget's reality is has levels.
(7) Critical realism links empirical realism with constructivism.
(8) Lonergan's critical realism is consistent with a wider notion of realism.
(9) Lonergan's realism guarantees objective knowledge.
(10) Lonergan's realism is non-relativist.
(11) Critical realism is consistent with plurality of theories.

Chapter 4

METHODOLOGY OF THE SCHOOL SCIENCE TEXTBOOK STUDY

4.1 Introduction

The task is now to examine some recent high school physical science textbooks, especially those used in South African schools, for signs of instrumentalism.

A science textbook may incorporate an **explicit** as well as an **implicit** account of scientific inquiry. This study will therefore search for the philosophy of science in textbooks under two main headings: (a) Explicit reference to the philosophy of scientific inquiry; and (b) Implicit presentation of the philosophy of science.

Those texts which do not include an explicit mention of their philosophy are naturally far more difficult to analyse, for the reader must judge for himself what philosophical approach is being adopted by the author. This, as Herron (1971, p.198) says,

> "... opens the possibility of a variety of interpretations of what is said."

No study, including the present one, is theory-free. This study is searching for signs of instrumentalism in school science textbooks. It may therefore be biassed towards an instrumentalist interpretation wherever there is doubt about the author's meaning. Every reader approaches a book with certain preconceptions, as Popper has pointed out:

> "One never reads or understands a book except with definite expectations in one's mind. ... **We approach everything in the light of a preconceived theory**. So also a book. As a consequence one is liable to pick out those things which one either likes or dislikes or which one wants for other reasons to find in the book..." (Popper in Lakatos and Musgrave 1970, p.51)

The language used by authors who are naive realists is very similar to that used by those who are instrumentalists. This compounds the difficulty even further, especially if the author provides no explicit indication of his philosophical stance, as is usually the case. The reader can interpret the language as he prefers, either in a realist sense or in an instrumentalist sense. Young children are generally naive realists, and so would read a textbook written by either kind of author in a purely realist way. Indeed, most teenagers as well as adults (including most science teachers) would almost certainly also interpret a textbook in a naive realist way. It would be unconsciosly assumed by most readers that the author is a naive realist, even though they are not aware of the term as such. As Selley (1989, p.29) says:

> "It is tempting to interpret this confident, assertive style as being consequent upon the author's naive realist metaphysics. However it is possible to read into school science a very different interpretation, namely instrumentalism."

For this reason, this study will attempt to objectify the readings as far as possible, by making use of analytical instruments devised by previous researchers, as well as of one devised especially for this study. By using **several** such tools, and assessing their results **jointly**, an overall impression of the philosophy of science portrayed in school science textbooks will be obtained.

A schema for the present study is as follows:

TABLE 4.1: **Schema for this study**

(1) Implicit philosophy:
- **A. Level of laboratory inquiries**
- **B. Level of reader involvement**
  - **-Questioning style in text**
  - **-Involvement indices**
  - **-Philosophy checklist**

(2) Explicit references:
- **A. Quotation of specific examples**
- **B. Preface analysis**
- **C. Metaphor analysis**

4.2 Selection of the Textbooks

Twenty-three high school physical science textbooks were chosen. Seven of these are texts widely used in British schools, as well as in English-speaking schools in Third World countries, such as Lesotho and Swaziland. Eleven are texts widely used in South African high schools, three are well-known American science textbooks, and two are science textbooks originating in other African countries (Nigeria and Kenya).

One of the aims of this study is to ascertain whether there is a greater or lesser degree of empiricism and/or instrumentalism in recent high school science textbooks specifically designed for educationally disadvantaged pupils in an African context. Selley (1989, p.29) noted that, even in Britain, there has been a return to textbooks having a non-participatory, transmission style, textbooks which portray a metaphysics which is naive realist and instrumentalist. This may also be a trend in African science textbooks, and in particular, South African science textbooks. The chief characteristic of such textbooks might be factual content, the provision of simple rules to be able to solve scientific problems, and emphasis on calculations. In other words, they might be highly instrumentalist.

For this reason, this study has included some textbooks with a distinct African orientation. Textbooks from the *Nigerian Secondary Schools Project*, as well as the *Kenyan School Science Project (SSP)*, were examined. Other textbooks with an African Third-world orientation include Broster and James's *Successful Science* for Standards 8, 9 and 10, which are recent high-quality South African textbooks specifically orientated towards academically disadvantaged pupils. Other South African books which are becoming increasingly popular, especially in schools lacking adequate laboratory facilities, are *Science Education Project (SEP)*. These consist of Workbooks (such as *SEP 8,* examined in this study) which are used with a specially-designed portable kit of basic laboratory hardware for scientific inquiry practicals as well as teacher-support materials. Finally, also belonging to this group of specifically African textbooks are Jansen and Dekker's *Understanding science* for Standard 6 and 7.

All of the South African textbooks, including *Successful Science* and *Understanding science,* are designed to cover the "new" 1985 Standard 8, 9 and 10 Physical Science Syllabus. The average age of pupils in Standards 8, 9 and 10 is 15, 16 and 17 years old respectively. The reason for choosing these Standards was to align the textbooks with corresponding British O-level and GCSE, as well as the American *Project Physics*, *CHEM Study* and *PSSC Physics*.

Eight of the books were read from cover to cover, in order to obtain an overall assessment of their philosophical stand- point. These were A, B, C, D, E, F, K and R in the list below (Table 4.2). The other books were speed-read or skimmed from cover-to-cover, and then certain chapters or topics were read in detail.

All the textbooks in Table 4.2 were subjected to the Philosophy Checklist test described below, but only six books (namely A, B, C, J, K and R) were selected from the twenty-nine for elaborate analysis.

Most of the textbooks studied contain practical **laboratory inquiries** which the pupils are expected to perform. As the approach taken in practical work can portray a definite image of the nature of science to pupils, a systematic analysis of laboratory inquiries should reflect something about the philosophy of science of the author.

Also characteristic of scientific inquiry are **questions** about natural phenomena, and about how we investigate them. Questions posed in textbooks can elicit specific types of inquiry behaviour, such as by directing emphasis to observation, or creative imagination. Therefore an ordered procedure for analysing questions in the text may also be an indicator of the underlying philosophy present.

An analytical tool, specifically designed to detect the presence of empiricism and instrumentalism adds to the objectivity of a study such as the present one. Such an instrument, known as the **"Philosophy Checklist"**, was specially devised for this study.

TABLE 4.2: **TEXTBOOKS SELECTED FOR THIS STUDY**

South African

A. Brink and Jones, 1985, *Physical Science Standard 8*, Juta.
B. Pienaar, Walters, de Jager, Schreuder, 1985, *Senior Physical Science 8*, Maskew Miller / Longman.
C. Broster and James, 1987, *Successful Science (Physical Science) 8*, Oxford University Press.
D. Brink and Jones, 1986, *Physical Science Standard 9*, Juta.
E. Pienaar, Walters, Schreuder, de Jager, 1986, *Senior Physical Science* 9, Maskew Miller / Longman.
F. Broster and James, 1987, *Successful Science (Physical Science) 9*, Oxford University Press.
G. Brink and Jones, 1987, *Physical Science Standard 10*, Juta.
H. Pienaar, Walters, de Jager, Schreuder, 1987, *Senior Physical Science 10*, Maskew Miller / Longman.
I. Broster and James, 1987, *Successful Science (Physical Science) 10*, Oxford University Press.
J. Science Education Project (SEP), 1986, *Physical Science Standard 8*.

British

K. Duncan, Tom, 1987, *GCSE Physics*, 2nd Edition, John Murray.
L. Pople and Williams, 1980, *Science to Sixteen*, Oxford University Press.
M. Atherton, Duncan, Mackean, 1983, *Science for today and tomorrow*, John Murray.
N. Lewis and Waller, 1986, *Thinking Chemistry (GCSE Version)*, Oxford University Press.
O. Pople S., 1986, *Explaining Physics (GCSE Version)*, Oxford University Press.
P. Warren P., 1985, *Physics Alive*, John Murray.
Q. Lambert, 1985, *Physics for first examinations*, Blackie.

American

R. *The Project Physics Course* (Harvard), 1970, Concepts of Motion, Holt, Rinehart and Winston.
S. *CHEM Study*, 1968, Chemistry an experimental science, Freeman.
T. *PSSC*, 1960, *Physics*, Heath.

African

U. *Physics, Books 1, 2 and 3*, 1980, Nigerian Secondary Schools Science Project, Lagos, Nigeria.
V. *Physics, Years 1 to 4*, 1971, School Science Project, Nairobi, Kenya.
W. Jansen E.G. and Dekker J., 1986, *Understanding Science 6 and 7*, Maskew Miller Longman.

Finally, the above three analytical instruments are amply supported by the quotation of relevant **examples** in the textbooks of various aspects of scientific method and philosophy, both by random sampling as well as by cover-to-cover reading. A close reading of all the **Prefaces** was undertaken, in order to analyse the authors' explicit aims from a philosophical and methodological perspective. It was also felt that **absence** of any reference to philosophy would also indicate the author's philosophical position. The type of language used, whether it was **literal** or **metaphorical**, could also be used as an indicator of the author's philosophical aims, literal language being the preferred expression of the empiricist scientist.

All of these tests and instruments of analysis, **taken together**, should provide a result which is as objective and reliable as possible. They should, at the very least, act as a control over the cover-to-cover reading and interpretation of the textbooks.

4.3 Previous studies of this type.

4.3.1 Levels of Inquiry: Herron

Herron (1971) conducted a study on three textbooks, namely, *CHEM Study*, *PSSC Physics*, and *BSCS Biology* (Blue Version). These textbooks claimed to confer on pupils some knowledge or mastery of the nature of scientific inquiry. Herron wished to determine the

> "clarity and coherence with which the doctrine is set forth and to determine the extent to which the doctrine is incorporated in the actual structure of the textual materials". (Herron 1971, p.172)

He first developed a conceptual framework for analysing accounts of scientific inquiry. This was, in effect, a checklist of aspects or topics at issue which any reasonably complete account of scientific inquiry should be expected to treat. He described scientific inquiry as

> "that disciplined form of satisfaction of human curiosity which involves scientists in 'on-going, self-correcting and revisionary processes' which result in 'bodies of currently warranted fact and theory'. The bodies of fact and theory accruing from such activities are contingent on the investigator, the 'operations he performs', and 'the conceptions which organise and control his operations'". (Herron 1971, p.179)

In scientific inquiry, a set of questions or problems is posed to an **agent** about some pre-selected **subject-matter**. The agent uses a **method** to investigate the **phenomena**, which yields **scientific knowledge**. Herron then expanded these five categories into a checklist which can be used to identify whether any procedure is genuine scientific inquiry or not.

Herron emphasised that the traditional 'five-step' Baconian method given in most textbooks is far from actual practice in scientific inquiry.

The five Baconian steps are:

(1) Problem
(2) Formulating a hypothesis
(3) Selection of method

(4) Experimental procedure
(5) Conclusion (Knowledge)

There are times when application of this traditional method may be useful. However, one of its weaknesses is that it severely limits the creative aspect. Indeed, the only opportunity for using creative imagination is the stage of making a hypothesis. This **Aim-Method-Conclusion** procedure prevalent in our textbooks gives the impression that there is **only one conclusion**, and that **absolute knowledge** is attained. The pupil-scientist is left with the idea that scientific knowledge is closed. The laboratory inquiry gives no indication of **revisionary feedback** that is, that the hypothesis or the experimental method itself is open to modification. Herron noted that what is unique to science is its "built-in dynamic revisionary component". If this most important self-correcting aspect of laboratory work is omitted, scientific knowledge may be seen merely as cumulative, which it certainly is not.

Herron's review of the philosophy of science in Einstein, Dewey, Peirce and Whewell revealed the **ideational** aspect of scientific inquiry. No description of science should omit this. Herron emphasised Schwab's point that inquiries are guided by **substantive structures** which are partially tied to phenomena. These conceptions are either borrowed from the pre-existing fund of cultural knowledge, or are invented by the inquirer. The scientist brings different substantive structures to his inquiry, that is, different ways of viewing phenomena which affect his decisions about how to operate on them. Thus, scientific inquiry is theory-laden. It is guided by Schwab's "substantive structures" or Kuhn's "paradigms".

Herron then examined the three textbooks. He did not describe the procedure he used to examine the textual content of the textbooks, but it seems he read them carefully, with the checklist beside him as a guide and a way of achieving uniformity. As for the laboratory exercises, he examined them for their content and their stated purpose. He constructed a useful device for analysing laboratory texts, based on Schwab's (1962) continuum of 'openness and permissiveness'. On the one hand, a textbook laboratory inquiry may pose a problem, provide the method of solving it, as well as the answer itself. On the other hand, the pupil may be left to pose his own problem, and work out his own method and solution. There are various combinations between these extremes. This results in a four-point scale which can be used to determine the **level of inquiry** or **degree of openness**. A diagram of this analytical device is shown in Table 4.3.

In their treatment of the philosophical attributes of scientific realism, both Lonergan and Popper advocated personal **activity** in the process of acquiring knowledge. Piaget and Dewey also emphasised active learning. Therefore it seems that **any school science textbook emphasising active inquiry** would portray science as being, at least in parts, a creative adventure of the imagination, as this would get away from the passive empiricist approach. Therefore an examination of the **level of inquiry in practical laboratory work** along the lines of Herron's analysis seemed relevant as an indicator of the type of **philosophy of science present.**

My method followed Herron's exactly, but went one step further and interpreted the various Levels in terms of empiricism. Levels 0 and 1 convey the impression

TABLE 4.3: **LEVELS OF INQUIRY**

Level of inquiry	Problem given	Method given	Answer given
0	yes	yes	yes
1	yes	yes	no
2	yes	no	no
3	no	no	no

that science is a passive procedure leaving little or no scope for imagination. Thus in this study, Levels 0 and 1 were interpreted as being empiricist. Levels 2 and 3, on the other hand, being more open-ended, were seen as more ideational, imaginative and constructivist, although there is some overlap.

Six books were selected from the twenty-three as being representative of the whole set. They are:

1.	Brink & Jones 8	Text A
2.	Pienaar & Walters 8	Text B
3.	Broster & James 8	Text C
4.	SEP 8	Text J
5.	Duncan GCSE Physics	Text K
6.	Harvard Project Physics	Text R

The first two are widely-used South African science textbooks. The third is a recent South African science textbook orientated towards the educationally disadvantaged pupil. *SEP 8* is a South African laboratory exercise workbook, also orientated towards the academically disadvantaged pupil. The last two are representative of British and American textbooks respectively.

The number of Laboratory Inquiries in a given textbook at a given Level was counted (see Appendix A), and then expressed as a percentage of the total number of Laboratory Inquiries in that book (see Table 5.1 below). These percentages were then compared and finally all textbooks were arranged in Rank Order, 1 representing a high Level of Inquiry, and 6 representing a low Level.

4.3.2 Analysis of Laboratory Inquiries: Tamir and Lunetta

Tamir and Lunetta (1978) extended and refined Herron's (1971) analysis of laboratory inquiries. They developed a 16-item instrument based on task analysis (Table 4.4) and a 4-item

TABLE 4.4: **TASK ANALYSIS OF LABORATORY INQUIRIES**

	Laboratory Inquiry No										
	1	2	3	4	5	6	7	8	9	10	11
1. Recognise and define problem											
2. Formulate hypothesis											
3. Predict											
4. Design observation and measurement procedures											
5. Design experiments											
6. Carry out observations measurements, experiments											
7. Record results, describe											
8. Transform results into standard forms											
9. Explain											
10.Make inferences											
11.Formulate generalisations or models											
12.Define limitations or assumptions											
13.Learn techniques											
14.Perform quantitative work											
15.Perform "dry" lab inquiries											
16.Work according to own design											

instrument that measures the degree of integration of the laboratory work with the other components of the course (Table 4.5). The sixteen task categories include inquiry skills and actual behaviours. The laboratory inquiries were taken at their face value. No attempt was made to consult the Teacher's Guide.

TABLE 4.5: **INTEGRATION OF LAB INQUIRIES IN TEXTBOOK**

	Laboratory Inquiry No.										
	1	2	3	4	5	6	7	8	9	10	11
1.Precede text											
2.Integrate with text											
3.Groups pool results											
4.Post-lab discussion											

The total number of laboratory inquiries was counted in each particular textbook. In each laboratory inquiry, Tamir and Lunetta noted as present each of the 20 items **if the instructions to the students called for performing that task at least once**. Hence, the highest possible score for a single laboratory inquiry is 20 (the number of items in the two instruments) and the highest possible score for each item is the number of laboratory inquiries in that textbook.

The instrument devised by Tamir and Lunetta has been adapted slightly for the purpose of this study. As with Herron's test, the same six textbooks were selected for this analysis, these being regarded as being representative of the whole set.

As with Herron's Levels of Laboratory Inquiry, levels 0 and 1 were interpreted as portraying an **empiricist** standpoint, because empiricism involves a more passive observational procedure and has more limited and closed thought patterns. Levels 1 and 2, being more open-ended, were deemed for the purposes of this test, to reflect a more correct, ideational philosophy of science.

Each practical laboratory inquiry was read, and the sentences were classified according to the 16 items in Table 4.4. If a characteristic was deemed to be present **at least once** in the inquiry, a value of 1 was awarded in the appropriate cell. (Thus each count is a **minimum** value.) If a characteristic was absent, a 0 was awarded.

Various items were then re-grouped into broader categories, **in order to bring them back into Herron's format of four items**. Although it is recognised that this is just the opposite of what Tamir and Lunetta originally intended, it served the purpose of this study well. This was done according to the schema outlined in Table 4.6. The justification for this re-grouping is explained in detail in section 4.3.4 below.

The way the various items are grouped into Levels is shown in Table 4.6. The number of items encountered ("flags") was added vertically for each Level. These totals were recorded at the bottom of the page in the table called x, Level 0 having a maximum score of 5, Levels 1 and 2 each having a maximum of 4, and Level 3 having a maximum of 3. Each score obtained was then divided by the maximum possible, to obtain a fractional factor. If this fraction turned out to be greater than or equal to 0,4, a value of 1 (called the y-value) was awarded at that Level. If x was less than 0,4, then the y-value was given as 0. The 0,4 cut-off point is arbitrary, but

TABLE 4.6: **TASK ANALYSIS OF LABORATORY INQUIRIES (Adapted)**

	Level	Lab Inquiry No 1	2	3	4	5	6	Total B	
1. Recognise and define problem	2								
2. Formulate hypothesis									
3. Predict									
4. Design observation and measurement procedures									
5. Design experiments	3								
6. Carry out observations measurements, experiments	0								
7. Record results, describe									
8. Transform results into standard forms									
9. Explain	1								
10. Make inferences									
11. Formulate generalisa -tions or models									
12. Define limitations or assumptions									
13. Learn techniques	0								
14. Perform quantitative work									
15. Perform "dry" lab inquiries	3								
16. Work according to own design									
Divide each total by maximum.	x { 0 (Max 5) { 1 (Max 4) { 2 (Max 4) { 3 (Max 3)								
If x > = 0,4 let y = 1 If x < 0,4 let y = 0	y { 0 { 1 { 2 { 3								
(Totals A) OVERALL LEVEL:									

was selected after many trials as being a suitable reflection of the total contribution of "flags" to that Level. These were recorded in the lower-most table (y). Finally, the overall Level was awarded on the following basis:

Flags	0	0	0 0	=	Level	0
	1	0	0 0	=	"	0
	0	1	0 0	=	"	0
	1	1	0 0	=	"	1
	1	1	1 0	=	"	2
	1	1	1 1	=	"	3

This system of flagging and interpreting combinations of flags yielded a reasonably consistent set of results of overall Level of Laboratory Inquiry which agreed well with a straight-forward reading.

From the set of Overall Levels at the bottom of each page of Table 4.6, the number of Laboratory Inquiries in a given textbook at a particular Level was counted and recorded in **RESULT A** (Table 4.7), and expressed as a percentage of the total number. These percentages were then compared for all the textbooks studied, and presented in Rank Order (see Table 5.3A below).

In addition to this procedure, an independent technique of determining overall level of inquiry was carried out. This was done by adding all scores horizontally along rows for each of the 16 items. Those belonging to a particular Level were added together, giving rise to Collective Totals B. These were then summarised in the Table **RESULT B** (Table 4.7). The percentage of each group of items of the total number of items in that group was also calculated and recorded in **RESULT B.** (Table 4.7)

TABLE 4.7 **RESULTS OF TASK ANALYSIS**

	Level	Totals across Max	%		Collective Totals B
1. Recognise & define					
2. Formulate hypothesis	2				
3. Predict					
4. Design procedures					
5. Design experiments	3				
6. Observe, measure					
7. Record results	0				
8. Transform results					
9. Explain					
10. Make inferences					
11. Generalisations	1				
12. Define limits					
13. Learn techniques	0				
14. Quantitative work					
15. Perform dry lab inqu					
16. Own design	3				

RESULT A: (Columns)

	Number Total	%
Level 0:		
Level 1:		
Level 2:		

RESULT B: (Rows)

	Number Total	%
Level 0:		
Level 1:		
Level 2:		

All actual results are shown in Appendix B. A comparison of the results of **RESULTS A** and **RESULTS B** is given in Table 5.3 below.

4.3.3 Analysis of Questioning Style in Textbooks

Lowery and Leonard (1978) maintain that inquiry teaching enables students to study natural phenomena with the same approach and spirit as that of the scientist. This approach involves the scientific processes of observing, comparing, classifying, experimenting, communicating, inferring, etc. If many teachers rely heavily on the textbook to shape their science programme, then

> "the science textbook must be examined as to its ability to stimulate students to inquiry." (Lowery and Leonard 1978, p.1)

Questions can be effective in eliciting inquiry behaviour. Lowery and Leonard examined the questioning style of textbooks in terms of types, frequency, and placement of questions in textual reading materials. To do this, they devised the *Textbook Questioning Strategies Assessment Instrument* (TQSAI) (see Table 4.8).

Lowery and Leonard studied a 10% random sample of pages from each textbook. On a selected page, the number of sentences was counted. A ratio of questions per total sentences and a mean number of questions to sentences per page were computed.

Each question encountered was identified as to type, as follows: **Experiential** questions are those whose answers lie within the past or current experiences of the student. **Non-experiential** questions are those that focus pupils' attention upon phenomena that they have not experienced.

Within these broad groups, there are two sub-categories:
(i) The first identifies **types** of questions, each type being defined as follows: **rhetorical** questions are those that do not require an answer or are immediately followed by an answer; **direct-information** questions ask the student to recall specific facts, concepts, or other information; **focusing** questions guide the student toward an answer the author intends to develop later in the text; **open-ended** questions invite the student to explore freely without restrictions; **valuing** questions ask the student to make a cognitive or an affective evaluation.

(ii) The second set of sub-categories identify basic **science inquiry processes**. These are: observing, communicating, comparing, organising, experimenting, inferring, and applying.

Textual questions were also categorised for their **placement**: initiatory (at the beginning of a paragraph); contextual (embedded within a paragraph); terminal (at the end of a paragraph); and captional (within a caption).

To facilitate an analysis of overall questioning style, frequencies of questions within all categories were converted to a percentage of total questions for the sample. In parts A and B of Table 4.8, the figure shown in each cell represents the percentage occurrence of questions in the given category compared to the total number of all questions in the 10% sample. An empty cell indicates no occurrence of questions

TABLE 4.8: **TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT (TQSAI)**

Textbook:____

No. of Sentences:________________________

No. of Questions: ________________________

Ratio S/Q:_________ Q/S:_________

A. <u>Non-experiential</u>

1.Rhetorical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing

B. <u>Experiential</u>

	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
a. Observing				
b. Communicating				
c. Comparing				
d. Organising				
e. Experimenting				
f. Inferring				
g.Applying				

C. <u>Position of Questions</u>

Initiatory	Contextual	Terminal	Captiona

D. <u>Comparison of Questioning Style in Reading Content</u>

TEXTBOOK:					
No. of Questions					
No. of Sentences					
% of Ques. per Sent.					
% of Experientl. Ques.					
% of Initiatory Ques.					
% of Contextual Ques.					
% of Terminal Ques.					
% of Captional Ques.					

for that category.

Parts C and D of Table 4.8 provide a summary comparison of all texts examined with regard to the criteria under consideration: frequency of questions, frequency of sentences, ratio of questions to sentences, frequency of experiential questions, and a distribution of the placement of all questions.

To gain insight into a **particular** questioning style of a given text or to contrast one or more texts on certain categories, an inspection of the frequency or percentage of questions asked within those categories was made. One can compare the percentage of questions a textbook asks in a particular category to that of another category, or to the percentage of questions another textbook asks in the same category. Significant differences become an evaluative judgement, not a statistical one.

The authors note the following:
(a) If one assumes that Piaget's 'active experience' is valuable to learning, then textbooks that ask experiential questions are more desirable (ie Part B of Table 4.8).
(b) Other studies suggest that questions placed at the beginning or end of paragraphs have more learning value to the reader than contextual questions. (Part C of Table 4.8).
(c) 'Higher level' questions occur on the right side of Parts A and B of Table 4.8.
(d) The 'higher order' scientific inquiry processes lie toward the bottom of Part B of Table 4.8. This would reveal 'levels of inquiry', and would be important if our aim is to portray to high school pupils a more correct image of science.

In the present study, Lowery and Leonard's method was adapted as follows. Instead of a 10% sample of pages, only 10 pages from each textbook (the same six books used in the previous tests) were randomly selected. The number of questions as a percentage of the total number of sentences was recorded. Each question was classified as being Non-experiential or Experiential. The former type of question does not draw on the student's prior experience, whereas the latter does. For the purposes of this study, **Experiential** questions were deemed to be more **constructivist**.

Non-experiential questions were graded from closed to open-ended. **Open-ended non-experiential** questions were interpreted in this study as being **instrumentalist** (calculative, fictional, thought-experiments, etc).

Experiential questions were recorded on a type of matrix (Part B, Table 4.8). Each row was graded from closed to open questions (from left to right), and each column was graded from low to high order of inquiry-type questions (from top to bottom).

B. Experiential	Direct Informtn	Focusing	Open-ended	Valuing
Observing				
Communicating				
Comparing	**EMPIRICIST**			
Organising				
Experimenting				
Infering			**CONSTRUCTIVIST**	
Applying				

The **upper-left** part of this matrix was interpreted as being more **empiricist** in orientation, and the **lower-right** as more **constructivist**. This is based on Lowery and Leonard's similar interpretation above regarding Piaget. The choice of the line of demarcation between these (see bold line in diagram) was guided by several trials. The final result was essentially a "best-fit" choice.

Since the judgement required on how to classify a particular question was sometimes far from easy, many variations being possible, the results of this test should not be taken as conclusive in themselves, but should be seen in relation to all the other tests performed. Results are summarised in section 5. 3. 1.

The percentage of Questions to Sentences (Q/S), as well as Sentences to Questions (S/Q), was also recorded. (Appendix C)

4.3.4 Correlation of meanings for this study

As mentioned above, it is suggested here that Level of Inquiry (Openness), as discussed by Herron (1971) and Tamir and Lunetta (1978), provides a way of determining the image of science portrayed in the textbook, and hence its philosophy of science. In this study, I shall interpret Herron's Levels 0 and 1 as giving to the pupil an image of science that is cumulative, factual, and proven knowledge. Because Levels 2 and 3 are more open-ended, they give the pupil more opportunity for imaginative hypothesis-making. This provides a more correct and up-to-date view of science, namely, that scientific inquiry begins with theory and not with observation. Similarly, Tamir and Lunetta's instrument can be used to assess the philosophy of science portrayed.

It is further postulated that any school science textbook, which uses the 'learning by inquiry' approach, should convey a better view of the philosophy of science than a 'factual knowledge' type. Therefore any instrument which can distinguish between "higher" and "lower" orders of scientific inquiry processes (Lowery and Leonard 1978, p.9) can be used to assess the philosophical standpoint of the author. Lowery and Leonard's (1978) analytical tool can be used to achieve this.

"Levels of openness" and "orders of scientific inquiry processes" are, however, not the same. "Level" is concerned about which **stage** of the process is given, whereas "order" refers to the **type of skill** used. There is clearly a positive correlation: Level 0 corresponds roughly to Low Order, Level 3 to High Order. Yet it is conceivable that many Low Order processes (eg observing, recording) are used in Level 3 (ie open-ended, self-initiated) inquiries.

Herron (1971, p.197) himself did not show clearly the difference between the three 'categories' he used to classify the laboratory inquiries in *CHEM Study*, and the 'levels of openness', based on Schwab (1962), he used in his analysis of *PSSC Physics*. In 'category' 1, the student was expected to 'discover', that is, make an inductive generalisation, see patterns. In 'category' 2 are exercises involving inference and problem-solving with no pre-determined, unique solution. In 'category' 3 are exercises used to 'illustrate', that is, 'see-for-yourself' type observations, as well as to give practice in laboratory skills. These are clearly 'orders' rather than 'levels', category 3 being low order. Yet Herron states that his Level 0 would involve low order exercises. He said:

> "Into such a category (ie Level 0) would also fall laboratory exercises in which students are simply to observe or 'experience' some unfamiliar phenomena or to learn to master some particular laboratory technique."
> (Herron 1971, p.200)

Therefore, for the sake of simplicity, I shall, in this study, interpret Level 0 as Low order, and Level 3 as High Order, bearing in mind that there is some degree of each Order in each Level. In addition, Tamir and Lunetta's Item Categories (1978, p.355) will be classified as follows: Low Order (Categories 6, 7, 8, 13, 14); Medium Order (Categories 9, 10, 11, 12, 15); Higher Order (Categories 1, 2, 3, 4); and Highest Orders (Categories 5, 16).

To summarise, this study will accept the correlations shown in Table 4.9 below:

TABLE 4.9: **CORRELATION OF MEANINGS**

Herron (1971, 197)	Herron (1971,200)	Lowery and Leonard (1978)	Tamir and Lunetta (1978)
Category 3	Level 0	Low Order	6, 7, 8, 13, 14
Category 2	Level 1	Medium Order	9, 10, 11, 12
Category 1	Level 2	Higher Order	1, 2, 3, 4
---	Level 3	Highest Order	5, 16, 15

4.3.5 Textual Analysis: Romey

Romey (1968, pp.44-51) proposed a way of assessing the degree of student involvement in reading textbooks. He drew up an instrument which yielded an Index of Involvement (Table 4.10). This concentrated on contextual content.

Romey randomly selected a sample of ten pages from a textbook. Ignoring headings and captions, he counted twenty-five sentences. From these sentences, the number of factual sentences, conclusions, definitions, questions, and statements directing the reader to perform a certain activity, were counted and recorded on Table 4.10. Sentences of types e, f, g and h were taken as being interactive, whereas sentences of types a, b, c, and d were regarded as being passive, non-interactive, and factual. An Involvement Index was calculated as follows:

$$\text{Involvement Index} = \frac{\text{No. of interactive sentences}}{\text{No. of non-interactive sentences}}$$

$$= \frac{(e + f + g + h)}{(a + b + c + d)}$$

TABLE 4.10: **TEXT ANALYSIS**

Page Number:										
a. Facts										
b. Conclusions										
c. Definitions										
d. Questions asked but answered immediately										
e. Questions requiring student to analyse data										
f. Statements requiring pupil to form conclusion										
g. Directions to pupil to perform and analyse activity										
h. Ques to arouse interest -not answered immediately										
i. Sentence directing student to figure										
j. Rhetorical questions										

$$\text{Overall Involvement Index for Text} = \frac{(e + f + g + h)}{(a + b + c + d)} =$$

TABLE 4.11: **ANALYSIS OF QUESTIONS AT CHAPTER ENDS**

	Page Number									
a. Answer in text										
b. Definition										
c Requires pupil to apply learning to new situation										
d. Requires pupil to solve a problem										
e. None of the above										

Overall Index for Questions $= (c + d) / (a + b) =$

A high value suggested a high level of reader-involvement.

Similarly, a further test on questions at the ends of chapters was carried out. This was done according to the format given in Table 4.11. Romey classified each question at the end of a chapter as being of the type asking for a factual answer (closed question) or of the type instigating further activity (open-ended or interactive question). An Index for Questions was calculated as follows:

$$\text{Index for Questions} = \frac{\text{No. of open-ended questions}}{\text{No. of closed questions}}$$

$$= \frac{(c + d)}{(a + b)}$$

A high value would indicate a high level of reader-involvement.

The same six textbooks (A, B, C, J, K and R) were subjected to Romey's tests. The results of the tests are contained in Appendix D, and are summarised in section 5.3.2 below.

4.3.6 The Philosophy Checklist

In order to be as objective as possible, it was deemed desirable to draw on the previous work done in this area. The combined results of these tests should yield as comprehensive and as objective a conclusion as possible. However, the original aim of the afore-mentioned studies was not specifically to analyse textbooks for the philosophy of instrumentalism. Therefore a further instrument, called The Philosophy Checklist, has been designed specifically for this purpose.

From the discussion of inductivism, empiricism and instrumentalism in Chapter 2 above, the essential features of each were listed, so that a systematic checklist or questionnaire could be drawn up. This checklist will be used to try to ensure a more uniform and systematic approach to the reading.

Since instrumentalism is a type of positivism, the six characteristics of positivism, as suggested by Hacking (1983, p.41), are useful. They are: (1) emphasis on **verification**, (2) emphasis on **objective observation**, (3) opposition to **causality**, (4) downplaying of theories as **explanations**, (5) reluctance to admit the existence of **theoretical entities**, (6) opposition to **metaphysics**.

Instrumentalists put great emphasis on (4), (5), and (6). The role of theory is downplayed. Theories do not explain reality; they are useful fictions. Explanations are speculations which verge on the metaphysical.

Inductivists and empiricists emphasise (1), (2), and (3). Science begins with observation which is as objective as possible. Generalisations are made from many particular observations, and these laws are verified by further observations. This gives rise to factual knowledge.

The following characteristics were chosen as being properties of the inductivist-empiricist view:

1. Science begins with **observation**.
2. Observation is **objective** (theory-free).

3. Inductive **generalisations** arise from several instances.
4. Experimental data yield a **unique conclusion.**
5. Observation leads **rigorously to laws and theories.**
6. **Laws are mature theories.**
7. Science produces **proven knowledge.**

The following characteristics were chosen as being representative of the **instrumentalist** view:

1. Observation is **objective** (theory-free).
2. Observations refer to **phenomena** only.
3. **Computative predictions** are 'expected'.
4. Procedures are **recipe-like.**
5. Definitions are **nominalist.**
6. Definitions are **operational.**
7. Theories are mere **fictions** (ie do not explain reality)
8. Theories are **not informative** (ie only rules of thumb)
9. Theories are only **convenient instruments** (ie pragmatic)

On the basis of these criteria, the **Philosophy Checklist** (Table 4.12) was drawn up. All the textbooks listed in Table 4.2 were analysed using this Checklist.

Using random number tables, ten pages were selected from **each** of the twenty-three textbooks (see Table 4.2 above). Thus, over the twenty selected textbooks, 230 pages were examined for their philosophy of science. Two distinct types of feature were sought on each page: (a) **inductivist-empiricism**; and (b) **instrumentalism.**

(a) **Inductivist-empiricism**

As far as the categories 1 to 4 in section A of Table 4.12 are concerned, if any of these features was encountered at least once, it was awarded a value of 1. If not encountered, a value of 0 was awarded. The 'face-value' reading of the texts was taken in each item. For example, 'observation' was interpreted phenomenally. Unless otherwise indicated, it was assumed that theories lead rigorously to laws. Similarly, any 'factual' knowledge was taken at face-value to be 'reliable'. If any impression was given that science can solve all contemporary problems (the 'technological fix' of Factor and Kooser), then this property was regarded as present. Emphasis on logical inference was assumed to show that science is 'always rational, logical'. That is, an instrumentalist interpretation was assumed.

Justification for accepting the above 'face-value' interpretations can be found in the positivist view that both the 'explanatory' (realist) approach and the 'phenomenalist' (empiricist/instrumentalist) approach are valid hypotheses. Both can account for the facts. Hence it is legitimate to read a textbook in an empiricist or instrumentalist way.

This point is important and needs to be elaborated in more detail. I have already referred to Herron (1971, p.198) saying that texts, at face-value reading, can be interpreted in a variety of ways. Also already noted above is Selley's (1989, p.29) point that it is possible to read into a science textbook both a naive realist approach as well as an instrumentalist approach. Hacking (1983, p.41) notes that positivists sometimes say that there are no electrons, at other times that we have no good reason to suppose that they exist. Gardner (1983) makes the point that, for positivist science, the language of phenomenalism and the language of realism both yield successful results. Powers (1982, p.164) also notes that positivists accept both interpretations. Helmholtz is quoted by Hacking (1983, p.53) as saying that realism is "an admirably useful and precise hypothesis". Since both phenomenalism and realism are good hypotheses, a neutral scientific statement will be interpreted realistically by a realist, and phenomenally by a positivist, empiricist or pragmatist. A pragmatist, especially, will accept both hypotheses if they are useful. Since I have made the initial assumption that textbooks are empiricist-inductivist and instrumentalist, it seems consistent and legitimate to interpret the textbooks in a 'face-value' way.

On a given page, all sentences in which the words "observe", "observation", or similar observational words, occurred, were counted, and recorded under 1b of Table 4.12. These were totalled for a given textbook, and converted into a percentage of the total number of sentences in the ten pages examined in that text. These percentages were then summarised in 1b of Table 4.13.

Totals for the ten selected pages of a given textbook thus have a maximum of 10 points. All the 10 values in a particular row were added. (These totals were then transferred to Table 4.13 for the sake of comparison, and averaged over the 23 textbooks.) These 19 totals were then added and divided by 190, and multiplied by 100, to find the percentage of empiricist characteristics encountered of the possible 190 in a given textbook.

It must be remembered that these percentages are **minimum** values. Detailed results are presented in Appendix E, and a summary is shown in Table 5.9 below.

(b) Instrumentalism

The categories 1 to 4 under section B of Table 4.12 were similarly awarded a value of 1 if such feature were encountered at least once. If not encountered, a value of 0 was awarded. All the 10 values for each item were added across a row. Totals for each textbook had a maximum score of 10. (These totals were transferred to Table 4.13, and averaged over the 23 textbooks.) Because there were 11 items, these were out of a maximum of 110. They were also recorded as percentages of the total number of sentences. These reflect the percentage of an instrumentalist approach in each textbook. Again, these are minimum values.The detailed results are shown in Appendix E, but a summary is provided in Table 5.9 below.

Classification of statements according to the criteria in the Text Analysis often called for perceptive judgements. Therefore, in addition to these results, a detailed set of written notes (section 5.5.1 below) was kept, justifying these judgements, especially where observation, computative predictions, definitions, induction, and theories and laws were concerned.

TABLE 4.12: **PHILOSOPHY CHECKLIST**

	Instance										
Random Page Number:											Tot
A. INDUCTIVIST-EMPIRICISM:											
1. **Observation**											
a. Science begins with observation											(1)
b. "Observation" mentioned											(2)
c. Observation objective											(3)
2. **Inductive generalisations**											
a. Inductive generalisations made											(4)
b. No. of instances few											(5)
c. Verification											(6)
3. **Laws and theories**											
a. "Law", "theory" mentioned											(7)
b. Obs. leads rigorously to laws											(8)
c. Laws are mature theories											(9)
d. Data yield unique conclusion											(10)
4. **Proven knowledge**											
a. Proven knowledge											(11)
b. Science "discovers" facts											(12)
c. Tone is "factual"											(13)
d. Questions answered immediately											(14)
e. Science is reliable											(15)
f. Technological "fix" (solves all)											(16)
g. Linear accretion of knowledge											(17)
h. Science always logical											(18)
i. Science leads to absolute truth											(19)

% of empiricist statements $= \frac{E}{190} \times 100$ E = ___

B. **INSTRUMENTALISM**:											
1. **Observation**: Assumed objective											(1)
Phenomenal only											(2)
2. **Computative predictions**											(3)
Predictions "expected"											(4)
Recipe-like procedures											(5)
Only terms in an equation											(6)
3. **Definition**: Nominalistic											(7)
Operational											(8)
4. **Theories**: Fictions (no reality)											(9)
Rules of thumb											(10)
Convenient, pragmatic											(11)

% of Instumentalist statements $= \frac{I}{110} \times 100$ I = ___

TABLE4.13: **PHILOSOPHY CHECKLIST: SUMMARY**

	Instance										
Textbook (SeeTable 4.2:	A	B	C	D	E	F	G	H	I	J	Aver
A. INDUCTIVIST-EMPIRICISM:											
1. **Observation**											
a. Science begins with observation											
b. "Observation" mentioned											
c. Observation objective											
2. **Inductive generalisations**											
a. Inductive generalisations made											
b. No. of instances few											
c. Verification											
3. **Laws and theories**											
a. "Law", "theory" mentioned											
b. Obs. leads rigorously to laws											
c. Laws are mature theories											
d. Data yield unique conclusion											
4. **Proven knowledge**											
a. Proven knowledge											
b. Science "discovers" facts											
c. Tone is "factual"											
d. Questions answered immediately											
e. Science is reliable											
f. Technological "fix" (solves all)											
g. Linear accretion of knowledge											
h. Science always logical											
i. Science leads to absolute truth											

B. **INSTRUMENTALISM**:											
1. **Observation**: Assumed objective											
Phenomenal only											
2. **Computative predictions**											
Predictions "expected"											
Recipe-like procedures											
Only terms in an equation											
3. **Definition:** Nominalistic											
Operational											
4. Theories: Fictions (no reality)											
Rules of thumb											
Convenient, pragmatic											

As in (a) above, if any statement could be interpreted in either a realist **or** an instrumentalist sense, the latter was assumed. This was deemed to be a legitimate procedure, because (1) positivism accepts both the realist theory or the instrumentalist theory as workable scientific hypotheses; and (2) the aim of this study involves reading the textbooks from an instrumentalist perspective. The justification for this has been discussed above. For example, if the word 'observe' was used in the text, it was assumed to refer to **objective** observation. In the same way, any calculation of the rote, plug-in type was interpreted as being a convenient computational device with no necessary connection with the real world, and hence not necessarily informative about the world; that is, as instrumentalist.

Any references to words like 'observe', 'look', 'measure', were carefully noted and counted. Similarly, any historical assertion about a scientist 'discovering' something was recorded. Any conclusions, or rules, or laws, were regarded as inductive generalisations.

The lack of any discussion of the meaning or role of theory, or law, as well as of the theory-ladenness of observation, was also taken to be a sign of instrumentalism.

4.4 Philosophy determined by direct reading of Texts

4.4.1 Preface Analysis: (Lynch and Strube)

Lynch and Strube (1985) drew attention to the fact that the majority of modern science textbooks include statements in their prefaces which emphasise that they were written to suit a specific syllabus or were appropriate for a certain range of pupil ability. In some cases

> "authors claim something more than a mere functional role, and indicate that they wish to present a particular view of science or a certain relationship between theory and experiment in their writing". (Lynch and Strube 1985, p.121)

Lynch and Strube did not devise an elaborate method. They **simply read the preface of each textbook** to determine what the authors **claimed** they would do in the text. The prefaces often revealed assumptions about the nature of science, either by explicit mention, or even by omission. They found that, in formalist and experimentalist textbooks, the authors usually defined their purpose in the preface and rarely intruded after that. In more conversationalist texts, however, the author was more likely to comment on the nature of scientific method, metaphysical commitments, and so on, both in the preface and within the text.

The present study makes extensive use of the Preface Analysis devised by Lynch and Strube. The results, contained in section 5.5.2 below, are most revealing as far as the various authors' philosophy of science is concerned. Indeed, of all the tests carried out in this study, this Preface Analysis is one of the most fruitful.

4.4.2 Value presuppositions in science textbooks

Factor and Kooser (1981) conducted a study of value presuppositions in science textbooks. They maintain that, in scientific texts, there are explicit and tacit assertions about, among other things, the nature of scientific method (eg its rationality, objectivity, and practice). They see textbooks as the teacher's "most important teaching vehicle". Indeed,

> "textbooks are the primary and sometimes the only pedagogic vehicle. As such, they play a large role in shaping student opinion about science ..." (Factor and Kooser 1981, p.1)

The methodology of Factor and Kooser was "arduous, sometimes tedious, but not elaborate". They **read each book** from cover to cover, and **took notes** on any mention of value judgements on social, political and economic issues.

When a large amount of space was devoted to an issue, they counted the number of paragraphs describing that issue. They emphasise that it is important to note that these paragraph counts often called for borderline judgements about content because authors often mix many issues. Consequently, their charts at the end of their study should be regarded as thumb-nail sketches which reveal differing directions and areas of emphasis. An author who has devoted fewer paragraphs to a topic than another author should not be seen as producing an inferior treatment. The quantitative method used is rough. In a general way it shows which issues are regarded by the particular author as important.

However, in the main, Factor and Kooser simply read the textual material, making notes as they proceeded.

4.4.3 Metaphor Analysis

Following the ideas of Pope and Gilbert (1983a) that metaphors are often used to go beyond the facts, and lead a person from the known to the unknown, it seemed possible that an analysis of the frequency of usage of metaphor, and a classification of their type, might reflect whether a textbook was "realist" or "constructivist". (The type of realist that Pope and Gilbert refer to is the **naive** realist, or better, **empirical realist.**) Thus textbooks lacking in metaphors, or using metaphors in a way to be explained below, might be seen as empiricist.

It is important to emphasise that my own interpretation of realism takes a constructivist stance. As pointed out in Chapter 3, I believe in a **critical realism** such as Lonergan advocates. Reality is not simply that which is given, it is the totality (and more) of that which is experienced by sensation, understanding, and judgement. In other words, reality is a construct rooted in an independently existing world. Thus, whereas Pope and Gilbert oppose "realist" and "constructivist", I would use the terms "empirical realist" and "critical realist" respectively (Bhaskar 1989, p.11).

For Pope and Gilbert, the (empirical) realist views reality as a stable arrangement of objective facts. Truth is the correspondence of facts to reality. The real world exists independently of the knowing subject. Observation is objective and theory-free. A teacher (or author of a textbook) who is an (empirical) realist, is mainly a transmitter of information, rules or values which have been collected in the past. The learner (or reader) can acquire truth by means of a process of iterative accumulation. The learner (or reader) is seen as having no previous knowledge of the subject. His mind is a *tabula rasa*, which absorbs presented knowledge passively. Even teachers and textbooks which advocate a 'discovery' approach to learning assume that there is out there a physical world waiting to be revealed. The (empirical) realist teacher might see understanding as an ability to recall facts and apply them algorithmically. Understanding depends on the proper sequencing of material. Explanations might be more descriptive. That is, the teacher might see the task of understanding as involving the transfer of a set-piece justification into the student's mind. Expository teaching is the teaching style used.

On the other hand, a teacher or textbook which takes a "constructivist" approach will be more conjectural. It will try to foster imagination and self-generation of justification by means of problem-solving, giving the pupil the option of multiple explanations, and cognitive conflict. Such a teacher or author might use metaphors in a more interpretive way. Metaphors may be designed to promote anomalous ideas, that is, cognitive conflict. This will encourage the learner (or reader) to change preconceived notions.

Pope and Gilbert note that Black (1979) distinguishes three types of metaphor. Firstly, there is the **substitution** view, in which the entire sentence that is the focus of the metaphor can be replaced by a set of literal sentences. In the **comparison** view, the sentence containing the metaphor can be reduced to a paraphrase which contains an implicit literal statement of some similarity or analogy. In a third type, the **interactive** view, the primary subject of the metaphor causes the learner to select some of the secondary subject's properties and causes **construction** of a parallel implication to fit the primary which induces changes in the secondary.

Both the (empirical) realist as well as the constructivist teacher or author use metaphors. But they perceive the way they operate differently. The (empirical) realist tends to use metaphors as an heuristic aid, but not necessarily to yield greater cognitive understanding. He uses it to compare two things (the **comparative** metaphor). It is implied that two apparently dissimilar things have some similarity in common. The constructivist might make more use of the **interactive** characteristic of some metaphors. The learner (or reader) is confronted with a choice on how to interpret the metaphor. The metaphor is deliberately used to make the pupil think, to force him to generate his own interpretation. Also, the constructivist designs metaphors to introduce an element of 'make-believe'.

The way a metaphor is presented can affect the way it is interpreted. Kelly (1969) distinguishes two modes of presentation: the **interpretive** and the **invitational**. Using the phrase "the floor is hard", the interpretive mode implies that the floor is hard, irrespective of who says so. The sentence's validity stems from the floor, not the speaker. The invitational mode might suggest to the listener a certain novel interpretation. For example: "Suppose we regard the floor as if it were hard. If ..." The listener is invited to make the experience, and all its ramifications, his own.

Petrie (1981, p.208) notes that a metaphor demands that the material be looked at in a new way. In a way, it **creates** the similarity. Petrie asks whether or not a metaphor can be identified by some set of linguistic features independent of its use. The criterion is not its literal meaning, but its figurative meaning. The pupil (or reader) is presented with an assertion, which in the classroom (or textbook) is expected to be true. However, a metaphor will always turn out to be false, because the world is simply not the way it is represented in the metaphor. In short (says Petrie), a metaphor is anomalous on its face. It is the anomalous character of an interactive metaphor that distinguishes the way the metaphor transfers chunks of experience from the way in which literal language or comparative metaphor transfers chunks of experience.

Finally, a word of warning is given. A listener or reader may interpret any metaphor in either a realist (empiricist) or constructivist way if it is known beforehand whether the speaker or textbook author favours a cultual transmission or an open-ended style of teaching. Also, the context in which a metaphor occurs may affect its meaning.

It seems to me that the use of metaphors in textbooks may reflect the degree of empiricism (or instrumentalism) therein. Those with a low frequency of metaphor use, or those using comparison metaphors, might be classified as more empiricist (instrumentalist) in their approach. Those with high counts, or those using interpretive metaphors, might be seen as constructivist (that is, truly critically realist, in Lonergan's sense of the term).

The method followed in the search for metaphors was to read (a) the Introduction to each textbook; (b) the first few paragraphs of each chapter in each textbook; and (c) specific topics which deal with "accepted" scientific metaphors (such as **field**, **current**, **frame of reference**, **planetary model**). Also, the way the textbook treated the notion of **models** was examined. These results were recorded in section 5.5.3 below.

4.5 Summary of the procedure followed in the textbook study

This study first searched for implicit signs of the philosophy of science present in the above textbooks. It did so in three distinct ways:

(i) Level of laboratory inquiry

Using Herron's (1971) and Tamir and Lunetta's (1978) instruments, a textual analysis of **laboratory inquiries** (ie practical experiments as described in the texts) was carried out. For these analyses, only six of the selected texts were examined.

The philosophy of science present was interpreted according to the discussion in 4.3.4 above, and especially Table 4.9.

(ii) Level of reader-involvement in the Text

Using Lowery and Leonard's (1978) and Romey's (1968) instruments, the **questioning style** and the proportion of **interactive** material of each textbook chosen in (i) above, was determined. Only textbooks A, B, C, J, K and R were examined. Not every test of Lowery and Leonard was relevant to this study, so attention was focussed on the "Orders of scientific inquiry processes" (Table 4.8 B). Also, it was deemed sufficiently meaningful to use a smaller sample: instead of 10% of the total number of pages being used, only 10 pages were selected from each text. Any bias created by the smaller sample would be offset by the fact that many other instruments were used. As with the first two tests (Herron's and Tamir & Lunetta's), the interpretation of the philosophy derived was correlated according to Table 4.9.

(iii) Type of philosophy determined by direct reading

Firstly, the **Philosophy Checklist** was used exactly as described above, in order to determine the degree of empiricism and instrumentalism.

Secondly, the books were read to find **explicit** references to the philosophy of science. This was done by using three techniques:

(a) Any **example** of any relevant scientific inquiry process (such as observing, theory-building, model-making, scientific laws), found either in a sampled page, or in topics deliberately chosen (eg Atomic Theory), was recorded and classified.

(b) Following Lynch and Strube's (1985) method, all **prefaces** were read to see if explicit mention was made of the philosophical stance of each author. If nothing was explicitly mentioned, an attempt was made to discern the tacit philosophy of the author.

(c) A search for any **metaphors** used anywhere in the texts was made. The assumption made was that lack of metaphors (that is, literal language) was favoured by authors using an empiricist methodology.

In conclusion, it is worth recalling here what the specific objectives of this part of the study are:

(1) to ascertain whether physical science school textbooks from Britain, America and South Africa are strongly empiricist and/or instrumentalist;
(2) to discover whether a particular country's textbooks have a stronger emphasis on empiricism and/or instrumentalism;
(3) to determine whether recent textbooks (of the 1980's) do have a trend towards instrumentalism; and
(4) to determine whether recent Third-world African textbooks are becoming increasingly instrumentalist.

Chapter 5

RESULTS OF THE SCHOOL SCIENCE TEXTBOOK STUDY

5.1 Introduction

The main body of the results of this school science textbook study is to be found in the Appendices . Summaries of each analysis will be presented and discussed in this chapter.

The order of presentation of results is as follows:

1. **Level of Laboratory Inquiry**
   A. Level of Laboratory Inquiry
   B. Task Analysis of Laboratory Inquiries
2. **Level of Reader Involvement**
   A. Textbook Questioning Strategies Assessment
   B. Text Analysis
   C. Questions at Chapter Ends
   D. Philosophy Checklist
3. **Direct reading survey**
   A. Examples quoted
   B. Preface Analysis
   C, Metaphor Analysis

5.2 Results of the Levels of Laboratory Inquiry Analyses

5.2.1 Level of Laboratory Inquiry

(a) Herron's Test:

From the twenty-three textbooks involved in this study, six were selected for Herron's Test: these were A, B, C, J, K and R. The examination of these six, regarded as being representative of the whole set, revealed that most of the laboratory inquiries in these texts were at Level 0 and Level 1. (See Appendix A, for detailed listing of results.)

TABLE 5.1

	Total No. of Lab Inquiries	Integrated in Text
SEP 8	68	NO
Harvard Physics	13	NO
Duncan GCSE Physics	48	YES
Pienaar & Walters 8	61	YES
Broster & James 8	69	YES
Brink & Jones 8	66	YES

Percentages of lab inquiries at Level:

	0	1	2	3	Rank Order
SEP 8	4	96	0	0	1
Harvard Physics	23	69	8	0	2
Duncan GCSE Physics	67	33	0	0	3
Pienaar & Walters 8	84	16	0	0	4
Broster & James 8	91	9	0	0	5
Brink & Jones 8	97	3	0	0	6

There is a heavy predominance of Levels 0 and 1 in these textbooks. Using the interpretation scheme suggested in Table 4.9, it seems that most of these laboratory inquiries portray science as consisting of cumulative, factual and proven knowledge. That is, the general philosophy of science portrayed is **empiricist.**

It should be noted, however, that this is based on the text alone, and does not take into account the possibility that the teacher might have pre-practical and post-practical discussions. Also, although most of the practical inquiries were open-

TABLE 5.2

Overall		87	%
	Level 0:	56	64
	Level 1:	28	32
	Level 2:	3	4
	Level 3:	0	0
South African		38	%
	Level 0:	25	66
	Level 1:	12	31
	Level 2:	1	3
	Level 3:	0	0
British		24	%
	Level 0:	17	71
	Level 1:	6	25
	Level 2:	1	4
	Level 3:	0	0
American		10	%
	Level 0:	2	20
	Level 1:	7	70
	Level 2:	1	10
	Level 3:	0	0
African		15	%
	Level 0:	12	80
	Level 1:	3	20
	Level 2:	0	0
	Level 3:	0	0

ended in themselves, their integration into the textbook meant that, in every case, the answer was given immediately afterwards.

Herron (1971, p.196) found that *CHEM Study* was decidedly **empirical** in its orientation. Accurate, objective observation and controlled experimentation are emphasised. Although the textbook treats "models" in science at some length, it does not point out the **ideational** or constructive aspects of "control" and "observation". It neglects the creative factors which guide scientific inquiry. The textbook gives the impression that eternal truths are discovered from phenomena.

Herron found that, apart from a discussion of models near the end of the first section, *PSSC Physics* makes no explicit mention of how scientific inquiry proceeds. This makes the task of analysing its inherent philosophy more difficult. Thus it may be interpreted either realistically or instrumentally. In general, this textbook portrays science as uncovering unchanging laws in the natural world. Laws are subject to change, more because of limitations in measuring procedures than intrinsic tentativeness of theories. The reader is left with the impression that one day, when technology is more refined, absolute truth will be attained. Thus, *PSSC Physics* also has an **empiricist** orientation.

Besides the six textbooks analysed in detail, randomly sampled pages from all the textbooks studied here (listed in Table 4.2) contained altogether 87 laboratory inquiries. These are shown at the end of Appendix A. The results of these sampled pages are summarised in Table 5.2.

From this broad picture obtained from a small sample of pages, it seems that the African books have low Levels of Laboratory Inquiry, followed closely by the British and South African books. The overall philosophy of science is **empiricist**. The American books contain a higher Level of Inquiry, yet nevertheless remain basically empiricist.

The general conclusion that can be drawn from applying Herron's adapted test to these books is that there is a strong underlying current of empiricism in these textbooks. However, *SEP 8*, *Harvard Physics*, and Duncan's *GCSE Physics* possess a greater proportion of higher levels of inquiry. That is, they have a stronger leaning towards constructivism

5.2.2 Results of Task Analysis of Laboratory Inquiries:

The results of this more refined Level of Laboratory Inquiry, following Tamir and Lunetta's instrument, are contained in full in Appendix B, especially on pages , 17, 24, 32, 40, 46, and 49.

Two sets of Results were obtained, those from totalling columns vertically (Result A), and from adding rows horizontally (Result B). The Level of Laboratory Inquiry was derived from Result A by means of the formula described in Chapter 4 (4.3.2). The Level of Laboratory Inquiry was derived from Result B by grouping items according to the scheme given in Tables 4.6 and 4.7.

Results of these Task Analyses, performed on the six selected textbooks, are summarised in Table 5.3A below. Results A and B agree reasonably well, in the sense that they both show similar relative proportions of each Level in particular textbooks. Table 5.3B summarises only Results A.

TABLE 5.3A

	LEVEL	RESULT A	RESULT B
Brink & Jones 8	0	55	50
	1	45	40
	2	0	0
	3	0	0
Pienaar & Walters 8	0	74	51
	1	26	27
	2	0	0
	3	0	0
Broster & James 8	0	73	55
	1	27	29
	2	0	0
	3	0	0
SEP 8	0	62	71
	1	22	31
	2	16	25
	3	0	3
Duncan	0	83	75
	1	17	15
	2	0	1
	3	0	0
Harvard	0	46	88
	1	46	44
	2	8	17
	3	0	5

Table 5.3B may be interpreted as follows. *SEP 8* has the highest Level of Laboratory Inquiry, therefore is the **least empiricist.** Duncan's *GCSE Physics*, having the greatest number of low-level inquiries, is therefore the **most empiricist**.

The high values obtained in the Task Analysis in categories 6, 7, 8, 13 and 14 indicate, from Table 4.9, that emphasis is placed on the basic skills of recording and classifying, and not so much on the open-ended, critical, imaginative skills. (See Appendix B). These textbooks suggest that observation provides unique factual knowledge. Observation is seen as being objective, and leading unerringly to hypotheses and theories. Science is generally portrayed as not requiring imagin-

TABLE 5.3B

Percentages of lab inquiries at Level:

	0	1	2	3	Rank Order
SEP 8	62	22	16	0	1
Harvard	46	46	8	0	2
Brink & Jones 8	55	45	0	0	3
Broster & James 8	73	27	0	0	4
Pienaar & Walters 8	74	26	0	0	5
Duncan	83	17	0	0	6

ation. In general, Tamir and Lunetta's adapted tests reveal the six selected textbooks as being largely **empiricist.**

5.3 Level of Reader Involvement in Text

5.3.1 Textbook Questioning Strategies

The analysis of questioning style in the chosen textbooks shows that there is a greater emphasis on questions asking for direct information. (See Appendix C, parts A and B of each test). A summary of these results follows:

TABLE 5.4	NON-EXPL	EXPERIENTIAL		Rank Order
	Instrumtl	Empiricist	Construct	
Duncan	55%	30%	15%	1
Harvard	38	36	26	2
Broster & James 8	26	57	17	3
Pienaar & Walters	18	54	28	4
Brink & Jones 8	15	55	30	5
SEP 8	7	66	27	6

In general, the left side of Parts A and B of Table 4.8 have higher scores than the right. Also the top part of B has higher scores than the bottom. According to Lowery and Leonard, this means that **Lower Order questions predominate,** a trend which gives the reader the impression that science does not ask open-ended questions, that science is a 'closed book', that scientific knowledge is proven knowledge.

Duncan is by far the most instrumentalist, *SEP 8* the least. Surprisingly, *SEP 8* is the most empiricist. This is due to the many questions directed at the pupil about observations (for example, "What do you observe?What is the reading on the ammeter?") These were regarded as factual, direct-answer types, and hence empiricist. However, taking *SEP*'s overall philosophy into account, in which the authors of *SEP* recognise that all observation statements are loaded with prior theory, the high proportion of empiricism in *SEP 8* should not be interpreted too literally. In other words, *SEP 8* contains a large amount of **empirical** as opposed to **empiricist** material.

TABLE 5.5 **Comparison of Questioning Style in Reading Content** (See Appendix C)

TEXTBOOK:	Brink	Pien	Bros	SEP8	Dunc	Harv
No. of Questions	20	11	23	15	27	27
No. of Sentences	220	160	251	74	217	225
Noof Ques. per Sent.	9%	7%	9%	20%	12%	12%
%of Experiential Ques	85%	82%	74%	93%	45%	66%
% of Non-Expertl. Ques	15%	18%	26%	7%	55%	34%
% of Initiatory Ques.	40%	9%	17%	20%	0%	26%
% of Contextual Ques.	0%	0%	0%	20%	0%	30%
% of Terminal Ques.	60%	91%	83%	60%	100%	44%
% of Captional Ques.	0%	0%	0%	0%	0%	0%

Total Sent: 1147 Total Ques: 123 Overall % Q/S: 11%

Using the percentage of Questions per Sentences found in Table 5.5, the following ranking order is obtained:

% of Question/Sentences		
SEP 8	20	Most constructivist
Harvard	12	
Duncan	12	
Broster	9	
Brink	9	
Pienaar	7	Least constructivist

The percentage of Non-Experiential questions is an indication of the degree of instrumentalism present. The ranking order is as follows:

% of Non-Experiential Questions		
Duncan	55%	Most instrumentalist
Harvard	34	
Broster	26	
Pienaar	18	
Brink	15	
SEP 8	7	Least instrumentalist

Table 5.5 also reveals that most questions are initiatory or terminal (rather than contextual). This means (following Lowery and Leonard) that all six textbooks make good use of High Order questions. That is, they all tend to have high levels of reader-involvement.

Terminal questions predominate. If these are ranked, the following ranking order is obtained:

% of Terminal Questions		
Duncan	100%	Most constructivist
Pienaar	91	
Broster	83	
Brink	60	
SEP 8	60	
Harvard	44	Least constructivist

Placed side-by-side for easier comparison we get:

Ranking	% of O/S	% of N-E	% of Term
1	SEP 8	Duncan	Duncan
2	Harvard	Harvard	Pienaar
3	Duncan	Broster	Broster
4	Broster	Pienaar	Brink
5	Brink	Brink	SEP 8
6	Pienaar	SEP 8	Harvard

Duncan features high on **both constructivism and instrumentalism**. So does Harvard. This suggests that there are two ways of achieving constructivism:
(1) By an empiricist textbook making good use of questions and calculations.
(2) By an empiricist textbook making use of rule-of-thumb, instrumental procedures.

This conclusion differs from my initial view that instrumentalism is opposed to constructivism, and therefore requires an explanation. A tentative explanation is that there are two opposing philosophies behind constructivism: the Deweyan and the Piagetian, or better, the pragmatist and the critical realist. Both lead to constructivism, but the instrumentalist version contains inherent philosophical dangers that the critical realist version does not.

To summarise the conclusions from this test of questioning styles:

Firstly, lower-order questions predominate. Therefore the textbooks emphasise the science-as-proven-knowledge idea. That is, they are **empiricist**.
Secondly, Duncan's textbook is the most **instrumentalist**.
Thirdly, it seems that an **instrumentalist book may also be constructivist**.

5.3.2 Textual Analysis

The results of Romey's Text Analysis reveal that there is a strong preponderance of facts, conclusions and definitions in the high school textbooks examined. (See Appendix D). Once again, this can be interpreted in terms of science as proven knowledge.

(a) Involvement Index

The Involvement Index is defined as follows:

$$\text{Involvement Index} = \frac{\text{No. of interactive sentences}}{\text{No. of non-interactive sent}}$$

TABLE 5.6

SEP 8	19,3	(high reader involvement)
Harvard	0,9	
Duncan	0,8	
Broster	0,7	
Brink	0,6	
Pienaar	0,2	(low involvement)

The abnormally high Index for *SEP 8* reflects the fact that this book is specifically designed as a practical workbook. It is therefore in a class of its own. Nevertheless, *SEP 8*, Harvard and Duncan are reflected here as the most **constructivist.**

(b) Index for Questions at Chapter Ends

This Index is defined as follows:

$$\text{Index for Questions} = \frac{\text{No. of open-ended questions}}{\text{No. of closed questions}}$$

TABLE 5.7

Harvard	47,0	(high involvement)
Duncan	13,0	
Brink	1,3	
Pienaar	1,2	
Broster	1,1	(low involvement)
SEP 8	(no questions at Chapter Ends)	

These results suggest that Harvard and Duncan are the most **constructivist.**

(c) Textual analysis

(All values in the first four tables are expressed as a percentage of the total number of sentences. The number of calculations per page are not percentages, but average values.)

TABLE 5.8

Facts		Definitions		Questions	
SEP 8	13%	SEP 8	0%	SEP 8	28%
Broster	42	Harvard	2	Broster	15
Harvard	49	Duncan	2	Duncan	10
Pienaar	50	Pienaar	4	Pienaar	8
Duncan	55	Broster	4	Brink	8
Brink	57	Brink	6	Harvard	5

Instructions		No. of calculations per page	
SEP 8	59%	Duncan	3,9
Brink	29	Broster	2,2
Broster	23	Pienaar	1,0
Duncan	21	Brink	0,9
Pienaar	18	SEP 8	0,6
Harvard	17	Harvard	0,4

These results show the textbooks placed in rank order. A few tentative conclusions from the Textual Analysis are that *SEP 8* is the most reader-involved book, followed closely by **Duncan** and **Broster**. That is, these are the most **constructivist**. At the same time, **Duncan** is the most **instrumentalist**.

Once again these results are consistent with the previous conclusion that **instrumentalism** is not necessarily opposed to **constructivism**, but indeed may be a means of promoting it.

5.3.3 Philosophy Checklist

The detailed results are found in Appendix E. A summary of the Philosophical Checklists for each textbook is given below in Tables 5.9 and 5.10.

The totals of all the instances of the various philosophical characteristics relating to Inductivist-empiricism and Instrumentalism are summarised below in Tables 5.11 and 5.12, expressed as percentages. The main results are in Appendix E.

It must be borne in mind that these figures are minimum values. That is, they reflect the minimum amount of empiricism or instrumentalism found in each textbook.

It is interesting comparing the set of results (in Tables 5.11 and 5.12) for the selected six, with the average number of calculations per page from Table 5.8 above. The latter should reflect the degree of instrumentalism present.

Rank	Empircm	Instrumntm	No. of Calcs/page	
1	Brink	Duncan	Duncan	Most instru-
2	Pienaar	Pienaar	Broster	mentalist
3	Broster	Brink	Pienaar	
4	Duncan	Broster	Brink	
5	SEP 8	SEP 8	SEP 8	Least instr-
6	Harvard	Harvard	Harvard	umentalist

The similarity between the ranking orders of the two right-hand columns is significant. A high frequency of calculations in a science textbook seems to be a good indicator of the degree of **instrumentalism.**

The degree of correlation between the two left-hand columns is less marked, but is nevertheless present. Very generally, it seems that there is a slight positive correlation, namely, that a high degree of **empiricism** is linked with a high degree of **instrumentalism.**

TABLE 5.9: **PHILOSOPHY CHECKLIST: SUMMARY**

		Totals for each book											
	Textbook (See Table 4.2):	A	B	C	D	E	F	G	H	I	J	K	L
A.	**'INDUCTIVIST-EMPIRICISM:**												
1.	**Observation**												
	a. Science begins with observation	5	5	4	4	6	5	7	3	5	7	3	6
	b. "Observation" mentioned	4	5	4	2	6	5	2	1	3	3	2	0
	c. Observation objective	5	5	4	2	7	5	7	3	5	6	3	8
2.	**Inductive generalisations**												
	a. Inductive generalisations made	3	2	3	2	4	5	4	2	4	0	2	4
	b. No. of instances few	2	2	3	2	4	4	4	1	2	0	1	4
	c. Verification	2	2	2	3	3	4	3	1	3	0	3	3
3.	**Laws and theories**												
	a. "Law", "theory" mentioned	5	2	2	3	1	0	0	2	1	1	0	2
	b. Obs. leads rigorously to laws	4	1	1	2	1	0	2	2	1	0	0	0
	c. Laws are mature theories	1	1	0	0	0	0	0	1	1	0	0	0
	d. Data yield unique conclusion	3	4	2	2	4	3	5	7	4	0	0	0
4.	**Proven knowledge**												
	a. Proven knowledge	6	6	4	5	6	8	7	8	7	0	4	8
	b. Science "discovers" facts	5	3	4	4	5	5	5	4	6	7	2	7
	c. Tone is "factual"	7	6	4	6	7	8	7	9	7	1	3	8
	d. Questions answered immediately	0	2	2	0	2	0	2	1	2	0	0	0
	e. Science is reliable	1	2	2	1	1	1	1	5	4	0	2	2
	f. Technological "fix" (solves all)	0	0	0	0	1	1	1	1	4	0	0	1
	g. Linear accretion of knowledge	2	1	1	1	2	1	5	3	5	0	1	0
	h. Science always logical	2	1	0	0	1	0	2	7	4	0	0	0
	i. Science leads to absolute truth	2	2	1	1	2	0	4	3	6	0	1	1
	% TOTAL:	31	27	23	21	33	29	36	34	39	13	14	28
B.	**INSTRUMENTALISM**:												
1.	**Observation**: Assumed objective	4	5	4	4	8	5	7	3	5	7	4	8
	Phenomenal only	1	0	1	0	1	0	4	4	4	5	3	1
2	**Computative predictions**	4	4	5	5	4	3	4	5	5	4	8	9
	Predictions "expected"	5	5	3	7	5	6	5	5	5	2	8	4
	Recipe-like procedures	3	4	4	5	4	6	3	5	4	1	6	3
	Only terms in an equation	2	2	4	5	2	6	4	5	4	2	6	2
3.	**Definition**: Nominalistic	3	4	6	2	4	3	2	4	3	0	3	2
	Operational	4	5	1	1	2	2	6	2	3	0	3	3
4.	**Theories**: Fictions (no reality)	5	2	1	5	2	2	3	5	3	1	5	2
	Rules of thumb	5	5	6	4	6	5	4	5	3	0	4	7
	Convenient, pragmatic	5	5	5	5	3	4	4	4	5	2	7	9
	% TOTAL:	37	37	36	39	37	38	42	43	40	22	52	45

TABLE 5.10: **PHILOSOPHY CHECKLIST: SUMMARY**

		Totals for each book												
	Textbook (See Table 4.2)	M	N	O	P	Q	R	S	T	U	V	W	Tot	Av
A. INDUCTIVIST-EMPIRICISM:														
1.	**Observation**													
	a. Science begins with observatn	8	8	9	9	9	3	9	8	6	8	8	145	6
	b. "Observation" mentioned	5	2	0	4	5	3	9	6	0	4	2	77	3
	c. Observation objective	8	6	8	9	7	2	9	8	6	8	8	139	6
2.	**Inductive generalisations**													
	a. Inductive generalisations made	6	7	0	9	7	4	9	5	3	5	5	95	4
	b. No. of instances few	6	2	0	1	3	1	3	3	0	2	3	53	2
	c. Verification	5	4	0	7	3	3	4	4	4	4	5	72	3
3.	**Laws and theories**													
	a. "Law", "theory" mentioned	0	1	0	0	2	0	2	2	3	1	0	30	1
	b. Obs. leads rigorously to laws	0	0	0	0	0	0	0	1	3	1	3	22	1
	c. Laws are mature theories	0	0	0	0	0	0	0	1	0	1	3	9	0
	d. Data yield unique conclusion	5	5	0	0	0	1	0	0	5	6	4	60	3
4.	**Proven knowledge**													
	a. Proven knowledge	6	9	9	7	8	1	5	4	8	8	9	143	6
	b. Science "discovers" facts	5	8	9	8	5	1	7	7	4	6	5	122	5
	c. Tone is "factual"	8	9	9	7	6	0	5	2	9	3	8	139	6
	d. Questions answered immediately	1	0	0	0	2	0	0	0	1	0	3	18	1
	e. Science is reliable	1	2	0	0	0	0	0	0	2	0	5	32	1
	f. Technological "fix"	0	1	0	0	0	0	0	0	0	0	4	14	1
	g. Linear accretion of knowledge	1	6	9	7	7	0	0	0	6	5	1	64	3
	h. Science always logical	0	1	0	2	2	0	0	0	5	0	2	29	1
	i. Science leads to abs. truth	0	6	9	7	7	0	0	0	7	6	5	70	3
	% TOTAL:	34	41	33	41	38	10	33	27	38	36	44	1333	58
B.	**INSTRUMENTALISM:**													
1.	**Observation**: Assumed objective	8	6	8	9	7	2	9	8	5	8	8	142	6
	Phenomenal only	5	8	1	3	3	0	1	0	4	4	5	58	3
2.	**Computative predictions**	4	2	7	5	1	4	6	4	6	5	4	108	5
	Predictions "expected"	4	2	7	5	2	2	4	2	6	4	4	102	4
	Recipe-like procedures	4	5	7	3	6	3	0	2	6	4	5	93	4
	Only terms in an equation	4	1	2	3	2	2	1	2	6	4	4	75	3
3.	**Definition**: Nominalistic	3	1	0	1	5	0	0	0	3	3	5	57	2
	Operational	3	2	4	2	2	2	0	1	4	2	3	57	2
4.	**Theories**: Fictions (no reality)	3	5	4	2	3	4	4	3	3	3	3	73	3
	Rules of thumb	5	7	6	7	8	0	1	3	4	3	4	102	4
	Convenient, pragmatic	7	7	4	8	7	0	0	2	5	3	9	110	5
	% TOTAL:	45	42	45	44	42	17	24	25	47	39	49	977	42

TABLE 5.11

Empiricist sentences

Jansen & Dekker	44%	
Warren	41	
Lewis & Waller	41	
Broster & James 10	39	
Lambert	38	
Nigerian Physics	38	
Brink & Jones 10	36	
Kenyan Physics	36	
Pienaar & Walters 10	34	
Atherton	34	
Pople (Expl. Physics)	33	
CHEM Study	33	
Pienaar & Walters 9	33	
Brink & Jones 8	31	*
Broster & James 9	29	
Pople (Sci. to 16)	28	
Pienaar & Walters 8	27	*
PSSC Physics	27	
Broster & James 8	23	*
Brink & Jones 9	21	
Duncan	14	*
SEP 8	13	*
Harvard	10	*

(Those marked with an asterisk are the six selected textbooks)

TABLE 5.12

Instrumentalist sentences

Duncan	52%	*
Jansen & Dekker	49	
Nigerian Physics	47	
Pople (Epl. Phys.)	45	
Atherton	45	
Pople (Sci. to 16)	45	
Warren	44	
Lambert	42	
Lewis & Waller	42	
Broster & James 10	40	
Kenyan Physics	39	
Brink & Jones 9	39	
Pienaar & Walters 10	39	
Brink & Jones 10	38	
Broster & James 9	38	
Pienaar & Walters 9	37	
Pienaar & Walters 8	37	*
Brink & Jones 8	37	*
Broster & James 8	36	*
PSSC Physics	25	
CHEM Study	24	
SEP 8	22	*
Harvard	17	*

(Those marked with an asterisk are the six selected textbooks)

Condensed summaries of the Philosophical Checklist results are given below in Tables 5.13 and 5.14.

Table 5.13:
Condensed Philosophy Checklist: Raw Scores

	TEXTBOOK:	A	B	C	D	E	F	G	H	I	J	K
A. INDUCTIVIST-EMPIRICISM												
1.	Observation	14	15	12	8	19	15	16	7	13	16	8
2.	Inductive generalisation	7	6	8	7	11	13	11	4	9	0	6
3.	Laws & theories	13	8	5	7	6	3	7	12	7	1	0
4.	Proven knowledge	25	23	18	18	27	24	34	41	45	8	13
B. INSTRUMENTALISM												
1.	Observation	5	5	5	4	9	5	11	7	9	12	7
2.	Computative predictions	14	15	16	22	15	21	16	20	18	9	28
3.	Definitions	7	9	7	3	6	5	8	6	6	0	6
4.	Theories	15	12	12	14	11	11	11	14	11	3	16

	L	M	N	O	P	Q	R	S	T	U	V	W	TOT	Av	Max
A.															
1.	14	21	16	17	22	21	8	29	22	12	20	18	363	16	30
2.	11	17	13	0	17	13	8	16	12	7	11	13	220	10	30
3.	2	5	6	0	0	2	1	0	4	11	9	10	119	5	40
4.	27	22	42	45	38	37	2	17	13	42	28	42	631	27	90
B.															
1.	9	13	14	9	12	10	2	10	8	9	12	13	200	9	20
2.	18	16	10	23	16	11	11	11	10	24	17	17	378	16	40
3.	5	6	3	4	3	7	2	0	1	7	5	8	114	5	20
4	18	15	19	14	17	18	4	5	8	12	9	16	285	12	30

Percentages of each of the above values were calculated as follows. The value in each cell was divided by the maximum for that cell and multiplied by 100. This procedure smooths out any differences in raw score totals and give a fairer basis for comparison.

Table 5.14:

Condensed Philosophy Checklist: % of Totals

TEXTBOOK:		A	B	C	D	E	F	G	H	I	J	K
A. INDUCTIVIST-EMPIRICISM												
1.	Observation	47	50	40	27	63	50	53	23	43	53	27
2.	Inductive generalisation	23	20	27	23	37	43	37	13	30	0	20
3.	Laws & theories	33	20	13	18	15	8	18	30	18	3	0
4.	Proven knowledge	28	26	20	20	30	27	38	46	50	9	14
B. INSTRUMENTALISM												
1.	Observation	25	25	25	20	45	25	55	35	45	60	35
2.	Computative predictions	35	38	40	55	38	53	40	50	45	23	70
3.	Definitions	35	45	35	15	30	25	40	30	30	0	30
4.	Theories	50	40	40	47	37	37	37	47	37	10	53

	L	M	N	O	P	Q	R	S	T	U	V	W	TOT	AV	%
A.															
1	47	70	53	57	73	70	27	97	73	40	67	60	1210	53	41
2.	37	57	43	0	57	43	27	53	40	23	37	43	733	32	25
3.	5	13	15	0	0	5	3	0	10	28	23	25	303	14	10
4.	30	24	47	50	42	41	2	19	14	47	31	47	702	31	24
													2948	130	100

	L	M	N	O	P	Q	R	S	T	U	V	W	TOT	AV	%
B.															
1.	45	65	70	45	60	50	10	50	40	45	60	65	1000	43	29
2.	45	40	25	58	35	28	28	28	25	60	43	43	945	41	27
3.	25	30	15	20	15	35	10	0	5	35	25	40	570	25	16
4.	60	50	63	47	57	60	13	17	27	40	30	53	952	41	28
													3467	149	100

Extracting the results for textbooks originating in various countries, we get Table 5.15. The percentages for each item per country were added and averaged thus: (A + B + D + E + G + H)/6; (R + S + T)/3; (K + L + M + N + O + P + Q)/7; (C + F + I + J + U + V + W) / 7. The values for each country were then added down a column. The number in brackets reflects the percentage of Inductivist-empiricism or of Instrumentalism contributed by the textbooks of that country. Note that for this Table (5.15), all Broster and James's textbooks (C, F, I) as well as SEP 8 (J) were included under "African" and not included under "South African". Thus A, B, D, E, G, H are South African; K, L, M, N, O, P, Q, are British; R, S, T, American; and C, F, I, J, U, V, W are African Third World.

Table 5.15

Averages of the percentage totals for each country

		S.Afr	Brit	Amer	African
A.	**INDUCTIVIST-EMPIRICISM:**				
1.	Observation	44	57	66	50
2.	Inductive generalisation	26	37	40	29
3.	Laws & theories	22	5	4	17
4.	Proven knowledge	31	35	12	33
TOTAL A :		123 (24%)	134 (26%)	122 (24%)	129 (25%)
B.	**INSTRUMENTALIST**				
1.	Observation	34	53	33	46
2.	Computative predictions	43	44	27	44
3.	Definitions	33	24	5	27
4.	Theories	43	56	19	35
	TOTAL B :	153 (27%)	177 (31%)	84 (15%)	152 (27%)
	TOTAL A + B :	276 (26%)	310 (29%)	206 (19%)	281 (26%)

A tentative conclusion from Table 5.15 indicates that the textbooks from all three countries are approximately **equally inductivist-empiricist**. As for instrumentalism, South African, African and British textbooks have a stronger emphasis than do American textbooks. The **British** textbooks lead in the degree of **instrumentalism** present, followed closely by the **African** and **South African** textbooks.

5.4 Summary of all quantitative results

All the texts examined revealed a predominance of an **inductivist-empiricist** approach. It should be recalled that these values are **minimum** values, the sought characteristic being noted **at least once** in the sampled page. Table 5.14 reveals that between 29% and 41% of the sentences sampled reflect a repeated assumption on the part of the authors that observation is impersonal and objective. Inductive generalisations, either as Laws, but more often as the conclusions of practical experiments in the laboratory, occupy 25% of the sentences sampled. 24% of the statements sampled suggest that science is a body of proven facts, that is, achieved, non-revisable knowledge. Only 10% made any mention of the term "theory" or "law", but the role of theory was not discussed.

Table 5.14 also reveals an emphasis on computative predictions (27%), and both nominalistic and operational definitions (16%). This, taken together with the implication that observation is theory-free, and also with the 28% reflecting that physical science makes great use of mathematical relationships as convenient devices for prediction rather than explanation, implies the existence of **instrumentalism** in high school physical science textbooks.

Virtually all of these laboratory inquiries were at Level 0 or 1, implying a strong commitment to **empiricism.**

About 55% of the sentences sampled were factual (see Table 5.10). Questions formed a large proportion of some texts (eg Duncan's *GCSE Physics*), but on average, only11% of the total number of texts examined comprised questions (see Table 5.5).

All of the above results are now placed alongside each other to facilitate comparison. In order to simplify the procedure, only the six textbooks (A, B, C, J, K and R) selected from the main set of twenty textbooks, will be compared in the following ranking orders.

5.4.1 Levels of Involvement

TABLE 5.16

Textbook	Herron Level				Tamir Level				Romey (High = Involved)	
	0	1	2	3	0	1	2	3	Inv.Ind	Qu.Ind
A Brink & Jones	97	3	0	0	55	45	0	0	0,6	1,3
B Pienaar & Walt	85	15	0	0	74	26	0	0	0,2	1,1
C Broster & James	91	9	0	0	73	27	0	0	0,7	1,0
J SEP	4	96	0	0	62	22	16	0	19,3	-
K Duncan GCSE	67	33	0	0	83	17	0	0	0,8	13,2
R Harvard Physics	23	69	8	0	46	46	8	0	0,9	47,0

The six textbooks were placed in ranking order according to the data in the above Table 5.16:

CONCLUSION →
DEGREE OF INVOLVEMENT

Herron:	Brink	Broster	Pienaar	Duncan	Harvard	SEP
Tamir:	Duncan	Pienaar	Broster	Brink	Harvard	SEP
Romey Text:	Pienaar	Brink	Broster	Duncan	Harvard	SEP
Romey Ques:	Broster	Pienaar	Brink	Duncan	Harvard	-

This ranking order strongly suggests that, on the whole, SEP, Harvard and Duncan are the **most constructivist.**

5.4.2 Textual analysis

Similarly, the data from the Table 5.8 above were set alongside each other in Table 5.17 below, and then the six textbooks were again placed in ranking order.

TABLE 5.17

TEXTBOOKS	Total No Sentences	% Facts	% Ques	% Defn	% Inst	Obsvn	Calcs
A Brink & Jones	100%	57	8	6	29	9	9
B Pienaar & W	100	50	8	4	18	17	10
C Broster & Ja	100	42	15	4	23	13	22
J SEP	100	13	28	0	59	4	6
K Duncan GCSE	100	55	10	2	21	2	39
R Harvard Phys	100	49	5	2	17	5	4

RANKING ORDER BY USING PERCENTAGES FROM TABLE 5.17

	Low %				High %	
Facts	SEP	Broster	Harvard	Pienaar	Duncan	Brink
Questions	Harvard	Brink	Pienaar	Duncan	Broster	SEP
Defintns	SEP	Harvard	Duncan	Pienaar	Broster	Brink
Instruct	Harvard	Pienaar	Duncan	Broster	Brink	SEP
Calculns	Harvard	SEP	Brink	Pienaar	Broster	Duncan

If we assume that a high degree of instrumentalism leads to a high level of involvement, and if we interpret that a high degree of involvement correlates with (a) a low % of facts, (b) a high % of questions, (c) a low % of definitions, (d) a high % of instructions to pupils, and (e) a high number of calculations, then a ranking of degree of involvement becomes:

→ DEGREE OF INVOLVEMENT

	Empiricist				**Instrumentalist**	
Facts	Brink	Duncan	Pienaar	Harvard	Broster	SEP
Questions	Harvard	Brink	Pienaar	Duncan	Broster	SEP
Defns	Brink	Broster	Pienaar	Duncan	Harvard	SEP
Instructs	Harvard	Pienaar	Duncan	Broster	Brink	SEP

This interpretation of Table 5.17 suggests that SEP, Duncan, Broster are the most **instrumentalist.**

5.4.3 Correlation of all Ranking Orders from all Tests

The six selected textbooks were placed in rank order for each of the above tests. In this summary of all results, Rank Order 1 = Most involved, that is, most constructivist.

TABLE 5.18 **SUMMARY OF RANKING ORDERS**
(Rank 1 = Most involved)

RANK	Herron	Tamir	Romey Involv	Romey Ques	Textual Facts	Defs	Ques	Instruct	% Q/S
1	SEP	SEP	SEP	-	SEP	SEP	SEP	SEP	SEP
2	Harv	Harv	Harv	Harv	Bros	Harv	Bros	Brink	Harv
3	Dunc	Brink	Dunc	Dunc	Harv	Dunc	Dunc	Bros	Bros
4	Pien	Bros	Bros	Brink	Pien	Pien	Pien	Dunc	Brink
5	Bros	Pien	Brink	Pien	Dunc	Bros	Brink	Pien	Pien
6	Brink	Dunc	Pien	Bros	Brink	Brink	Harv	Harv	Dunc

The above Table awards each textbook a particular ranking number for each test. These ranking scores were then added across for each textbook, to obtain a total score for that textbook. For example, the respective scores are as follows:

SEP	1 + 1 + 1 + 0 + 1 + 1 + 1 + 1 + 1	=	8
Harvard	2 + 2 + 2 + 2 + 3 + 2 + 6 + 6 + 2	=	27
Broster	5 + 4 + 4 + 6 + 2 + 5 + 2 + 3 + 3	=	34
Duncan	3 + 6 + 3 + 3 + 5 + 3 + 3 + 4 + 6	=	36
Pienaar	4 + 5 + 6 + 5 + 4 + 4 + 4 + 5 + 5	=	42
Brink	6 + 3 + 5 + 4 + 6 + 6 + 5 + 6 + 4	=	45

This gave rise to the final overall order of placement for degree of **involvement** in Table 5.19 below. The right-hand listing in Table 5.19 below for ranking order for **instrumentalism** is taken directly from the results of the Philosophical Checklist in Table 5.12 above. That for **empiricism** is taken directly from Table 5.11 above.

TABLE 5.19 **FINAL UNIFIED SUMMARY**

INVOLVEMENT	INSTRUMENTALISM	EMPIRICISM
1. SEP 8	1. Duncan	1. Brink
2. Harvard	2. Pienaar	2. Pienaar
3. Broster	3. Broster	3. Broster
4. Duncan	4. Brink	4. Duncan
5. Pienaar	5. Harvard	5. SEP 8
6. Brink	6. SEP 8	6. Harvard

This final ranking order suggests that there might be an inverse relationship between degree of involvement and degree of instrumentalism. **SEP 8** and **Harvard** are **most** involved (that is, **constructivist**), yet are also **least instrumentalist**. Yet **Broster & James 8** and **Duncan** suggest just the opposite, namely, that a **high** degree of **constructivism** correlates well with a **high** degree of **instrumentalism**.

Perhaps the fairest conclusions that can be drawn from the above quantitative study are that:

(1) The textbooks which are most **empiricist** (Brink, Pienaar) are the least **involving.**

(2) A strongly **instrumentalist** approach (Duncan) can raise a fairly strong **empiricist** textbook to a higher level of **involvement** (Duncan).

(3) An **instrumentalist** approach can be used to promote **constructivism.**

5.5 Results of the direct reading survey

5.5.1 Examples in the Texts of key scientific concepts

Some of the textbooks were read from cover to cover in order to extract references to their philosophy of science. In others, specific chapters, or topics, were closely read, especially where references to 'observation', 'theory' or 'model-building' were made - such as in chapters dealing with the historical development of the atomic theory, and the various models of acids and bases.

Some examples and quotations from the various textbooks are now presented, illustrating their authors' views of **observation, computative prediction, definition, induction,** and **theory.**

(a) Observation

Most of the texts assume that observation is objective and completely unaffected by previous theoretical presuppositions. Statements suggesting this are:

> "Because the scientist cannot directly observe the atoms ... an atomic model has been devised which explains the different observations." (Text B, p.229)
> "You have observed evidence for this ..." (Text E, p.96)
> "Human beings find out things by using their senses." (Text N, p.3)
> "We see that ..." (Text C, p.16)
> "We observe that ..." (Text B, p.188)
> "Note ... Measure ..." (Text M, p.204)
> "Measure the ..." (Text K, p.18)

The three exceptions, which briefly but clearly discuss the limitations and subjectiveness of observation, are the American books (Texts R, S and T). The *Project Physics Course* (Text R) stands out from all the others in that it shows that observation is theory-laden by giving a detailed historical treatment of the Aristotelian versus the Galilean view (eg. Text R, p.43).

Once again it must be pointed out that the above examples could be seen to be nit-picking. We all know that the author realises that sensory observation is influenced by external and internal factors which modify its objectivity. Yet in a study like this, we can only read the words as they stand, and take them at their face-value, unless the author has explicitly tried to explain his meaning.

(b) Computative prediction

There are naturally many examples of the use of mathematical equations in most of the texts. These may (or may not) be used by the pupil in a rote, 'plug-in', instrumental way, merely 'to get the right answer', with little thought of relating it to real life. If this is done, the computations are 'expected' predictions (that is, not really informative about the world). They are simply convenient devices.

Worked examples abound in most of the texts. There are examples on Ohm's Law, Boyle's Law, heat calculations, chemical calculations, as well as large numbers of Exercises at the end of chapters.

Calculations using equations like $v = f\lambda$, $R = V/I$, may be interpreted as non-causal. That is, there is no indication that V **causes** I, but only that I always **accompanies** V. The focus of interest implied here is the **relationship** between the variables. This instrumentalist technique sidesteps problems involving whether I or V actually exist or not.

Predictions of another kind, namely, inductive predictions, are also found in several of the texts. Inductive predictions are those in which, on the basis of having observed the regularities of some past events, we can predict the occurrence of a future one. Here are some examples:

> "We can therefore predict that fluorine will be even more reactive."
> (Text B, p.188)
> "A precipitate will be formed if ..." (Text B, p.285)

From the regularities of observed phenomena, rules can sometimes be made in order to predict. For example:

> "Can we predict when a precipitate will be formed and when not? Do any rules exist in connection with solubilities?" (Text B, p.282)

(c) Definitions

Among the many types of definition, only two were systematically sought for in the textbooks: **nominalist** definitions, in which a **name** is given to a phenomenon or relationship; and **operational** definitions, which define a concept in terms of the actual operations carried out to obtain it. These are sometimes closely connected. For example, 'density' is the **name** given to 'mass per unit volume', and also the **operation** of dividing mass by volume. Operational definitions are also related to mathematical equations, such as resistance using Ohm's Law.

Here are some **nominalist definitions** from the textbooks:

> "Upthrust is the name we give ..." (Text Q, p.94)
> "... called the critical angle." (Text M, p.204)
> "... are called allotropes." (Text E, p.316)
> "... is called a nuclide." (Text Q, p.249)
> "... is called the time base." (Text P, p.221)
> "... are called hydrogen bonds." (Text N, p.277)

"... is called the cut-off potential." (Text D, p.92)
"... called the anode." (Text A, p.202)
"... is called the latent heat." (Text B, p.326)

Examples of **operational definitions:**
"... Resistance R is defined by R = V/I." (Text K, p.172)
"(Refractive Index)... is defined by the equation ..." (Text K, p.18)
"... covalent radius, where the radius (r) is half the distance (d) between two nuclei ..." (Text D, p.285)
"The following equation defines resistance: ..." (Text C, p.62)
"1 mole of any gas ..." (Text M, p.240)
"A conductor has a resistance of 1 ohm if ..." (Text B, p.106)
"Acceleration = $\frac{\text{change of velocity}}{\text{time taken for change}}$ " (Text M, p.151)

Operational definitions define concepts in terms of the procedures required to measure them. Operational definitions have the instrumentalist property of avoiding difficult questions of a metaphysical nature, for example, that of real existence. But operational definitions have a severe weakness: not all the conditions required to define them can be specified.

Usually, a definition should be informative about the real world. It asks the question "What is it?" of the term on the left side of the definition, and answers it by the defining formula on the right. However, according to Popper (1983, p.92), this is not the way modern science works. Modern science asks: "What shall we call 'mass per unit volume'?" and answers with the name: 'Density'. It starts with the defining formula, and calls for a name for it. Hence in modern science, definitions are merely shorthand symbols or succinct phrases, to make language less cumbersome, rather than ways of providing information. Now there is nothing intrinsically wrong with this approach. Indeed, elimination of 'excess baggage' is one of the reasons for the enormous success of science.

However, the cost of using nominalistic definitions is great, because the tendency to give names to complex relationships and phenomena can lead to discussions about the meaning of words, rather than about the physical phenomena to which the words refer. Also, the danger of any definition is that it gives the impression that knowledge is a closed book, no longer open to revision. Definitions that seek the essence of things, ultimate truth, are wrong. For of its very nature, truth is always provisional and tentative.

This applies especially to scientific inquiry, with its built-in self-correcting approach. Every author who uses definitions should therefore make it quite clear that definitions are always open to revision. This was not done in any of the textbooks examined.

(d) Induction

Induction is the process of generalising from a relatively few instances. It includes drawing **conclusions**, formulating **laws** and **rules**, **verification**, and the idea that scientific knowledge is **established** by many **confirmations**.

Popper endorsed Hume's criticism of induction: by its very nature, it goes beyond the facts. It is logically invalid to assert a universal property on the basis of a comparatively few observations. However, inductive generalisations abound in science. As Hanson (1971) pointed out, there is nothing wrong with this, because the risky leap into the unknown is balanced by the fact that the leap takes place in the context of an umbrella theoretical structure. Induction, like all scientific processes, is saturated in theory. Therefore induction is a valid scientific technique. But its limitations should be pointed out by authors of science textbooks.

Examples of **inductive generalisations** in the texts:

> "The wave phenomena we observed ... are characteristic of all types." (Text B, p.4)
> "All waves ..." (Text B, p.4)
> "It is clear that there are certain properties which are common to all chemical combination ..." (Text B, p.230)
> "In general, surfaces that are good absorbers of radiation are good emitters when hot." (Text M, p.182)
> "It is found that ..." (Text M, p.240)
> "All masses attract ..." (Text L, p.82)

In those texts containing practical laboratory inquiries, many experiments conclude with an inductive generalisation. On the basis of the single experiment performed by the pupil, there emerges a universal law, without any precautionary statement, or any reference to the many thousands of scientists 'out there' whose experiments provide many confirmatory instances. Every textbook should, at least once in the text, make it quite clear to the pupil that inductive generalisations are problematic and must be used with care.

Examples of **verification**:
Many of the practical experiments are provided merely so that the pupil can verify a law or principle. That is, they are of the 'see-for-yourself' type, for example:

> Verification of Faraday's Law (Text C, p.80)
> Tests for anions (Text B, p.285)
> "This can be checked by ..." (Text M, p.342)

References to **scientific laws**:
Various laws are mentioned (eg Newton's Laws of Motion and Gravitation, Ohm's Law, Faraday's Law, Boyle's Law, Snell's Law, Lenz's Law), but none of the texts discusses the notion that laws are inductive generalisations, with the Humean characteristic of enlarging

> "the information content of the axioms and premises or the observation statements from which it proceeds." (Medawar 1984, p.79)

Examples of the **proven knowledge** idea:
High school physical science textbooks are often accused of portraying scientific knowledge as proven knowledge, with little if no room for further research. Of course, science does have a 'body of knowledge' which is very reliable. But the self-critical nature of scientific method ensures that even this 'body of knowledge',

is always open to change or refinement. Yet, if the history of science, as described in textbooks, suggests that scientific discoveries led cumutively, inexorably and linearly to our contemporary store of scientific knowledge, then it follows that such knowledge is established and unrevisable. Further, the notion that phenomena were waiting to be **discovered** implies that, when discovered, that is the end of the story. Here are some examples:

> "... experimentation established finally that ..." (Text A, p.15)
> "Soon afterwards Madame Curie discovered radium." (Text I, p.379)
> "(Oersted) ... discovered ..." (Text A, p.87)
> "... it was concluded that ..." (Text E, p.100)
> "Today radioactivity is used ..." (Text M, p.379)
> "Towards the middle of the 17th century, Robert Boyle and Issac Newton began to realise that scientific theory could be based only on accurate experimental observations." (Text A, p.136)
> "In 1932 Chadwick discovered that ..." (Text A, p.150)

The only explicit reference to the term 'induction' that could be found in any of the texts was in *CHEM Study*. On page 3, induction is described as an elementary logical thought process, and the bounds within which inductive generalisations are valid are given.

(e) Theories and models

Discussion about the role of theory, or the interaction with, and priority of, theory in all stages of the scientific inquiry process, is most conspicuous by its absence in most of the textbooks examined. There is also a noticeable lack of any explanation about models and their importance. The exceptions are *The Project Physics Course* (Harvard), and to a lesser degree, *CHEM Study* and *PSSC Physics*.

In actual fact, most scientific theories are arrived at, not by generalising the sensory data, but by modifying already-existing theories. This is Popper's view (Magee 1973, p.32). Popper defends the priority of theory. Science begins with a pre-existing theoretical framework, not crass observation. Observation is always selective and interpretive. It needs a point of view or interest, which, in turn, 'colours' the observation. Some kind of theory exists in the mind before any observation is made. The mind is not a *tabula rasa*, as the empiricists maintain.

> "All observation involves interpretation in the light of our theoretical knowledge..." (Popper 1983, p.48)

Yet, in spite of this, we read statements like the following in our textbooks:

> "A theory is a set of ideas formed from facts or reasoning in an attempt to prove something." (Clarke, Hurst, Thoka, 1987, *Successful Science 6*, p.221)
>
> "Initially the existence of electrons was determined by experiment ..." (Text B, p.219)

Of course, this is true, but the theory-ladenness of experiment is not mentioned, either here, or anywhere else in the text. The British and South African textbooks make an occasional mention of 'theory' in passing, without any attempt to highlight its imaginative role, or any other role, for that matter. They are the poorer for this neglect.

Explicit mention of theory is made only in the following textbooks:

> "Theories are ideas which are used to explain facts." (Text J, p.3)
>
> "(A model) is an idea, a picture, a system of concepts which creative intuition and hard work lead us to think (about and) describe the things we investigate." *(PSSC Physics*, p.151)

CHEM Study talks briefly about the tentative, revisable nature of theories and models. (*CHEM Study,* p.4)

Harvard *Project Physics* again excels itself, not only by showing how theory develops historically, but also by its helpful marginal notes, for example, those on theory on page 48 of *Text and Handbook 1, Concepts of Motion.*

The relationship portrayed in the texts between theory and the real world is an ambiguous one. Most people, as Gardner (1983) states, are naive realists. When we talk about an electron, we believe that there is something out there, existing independently of our thinking, called an electron. And certainly, school pupils, particularly younger ones, are naive realists. No doubt, the authors of these textbooks believe in the independent reality of electrons and photons and other unobservables. In this sense, they too are realists. So when they talk about 'kinetic theory', they surely hold that matter really consists of particles in constant, random motion. Yet, as was mentioned in some previous collaborative research (Jacoby and Spargo 1989, p.47), it is possible to read their words in a purely instrumental way. Their 'kinetic theory' could refer to reality, but equally it might not. It could be regarded as a convenient fiction only, with no sense of commitment to a common-sense reality. Selley (1989, p.29) also found this realist/instrumentalist ambiguity in school textbooks. British (and South African) authors of high school physical science textbooks are caught up in the atmosphere of British empiricism and now out-moded logical positivism. Textbooks tend to capture the philosophical atmosphere of past rather than present philosophies. Hence it is not surprising that the science textbooks of today still contain an instrumentalist slant, even though it is now out of fashion. The philosophy of Popper and Kuhn has not yet permeated into the high school classroom.

It must be pointed out that references in the textbooks to 'unobservable', theoretical entities may be regarded by the authors equally in a realist or anti-realist way. For example, statements about the Law of Conservation of Energy:

> "All the energy essentially ends up as heat." (Text L, p.92)
>
> "Heat lost equals heat gained." (Text B, p.294)

These can be either convenient bookkeeping devices, or a true description of reality. The words themselves do not suggest which interpretation the author of the textbook believes. Even in a textbook like the Harvard *Project Physics*, which continually emphasises the theory-dependence of observation, we can read about Galileo's kinematics in an instrumental, rather than a realist, way. Indeed, it could be argued that Galileo was an instrumentalist as far as kinematics was concerned, but a realist as far as astronomy was concerned. Perhaps all scientists (and hence also school science educationists) experience Koestler's "controlled schizophrenia", sometimes behaving as instrumentalists, at other times as realists.

In the Harvard *Project Physics* Text and Handbook 1, **Concepts of Motion**, we read Galileo's definition of acceleration in an instrumentalist way:

> "A motion is said to be uniformly accelerated when, starting from rest, it acquires during equal time intervals, equal increments of speed." (p.48)

Sagredo, one of the three characters taking part in the dialogue, a man of good will and open mind and eager to learn, says that all definitions are arbitrary. He asks whether Galileo's arbitrary definition of acceleration actually corresponds to the way real objects fall. Sagredo, therefore, notes that it is possible to interpret Galileo's theory in an arbitrary, instrumental way. Further, Sagredo suggests that they should look for the **cause** of acceleration. But Salviati (speaking for Galileo) replies that this invites too many speculative answers. All such notions of cause are "fantasies". Instead of looking for causes, they should simply **describe** the properties of accelerated motion.

It is obvious that this is nothing more than an instrumentalist approach. Ignore metaphysical speculations about causality. Theories about causes are fantasies. Explanations are not wanted, only descriptions. Even Galileo's experiments with accelerated motion continued this instrumentalist approach, for his experiments, though dealing with real objects, gave rise to descriptions rather than explanations.

What was needed to take Galileo's theory beyond instrumentalism and towards realism, was a **physical** theory. Dynamics had to supercede kinematics. It took Newton to do this. Although Galileo did prepare the way for Newton, nevertheless, there can be no doubt that Galileo's world-view was realist: he believed that the sun was at the centre of the orbiting planets, and that some kind of force caused the planets to move. He tried to substantiate this with his theory of tides (Koestler 1957, p.477). He came very close to a correct theory of impetus, namely, Newton's First Law of Motion. But Galileo stated that if a body is left to itself, it will continue, not in a straight line, but in a circular path. It can be seen that although Galileo was still very much influenced by Aristotelian ideas, he was nevertheless struggling to liberate himself from them. Although he never fully reached a true **physical** theory, he was tending towards it, and on these grounds can be regarded as a realist.

The authors of the Harvard *Project Physics* obviously assume that Galileo's theory is an attempt to reach a true description of reality. Galileo's theory is better than Aristotle's. On page 153, the authors invite the student to decide for himself, on the basis of preceding experiments, whether it was Aristotle or Galileo who was correct. The experiment described on page 153 is clearly meant to be taken as more than a mere manipulation of variables. It affects reality. Taken as a whole, the authors of *Project Physic* project a realist view rather than an instrumentalist one.

Similarly, in PSSC Physics, there is also an explicit commitment to realism:

> "We therefore test all models to see how well they represent the real thing." (p.152)
>
> "Our models, the physical theories that we now have, describe much of our world." (p.152)

The scientific realism portrayed in the Harvard *Project Physics* and the *PSSC Physics*, however, does not fully take into account the theory-ladenness of scientific inquiry. They adopt what Bhaskar (1989) calls empirical realism, making no allowance for the constructive element of cognition. The British and South African books, following the line of British empiricism, assume that a real physical world exists independently of the observer. Like the American books, they make no explicit reference to it. When they do say that we observe the natural world, the implication is that observation is pure, impersonal and theory-free.

(f) Pragmatism and utilitarianism

There are many references in most of the textbooks examined to industrial applications of science. For example, on the pages sampled, the uses of transformers and electric motors, as well as the industrial preparation of ammonia and sulphuric acid, are described.

Although it could be argued that these are direct references to the realism of science, this is not so. Usefulness of science in real life is not the same as an explanatory understanding of the real natural world. Truth is more than usefulness.

5.5.2 Results of the Preface Analysis

A reading of the preface to each textbook reveals a general unawareness on the part of the author(s) of the philosophical implications and weaknesses of the instrumentalism present in the corresponding text. Those few who do refer to scientific method have a notion of scientific method which is strongly criticised by contemporary philosophers of science.

Text A: Brink and Jones 8: The separation of observation and theory, and the notion that observation leads rigorously and inexorably to theory, is clearly stated:

> "It is important in the study of Physical Science that concepts and theories be developed from actual experimental observation and discovery."

The role of prior theory as a guide to investigation is not mentioned. The authors emphasise understanding of phenomena, rather than learning of facts. They maintain that questions asked in the text amd during practicals will enable pupils to discover for themselves the theories and principles. However, as Driver (1983) points out, experience alone is not enough in activity methods. The authors were, however, very close to doing what they should have explained more explicitly, namely, that the teacher must supply the theoretical framework and guiding principles. Pupils cannot obtain this from the textbook alone, for the textbook is too condensed and consequently instrumentalist.

Text B: Pienaar, Walters et al, 8: There is no explicit reference to the nature or method of science in this preface, only that the presentation is pupil-orientated, both as regards text and experiments. There is no suggestion that class discussion should both precede and follow laboratory work.

Text C: Broster and James 8: Because the text is written for the pupils, and especially for the more socially disadvantaged pupils, the authors have aimed to keep it as brief as possible. The authors believe that science must be experienced to be understood. Therefore the emphasis is on doing experiments. The pupils should do these experiments themselves. Pupils are also encouraged to keep a list of definitions for study purposes. All comments in the preface are of a similar pragmatic nature. There is no explicit reference to scientific method or the authors' philosophy of science.

Text D: Brink and Jones 9: This preface expresses the same sentiments as in Text A above. Understanding and pupil involvement, particularly in practical work, are regarded by the authors as important. Concepts and theories should be developed from actual experimental observation and discovery. Again, these authors come close to a discussion of the philosophy of scienctific observation and theory, but do not devote nearly enough attention to it.

Text E: Pienaar, Walters, et al, 9: The authors state that they have made this text pupil-orientated. New concepts appearing for the first time are fully explained. Summaries and questions are designed to assist pupils. Practical experiment are integrated into the text.

Text F: Broster and James 9: No preface whatsoever is provided in this textbook. Since these authors obviously wrote their textbook with a wide pupil-population in mind, including the more disadvantaged pupil, this is a glaring omission. The content and presentation of the material are very good indeed, but the philosophical approach is clearly instrumentalist. Some sort of preface is therefore necessary, to guide teachers - and particularly the under-qualified teachers who all too frequently form the majority of staff in schools for disadvantaged pupils.

Text G: Brink and Jones 10: As in their Standards 8 and 9 textbooks, the authors reiterate the need for the pupil to understand scientific concepts. This is best achieved through actual active observation and discovery. Again, there is need for a brief but more comprehensive treatment of the history and philosophy of science.

Text H: Pienaar, Walters, et al, 10: The authors merely summarise the fact that they have kept to the "new" Syllabus. There is no explicit reference to scientific method, nor to the history or philosophy of science.

Text I: Broster and James 10: In "Notes to the Teacher", the authors suggest that many scientific principles can be demonstrated using very simple apparatus. "After all, the early scientists such as Dalton, Newton, Galileo, Archimedes and Copernicus had no sophisticated equipment but were able to demonstrate their theories by using simple home-made apparatus ..." Although the reader could perhaps question whether Copernicus used simple, home-made equipment, and also whether theories are demonstrated (rather, their consequences are tested), nevertheless it is refreshing to see at least some reference to the history of science and the role of practical work. However, such a reference is far too brief, and needs further elaboration.

Text J: Science Education Project (SEP) 8: This preface has an up-to-date view of the philosophy of science. It makes it clear that the book is not a textbook, but rather a practical workbook of laboratory inquiries. Science is seen by SEP as something the pupil does. It is a problem-solving process. Certain skills are needed for this, like deciding how to classify, inferring something new, looking for patterns, make hypotheses (reasoned guesses) to explain what you observe, thinking of ways to test hypotheses. SEP emphasises pre-lab discussions to decide on a way to solve the problem posed. It is implied that there is no one method, and that words are understood in different ways by learners. This mention of alternative conceptions implies that theory is prior, but this point could have been elaborated more fully, even though it is treated in some detail in the Teacher's Guide.

The Teacher's Guide explains how "scientists **create** science". (My emphasis. The word create is important.) The authors continue:

> "Scientists are people who are full of curiosity about the world. A scientist focuses on a particular interesting event and asks QUESTIONS about the event and turns these questions into a clear PROBLEM. She investigates the problem and debates her results with other people. Out of the DEBATE comes a summary of the results that other scientists have accepted but the results raise MORE QUESTIONS!" (*SEP Teacher's Guide* p.2)

Further on, on page 3, we again read:

> "Scientists **create** science. Science is not 'discovering facts' we **make** those facts because **we decide** to study some things and **ignore other things**. We also **make** the facts when we make up new words to describe our ideas." ... "We should not speak of facts as though they have always been there, waiting to be discovered. Rather, we have created ideas, or **concepts**, that are **useful to us** in describing the world."
>
> "The scientist asks, above all, 'What was the CAUSE of that happening?'"

Various **process skills** are discussed, and then the point is again made that **people create science.** The teacher is left with three points:

(1) We should not give students the idea that science is just a collection of principles and results.

(2) We should tell the students some of the history of science and scientists,

especially decisions being made about science in South Africa nowadays.

(3) We as teachers should try to understand and practice some of the process skills in our own thinking. This is followed by a 12-page interesting description of the main skills of scientific inquiry:
Using models
Observing
Measuring
Recording information
Making inferences
Classifying
Stating relationships and patterns
Predicting from patterns
Hypothesizing
Fair testing
Making models

Another 12 pages are devoted to scientific method and the philosophy of science. Topics such as: what science is, the role of hypothesis, science as what scientists do, the role of the scientific community, the tentativeness of scientific knowledge, are well covered.

All this is in the Teacher's Guide and not in the pupil's Workbook. Yet it is so important that it should be in the pupil's book, at least in a shortened form.

Text K: Duncan GCSE Physics: In his preface, the author states that the emphasis in this textbook is on answering questions, over 800 being provided! Hints for pupil revision are given. There is no mention of scientific method or the philosophical aims of the author. However, immediately following the preface is a two-page (mainly photographs) discussion of Physics and Technology. Here we read that physicists

> "find the **facts** by observation and experiment (and) try to discover the **laws** that summarise (often as mathematical equations) these facts. Sense has then to be made of the laws by thinking up and testing **theories** (thought-models) to explain these laws".

The author feels that this leads to a better understanding of the physical world. He says that technologists use physics to solve practical problems for the benefit of mankind. This interesting preface serves two good purposes: it suggests that theories are thought-models and thus imaginative; and it suggests that the aim of science is to give an explanatory understanding of the real natural world. By doing this, this preface offsets to some extent the strong instrumentalist line of the content material of this textbook.

Text L: Pople and Williams: These authors state that science is about asking questions. Answers are found using experiments or looking up a reference book. The authors believe that the information that scientists have gained is important. This information can be used to help understand the world. No other mention is made regarding philosophy, but the overall impression gained by reading this preface is that the aim is pragmatic rather than one of understanding.

Text M: Atherton, Duncan, Mackean: In this preface, the authors describe the practical usage of this textbook. Each chapter contains essential facts, ideas, details of experiments, everyday applications, and questions for revision. The authors' primary concern has been to provide access to information. They see their textbook as a body of achieved knowledge rather than as an inquiry.

Text N: Lewis and Waller: These authors say that their text is designed to encourage the formation of concepts and to show the applications of chemistry. The aim of this book is understanding rather than memorisation of facts. The main concepts are developed through analysis of experimental facts. Facts and theory are carefully kept apart, and are presented in a way that reflects the traditional scientific approach, where observation comes first, then inference. This preface clearly reflects the philosophical standpoint of the authors, which is inductivist-empiricist. This, as well as an instrumentalist approach, is also evident in the body of the text itself.

Text O: Pople: The preface informs us that this book deals with physics and its applications. However, the author does not expand on this, nor does he mention his philosophical standpoint. The preface merely discusses the structure of the book. It notes that practical work is not included, as it is assumed that the school would have its own practical programme. This textbook is thus seen as a body of established facts.

Text P: Warren: The author's aim in this text is vocational, as well as to promote understanding of the natural environment. Each new idea is introduced gradually, and investigated by simple experiments. The emphasis is on active involvement and learning from first-hand experience. Summaries identify a "body of knowledge" to be learned. Many questions are provided, to give the pupil practice in problem-solving. Physics is shown as a human enterprise in which man grapples with the puzzling and unexpected. The reader of this preface is, unfortunately, left hoping in vain for a brief treatment of Kuhn's 'puzzle-solving' or Popper's 'conjecture'. This omission leaves the reader with mixed impressions: the text seems to be instrumentalist with a science-and-society orientation.

Text Q: Lambert: This author states that this book is full of questions, which encourage hard thought. Summaries are given at the end of chapters. No reference at all is made to any philosophical standpoint. The overall impression given is that science is nothing but problem-solving and formal logic.

Text R: Harvard Project Physics: The declared three main aims of this course were: to design a humanistically orientated physics course; to attract more pupils to physics; to find out more about the factors affecting the learning of science. Instead of concentrating on isolated pieces of information, the focus is on ideas that characterise science at its best, and as a human activity. Hence it is presented in a historical and cultural way in this course. The authors clearly intend to give the student a feel for real science.

Text S: CHEM Study: These authors state that they wish to show that chemistry affects our daily lives. A study of chemistry will not only help us to understand our environment more fully, but also to show us how scientific inquiry works. The emphasis is on experimentation. Principles grow out of observations. By understanding principles, the need for memorisation of facts falls away. Active engagement permits the student to some extent to become a scientist at school. The excitement of explaining unexpected observations will develop in the pupil a habit of questioning. This preface was helpful in providing a fairly well-balanced, up-to-date philosophy of science.

Text T: PSSC Physics: This text aims to present physics not as a body of facts but as a continuing process by which men seek to understand the nature of the physical world. Concepts grow through exploration in the laboratory, and analysis of the text. Science is a very human thing. How we grasp and measure physical quantities, and how instruments are extensions of our senses, is explained. Direct experience is provided, and the use of the imagination is encouraged. The role and development of theory and models is described. In kinematics,pupils learn to predict. Thus armed, pupils can follow the extraordinary story of the discovery of universal gravitation, Newton's 'educated guess' with which he jumped from known laws of motion to the Law of Universal Gravitation. Models are discussed in areas where direct experimentation becomes harder, for example, atoms and light. The reader of this preface is given a brief but comprehensive view of contemporary philosophy of science.

Text U: The Nigerian Secondary Schools Science Project (Physics Books 1 to 3) has about two pages of preface. The authors summarise the content of their textbook. The text serves as a laboratory book, thus providing a discussion of the "science that the experiments reveal". This is done by posing questions about the experiments. Activities should involve the pupil, arouse his curiosity, and help him acquire skills. Mathematical calculations are deliberately avoided, for the authors believe that "tedious arithmetical calculations disguised as physics problems do not help the young learner. It is preferable that the pupil should be able to give a conceptual explanation of a physical phenomenon". Apart from these general statements, the authors do not raise any questions about the philosophy of science.

Text V: Kenyan School Science Project: The prefaces of this course emphasise that the concepts of science should be discovered by pupils. This means that students should be able to perform experiments, and analyse their observations and measurements. No explicit mention is made of philosophy. It appears that the authors assume that all observations are objective and that science leads to absolute truth.

Text W: Jansen and Dekker's textbook summarise the aims of the "new" 1985 South African General Science syllabus. These aims are that the pupil should acquire, among other things: (1) a knowledge of the facts of science; (2) skills in using materials and apparatus; (3) understanding of certain concepts; (4) an interest and satisfaction in the study of science. The authors then go on to say that science cannot be learnt from a book alone. Good science teaching is based on observation and experiment. Practical work is therfore important. The text includes a summary for systematic revision. It is clear from this preface that this is a "skills-and-drills" type textbook, and that the authors' philosophy of science is empiricist.

Discsussion of the Prefaces:

Apart from the three American texts above, and the Teacher's Guide for *SEP*, all the others reflect a strong separation between observation and theory. Their implicit approach is inductivist-empiricist. Even *PSSC Physics*, while acknowledging the limitations of scientific procedures and the importance of creativity, follows an inductivist line. It does not mention that observation is always done in the context of a pre-existing theory. Only *SEP 8* does.

Indeed, the lack of discussion of the processes of scientific inquiry or the philosophy of science suggests that the authors are either unaware of the current issues in the philosophy of science (issues such as theory-ladenness of observation, facts are created rather than eternal truths uncovered, scientific realism versus Kuhnian relativism, etc), or are unconcerned about their effects.

The prefaces generally reveal a strong commitment to traditional Baconian scientific method. Since this inductivist-empiricist approach has serious inherent philosophical weaknesses, I feel strongly that a brief discussion of its educational implications should be included in the preface of every high school physical science textbook.

5.5.3 Results of the Metaphor Analysis

A comparison of randomly selected pages of four of our textbooks reveals the following:

The textbook *Physical Science 8* by Brink and Jones contains many good explanations. These explanations are of the type which give literal answers and reasons. For example, on page 103 we read:

> "The magnetic field caused by the magnet passes through the coil and cuts through the windings of the coil".

This use of "field" is obviously intended in a literal sense. There is no metaphor here. On page 157, the authors use a comparison of a dartboard to illustrate Heisenberg's Uncertainty Principle. They say:

> "To understand the uncertainty principle more clearly, look at the dartboard in Fig 13.1 It is obvious that when we look at the distribution (density) of holes on the board, that the dart has in the past struck the central portion more frequently than the outer area of the board. Should a person now prepare to throw at the board, we may with reasonable certainty predict that the dart will probably strike the board close to the centre, where the holes are more numerous."

The metaphor is clear. A comparison is made between a dartboard and a probability-density diagram. The reader is, to a small extent only, invited to "look at". A degree of involvement is present, but it is small. The metaphor is comparative rather than interpretive, for the justification is given rather than elicited. Nevertheless, there is a worthwhile attempt on the part of the authors to involve the reader.

Comparing this with corresponding topics in *Senior Physical Science 8* by Pienaar and Walters, we read on page 134: "The induced current flows only while the magnetic field moves relative to the solenoid". In a way, "current" is a metaphor, but it is so widely used that it is usually meant literally, at least at high school level. Again, on page 206, we read:

> "In 1925, the Austrian Erwin Schrodinger, proposed a wave-mechanical model in which the moving electrons form a three-dimensional wave (wave space) surrounding the nucleus of the atom."

This sentence is completely literal and expository. There is absolutely no attempt to involve the reader by any kind of invitation to reason or link separate ideas. No metaphor whatever is present.

Peter Warren's *Physics Alive* as well as Tom Duncan's *GCSE Physics* are purely expository. The information is presented as factual. There was no detectable use of metaphor. Explanations are factual. For example, in Duncan (p. 219):

> "Although it is still useful for some purposes, the Rutherford-Bohr model has now been replaced by a mathematical model ..."

And again (on p. 109):

> "This is Newton's second law of motion. When using it two points should be noted. First, **F** is the resultant (or unbalanced) force causing the acceleration **a**."

There is no attempt to use metaphor. Indeed, both textbooks are highly instrumentalist, consisting largely of brief, literal descriptions, questions, rules, and calculations. The overall impression is one of bare-bones science, practical utility, suspended belief.

In contrast, the Harvard *Project Physics Course* make abundant use of interpretive metaphors. In their *Concepts of Motion* there are many examples of the following style:

> "... the disk fails to live up to our Aristotelian expectations. It is always surprising to see this for the first time." (Harvard, p. 75)
>
> "Take, for example, a tug-of-war. Suppose two teams were sitting on the deck of a barge that was drifting with uniform velocity down a lazy river. Two observers - one on the same barge and one on the shore - would each give a report on the incident as viewed from his own frame of reference. The observer on the barge would observe that the forces on the rope were balanced and would report that it was at rest. The observer on the shore would report that the forces on the rope were balanced and that it was in uniform motion. Which observer is right? They are both right; Newton's first law of motion applies to both situations." (p. 77)

"Now imagine for a moment a ridiculous but instructive thought experiment: as you stand on the scale, the floor (which, sagging slightly, has been pushing up on the scale) suddenly gives way, and you and the scale are dropping into a deep well in free fall. At every instant, your fall speed and the scale's fall speed would be equal, since you started falling together and fall with the same acceleration. Your feet would now touch the scale only barely (if at all), and if you looked at the dial you would see that the scale registers zero. This does not mean you have lost weight - that could only happen if the earth suddenly disappeared, or if you were suddenly removed to far, interstellar space. No, F_g still acts on you as before, accelerating you downward, but since the scale is accelerating with you, you are no longer pushing on it - nor is it pushing on you." (p. 84)

The Harvard textbook uses language which involves the reader ("imagine", "suppose") and confronts him with anomalous situations, inviting him to construct his own interpretation. However, at the end, the textbook provides the 'right' answer in usual textbook fashion. But the approach and the use of metaphor is refreshing. The following is the set of results obtained from the metaphor search.

Harvard Text and Handbook 1 (Concepts of Motion):

"flood of information" (p.5)
"light beams dart..." (p.9)
"earth, our majestic spaceship..." (p.9)
"Material bodies have, so to speak, a stubborn streak." (p.77)
"The proper language of nature is mathematics." (p.104)

Harvard Text and Handbook 2 (The Triumph of Mechanics):
On pages 71 to 73 we are told that theoretical models help make predictions which can be tested. By treating gas molecules **as if** they were tiny billiard balls, such a theory can lead to (1) explanations in terms of empirical laws (eg Boyle's Law), (2) prediction of new relationships (eg fluid friction), (3) calculation of the sizes and speeds of gas molecules. A theory is regarded as successful and useful if relevant models are consistent with it. A model is not valid for all phenomena and conditions. Therefore it is in the nature of models that they are tentative and subject to revision. On p.74:

"In our model we **visualise** the gas as consisting of a large number of very ... "**A theoretical model exists only in our imagination** and helps us to understand the real world of experience.

Harvard Text and Handbook 4 (Light and Electromagnetism): On pages 2 and 3 there is a general discussion of metaphorical-type links between knowns and unknowns. For example, action at a distance is contrasted with direct contact.

On p.35, "models" are discussed. A model is "a set of invented ideas which help us to describe and summarise what we can see happening." For example, the **concept** of charge or the **rules** of attraction and repulsion constitute a model.

On p.42 the metaphorical function of scientific language is discussed. Many terms in physics are really adaptations, with important changes, of commonly used words (eg. work, force, body). Because of these specialised meanings, bridges are needed. This idea is illustrated by discussing the concept "field" in terms of a football field as a region of interaction, or a sphere of influence in politics, or what happens to the brightness of a streetlamp when you walk towards it along a street.

On p.53, we read: "The obvious explanation is to imagine that the charges move..." This is the **only** explicit reference to the current-as-river analogy. Yet it is good in that it conveys the idea of **explanation** in terms of **imagination**, albeit very briefly.

On p.126, the progression from models to more comprehensive theories, which goes well beyond models, is alluded to. Then follows a quotation from Richard Feynman on what a field might look like.

> "...Disparity between common-sense ideas that develop from direct human experiences and the subtle mathematical abstractions developed to deal with effects that we cannot sense directly. ... Yet these highly abstract theories do ultimately have to make sense when couched in ordinary language."

For the consequences of such theories are subjected to concrete tests, and they have practical effects (eg the space programme, TV sets, microwave ovens), and they also contribute to our understanding. This excellent philosophical discussion is what should be included somewhere in every textbook.

Harvard Text and Handbook 5 (Models of the Atom): The whole book gives a fairly detailed account of the history of the development of the atomic model, but no specific treatment of "models" could be found. The notion of "model" is implicit.

Pople: *Explaining Physics*: In general, the language is literal. The accepted metaphors (eg electric current as a water flow (p.239), the plum-pudding atomic model (p.357)) are assumed as understood. No explicit discussion of metaphors, or models, or theories, is given. The **instrumentalist** notion that a theory is a useful fiction is given on page 25:

> "It is sometimes useful to think of the Earth being surrounded by a gravitational field which exerts a force on any mass in it."

Similarly, scientific realism as **reference** is implied in:

> "Atoms are far too small to be seen, but a great deal is now known about their structure. Much of the early information was gained by bombarding atoms with alpha particles."

This is reminiscent of Hackings point that, if you can bombard them, they are real.

PSSC Physics: While the introductory chapters, as well as the introductory paragraphs of most chapters, display some metaphorical language, the main body of the text is purely literal. On page 2 we read an extended metaphor of the human tentativeness of scientific inquiry:

> "So the subject grows. It is like a great building under construction, not a finished structure around which you have only to make a guided tour. ...(It is) useful and beautiful. ... Once in a while, a finished room in this structure known as physics is found unsafe ... and the room is abandoned or rebuilt."
>
> "It (physics) fathers other sciences." ... "The key tool of the physicist is his mind." (p.4)
>
> A **model** is "an idea, a picture, a system of concepts which creative intuition and hard work lead us to think describe the things we investigate." (p.151)

For example, "electron cloud" is more than what it might **look like.** It includes **what happens** in clouds, the turbulence, movements, etc. and is consistent with all our tests and conclusions.

This textbook, while basically empiricist, contains a worthwhile account of the constructivist aspect of scientific knowledge. It is basically empiricist in the sense that its language is mostly literal, 'unobservables' are able to be observed by extending our senses through appropriate instrumentation, absolute truth eludes us at present only because of limitations in our measuring techniques.

CHEM Study: On page 1 we read that experiment is "the mother of all certainty", and on page 2 that

> "the activities of science begin with observation. ... A controlled sequence of observations is called an experiment All science is built upon the results of experiments".

This empiricist viewpoint is further substantiated by its almost complete use of literal language. This overall impression, gained from its lack of metaphorical language, is gained in spite of a fairly detailed treatment of the role of scientific method, explanation and models.

As opposed to school textbooks, popular science books for the educated layman abound with metaphors. For example, Isaac Asimov's *Guide to Science 1: The Physical Sciences* contains the following examples among many of metaphorical language:

> "The higher the temperature, the faster they moved, the more 'elbow room' they required." (p.266) "
>
> "...they (alpha particles) brushed aside this froth of light particles ..." (p.296)

On the metaphor 'frame of reference':

> "One is tempted to ask which planet would really be foreshortened and doubled in mass, but the only possible answer is: that depends on the frame of reference. If you find that frustrating, consider that a man is small compared to a whale and large compared to a beetle. Is there any point in asking what a man is really, large or small?" (p. 378)

This is a good example of an interactive metaphor, designed to create an anomaly.

In John Gribbin's *In search of Schrodinger's cat* we come across these metaphors, among many others:

p.31: "... Thomson's watermelon model" (A new one!)
p.32: "... retinue of electrons"
p.70: "The cloud of electrons provides the outward face of the atom"
p.70: "... the heart of the electron cloud..."
p.124:"... even without understanding why the recipes work people are able to cook so efficiently with quanta."

(Indeed this is a good metaphor for instrumentalism!)

In Nigel Calder's *Einstein's Universe:*

p.24: "... the waves are crowded together."
p.30: "Matter is frozen energy." This is a breathtakingly simple idea, yet it stops one in one's tracks while reading the text.
p.64: In free fall "there exists for him during his fall no gravitational field."

Perhaps the gravitational field does exist, but he does not experience its effect as weight. It does not exist for him. The anomalous nature of this statement makes it highly interactive with the reader.

p.76: "Picture now a little particle of light ..." The reader is involved.

There is no doubt that such popular science books for the layman gain much from a warmer, more human, metaphorical approach. They interact with the reader through their textual content. However, what they gain in interaction (and perhaps constructivism through metaphor), they frequently tend to lose through loss of precision. They lack precision particularly in their deliberate avoidance of any mathematical treatment. However, this is precisely where the school science textbook exercises its interactive aspect: through calculations and questions at chapter ends.

To summarise this point: school science textbooks are constructivist insofar as they are instrumentalist, whereas ordinary popular science books are constructivist through their use of metaphorical language. The ideal would be to combine both approaches in one textbook, much as Harvard has attempted to do. But the two chief disadvantages would perhaps be cost, and too much for the average high school pupil to read. Perhaps a reason why Harvard *Project physics* has not been as popular as it should have been is that there is simply too much reading material there. Too many students are unfortunately chiefly concerned with the very instrumental aim of passing a final examination. For them, the more condensed the textbook, the better.

It seems that there is a definite trend towards bare "skills and drills" type textbooks both in Britain and in South Africa. The South African and African textbooks almost lack any attempt to use metaphorical language: literal language is preferred. Even the accepted metaphors of science (eg current, field) are not explained or compared with the basic idea.

5.6 General discussion and conclusion

Both the quantitative and the qualitative results obtained in this study are consistent with the hypothesis made at the start, namely, that school science textbooks have a definite leaning towards empiricism and instrumentalism.

PSSC Physics and *CHEM Study* are strongly empiricist (Herron 1971). Selley (1981 and 1989) pointed out that the earlier *Nuffield* textbooks were discovery-orientated, but lacked any philosophical discussion. However, the recently published *Nuffield Science 11-13* (Lyth, 1986, pp. 11, 12, 26) shows "considerably greater sophistication and breadth in its treatment of philosophical matters". (Selley 1989, 27)

The quantitative analyses suggest that *SEP 8* and *Harvard Physics* have the highest overall Level of Involvement, both in practical laboratory work and in reader-interaction in the text itself (Table 5.19). That *SEP 8* takes first place comes as no surprise, not only because it is not a textbook as such but a practical workbook, but also because of the soundly thought-out philosophy revealed in its Teacher's Guide. It is therefore in a class of its own in relation to all the other textbooks examined in this study. *Harvard Physics*, as a textbook, stands head and shoulders above the other textbooks as far as its treatment of the history and philosophy of science is concerned.

It was a surprise to see **Broster & James 8** and **Duncan** *GCSE Physics* in 3rd and 4th place respectively. My initial cursory reading of both of these would have placed them below **Brink & Jones 8**. However, they obviously earn their place because of their emphasis on questions, particularly questions at the end of chapters. Both are very attractive textbooks, but their philosophy of science seems more empiricist and instrumentalist than does that of **Brink & Jones 8**. From this paradox I can only conclude that a textbook may be highly instrumentalist **and** also have a high level of involvement. In other words, a highly instrumentalist textbook may promote a high degree of constructivism. Thus it would seem that there is indeed some truth in Selley's (1989) point that instrumentalism may be a good and useful way of leading to constructivism. The results of Table 5.5 also corroborate this adjustment of my view in which instrumentalism was opposed to constructivism.

The final unified summary of instrumentalism (Table 5.19) shows *SEP 8* and *Harvard Physics* as the least instrumentalist. Of the South African textbooks, **Brink & Jones 8** portrays the best, most up-to-date philosophical standpoint. It is far from perfect philosophically, but it is more well-rounded than the others.

Duncan GCSE Physics turns out to be the most instrumentalist, an impression I also gained from a cover-to-cover reading. It is generally representative of all the other British textbooks examined. British textbooks still seem to be saturated with the heritage of British Empiricism.

However, it should be pointed out that it is a little unfair to compare general British textbooks with three undoubtedly 'special' United States textbooks, namely, *PSSC Physics*, Harvard *Project Physics*, and *CHEM Study*. One suspects that many 'normal' United States school science textbooks are just as instrumental as Duncan's *GCSE Physics.*

Taking the results of all the Textual Analyses together, as well as the readings of specific topics and Prefaces, it seems that the dominant image of science portrayed in all the British and South African textbooks examined is strongly inductivist-empiricist and instrumentalist.

The qualitative research shows that, in these books, there is a sharp distinction between observation and theory. Observation is perceived to take place prior to theory, and done in an objective, impersonal way. The impression is given that any observation yields a unique result, and that multiple interpretations are out of the question. Alternative conceptions are not acknowledged in any way. This separation of observation from theory is the chief characteristic of a positivist approach, and the main attribute of **inductivist-empiricism** and **instrumentalism.**

There is also ample evidence from direct reading of the texts that calculations are of the plug-in, recipe-like type, leading deductively to a solution that is isolated from the real world. Such rote, mechanical calculations may easily become mere computative devices for prediction and control; nothing but 'puzzle-solving'; in a way, only games. This procedure is characteristic of **instrumentalism**.

Also characteristic of **instrumentalism** is the abundant use of definitions in the textbooks. Analysis revealed the existence of a number of operational and nominalistic definitions. As discussed above, such definitions may be only convenient shorthand for complex terms, that is, names for a procedure. They may have little interest in the real objects.

An interesting by-product of the study is that there may be a link between instrumentalism and constructivism. The possibility of using an instrumentalist approach in collaboration with a critical realist approach in order to promote constructivism will be explored in the next chapter.

Conclusion:

There are clear signs of a **mild but widespread instrumentalism as well as a strong underlying empiricism in the selected British, South African, African and American high school physical science textbooks examined**. The British textbooks contain an even stronger emphasis on an instrumentalist attitude than the South African. The three American textbooks examined, while not nearly as instrumentalist as the British and South African textbooks, nevertheless do show signs of it.

The most important finding as far as this present study is concerned is that there is a definite **trend towards empiricism and instrumentalism** in recent textbooks, especially those designed specifically for educationally disadvantaged students. The implications of this will be discussed in the next chapter.

This conclusion corroborates the hypothesis made at the start of this study.

Chapter 6

EDUCATIONAL IMPLICATIONS AND RECOMMENDATIONS

6.1 Introduction

From the kind of textbook presentation revealed in Chapter 5, the pupil could perhaps perceive science as essentialy a method for verifying facts already known. He might obtain a view of science as being completely objective and unimaginative. And he could possibly regard science as a convenient tool for predicting and calculating in a rote fashion, with little relevance to real life.

However, it is difficult to see how any textbook can be written in any but an inductivist-empiricist, instrumentalist way. The very aim of a textbook is to be a condensation of the current state of scientific knowledge. It is a reference book, and so must of necessity contain a large proportion of facts. Kuhn (1970, p.188) believes that one of the primary tasks of textbooks is to introduce the future scientist into the scientific community by means of exemplars (that is, typical problems and solutions agreed upon by the scientific community). The student needs to **act** on such problems, in order to get a feel for science.

Similarly, Ravetz (1971) acknowledges that, while a textbook is a caricature of real science, it is necessary for condensation and standardisation to occur. As desirable as it may be for every pupil to discover every scientific law for himself, it would be absurd to expect this. There is simply not enough time in the few years of high school. Ravetz (1971, p.200) says that standardisation

> "...is quite necessary, if the fact is to be useful to those who lack the time, skill or inclination to master the elaborate theoretical context..."

Something is inevitably lost in this process. School science textbooks, in particular, are "standardisations of standardisations", according to Ravetz. Vulgarisation of science can easily occur in schools, where many teachers - and particularly in the Third World - are not science specialists and lack sufficient training in physics and chemistry.

> "These inherent limitations of the schoolteaching situation, along with its function of imparting basic craft skills rather than 'understanding', must be recognised if there is to be any fundamental improvement in its quality." (Ravetz 1971, p.207)

To write a good textbook requires a special skill. Ravetz makes a plea for the inclusion of historical case studies in textbooks in order to humanise them a little and give a more correct notion of scientific inquiry. However, cost factors unfortunately impose a severe limitation on this.

In the end, therefore, it seems that textbooks cannot be otherwise than largely inductivist, empiricist and instrumentalist. So the responsibility rests squarely on the teacher to counteract the philosophical disadvantages of these. **Hence the teacher must be aware of the dangers involved.** For this reason, I believe that all authors should, at the very least, provide some guidance in their preface. This is often especially desirable in Third World countries where teachers lack the required training in science and rely particularly heavily on the textbook. **This study therefore recommends that all physical science textbooks should include in their preface a short summary of the dangers of instrumentalism.**

6.2 Gathering the threads

In Chapter 2, the characteristics and philosophical implications of instrumentalism were examined. The following main points emerged:

(1) Weak instrumentalism reserves judgement on the real existence of theoretical entities (eg electrons), but works with them **as if** they exist.
(2) It is more interested in operational definitions and rules for predicting, and internal self-consistency.
(3) It does not take the implications of scientific theories seriously, regarding them only as useful fictions, easily discardable. The instrumentalist identifies theories and models.
(4) It is not truly informative about the world because, by confining itself to only sensory experience, it is too cautious. It does not yield novel facts.
(5) Its limited view is inclined to lead it towards an inward-looking attitude, resulting in scepticism, idealism, and pragmatism.
(6) Because it does not take its theories seriously, the scientific enterprise may be regarded as a game.
(7) Instrumentalism is a form of pragmatism. Truth is usefulness and convenience, that is, what works. Thus it is relativist.
(8) Instrumentalism and constructivism are both forms of pragmatism. Both have low regard for the role of scientific theory, and therefore may discard old theories in an uncritical way. Uncritical constructivism may lead to an instrumentalist approach. But a severely critical constructivism may lead to a full-blooded realism.

Chapter 3 explored in more detail the relationship between constructivism, instrumentalism and realism. A major concern was the premise that both constructivism and instrumentalism are relativist and subjective. That is, they are both anti-realist. A survey of the philosophical and psychological underpinnings of constructivism and scientific realism revealed that:

(1) The problem about subjectivity arises only because of the prevailing empiricist attitude which still pervades science today. By over-emphasising sensory experience, objectivity is seen as an impersonal view of an external natural world which exists 'out there' independently of the mind. Reality, according to this view, is 'already out there now'. In fact, reality is what we make of the world. Reality is an intellectual construct, soundly rooted in the world out there, and ratified by the severe and constant criticism of the scientific community. Likewise, the objectivity of our personal knowledge is guaranteed by the constant and severe critical attitude of the community. Hence objectivity is the result of authentic subjectivity. So, by revising our notion of subjectivity and objectivity in terms of contemporary philosophy and psychology, we have returned to a more well-rounded notion of reality.

(2) This critical realist approach has an important corollary relevant to this study, namely, that theory is part of reality. There are degrees of reality. All scientific knowledge, like any human knowledge, is theory-laden.

(3) Constructivism deals with comparison of rival theories. Choice of the best theory depends on the decision of the community. Constructivism is therefore relativist, but this is counteracted by its revised objectivity.

(4) Piagetian (but not Deweyan) constructivism accepts the 'degrees of reality' idea. Further, and more important, it regards theories as structures, and not as functional events or passing interactions, as instrumentalists do.

(5) Critical realism (especially that of Bernard Lonergan) offers an acceptable solution to the problems of relativism, subjectivity, and anti-realism inherent in the constructivist and instrumentalist approaches to scientific knowledge.

The quantitative and qualitative results of the textbook study, described in Chapters 4 and 5, are consistent with the hypothesis that high school physical science textbooks have a strong bias towards empiricism and instrumentalism. Although the literal wording has a realist import, most of the textbooks may be read from an instrumentalist point of view, as mentioned earlier by Jacoby and Spargo (1989, p.47; refer Appendix F) and Selley (1989, p.29). Further, it seems that, during the latter half of the 1980's, there has been a growing trend towards a greater degree of instrumentalism in British and South African textbooks. This accords with Selley's contention that there is a growing non-participatory transmission style in science textbooks, in which it is implied that the information in the textbook is simply the truth, as far as it is known. (Selley 1989, p.29)

Putting all this together, we obtain the following synopsis:
(a) Our textbooks are largely instrumentalist.
(b) Instrumentalism has advantages (it is successful), but also has disadvantages (unsound implications).
(c) Critical constructivism may help overcome the weaknesses of instrumentalism.
(d) Critical realism may be the means as well as the end of this process.

6.3 Possible strategies to promote critical realism

Science education, especially as presented in textbooks, is heavily biased towards empiricism. It over-emphasises sensory experience. It needs to be broadened to include other cognitive activities, such as understanding, judging, imagining, and so on. The following contains some practical suggestions on how to promote critical realism in science education, particularly through textbooks.

6.3.1 Theory and model-building activities

School science textbooks should pay far more attention, not only to an explicit account of the role of scientific theory, but also to ways of actively eliciting theory-building in pupils. A clear distinction should be drawn between models and theories. For the critical realist sees models as introductory phases on the way towards theories. Theories are not the same as models, as some instrumentalist textbooks suggest. Theories are far more comprehensive than models.

What kind of reality status do models have? This is a question which must be addressed in textbooks, even if very briefly. In most textbooks, reality status is attributed to such **defined** quantities as density, electrical resistance, specific heat capacity, force, and kinetic energy. Selley (1989) suggests that students should be invited to question whether something, like Centre of Gravity, is real, and be asked by what means they might test its reality. This would help students to be aware of the instrumentalist attitude, where theories can be arbitrarily changed with minimal regard for critical testing. As Selley (1989, p.29) points out:

> "...the more reflective reader must become aware that at least a number of these theoretical terms, ideas, and procedures are human inventions, devised for convenience. This entails the recognition that any part of the body of theory could be changed, not necessarily through refutation by newly discovered phenomena, but simply because some new theoretical statement comes to be accepted as working better."

Selley maintains that this instrumentalist attitude could be developed into a philosophical view which he sees as at least as comprehensible as inductivist convergent realism. He suggests that critical realism is the way to do this:

> "By abandoning the untenable distinction between observed and theoretical entities, and by at the same time denying any one-to-one reference to an external world, we arrive at **critical realism**, in which all concepts are regarded as constructed, though constrained by empirical data obtained by human interaction with the natural world. All scientific knowledge - indeed all knowledge - is to be regarded as a set of more or less well-established models: not only is the electron a constructed model, but so is the television picture which it produces."
> (Selley 1989, p.29)

According to Hodson (1985), it is quite common to have, in school science, a **realist theory** (for explanation) and an **instrumentalist model** (for prediction) for the same phenomenon. Also, it is sometimes found that school science has alternative, conflicting instrumental models for different aspects of the same phenomena (eg. wave and particle models of light). What is confusing to children (says Hodson) is that the role and status of theories and models are not defined. In order to avoid an excessively instrumentalist view without falling into the trap of naive realism, Hodson proposes that **theory** in school science should pass through several stages:

(1) Tentative introduction as a model.
(2) A search for evidence through observation and experiment.
(3) Further elaboration of the model into a theory.
(4) Acceptance of the theory into the body of scientific knowledge.
(5) Use of the sophisticated theory to explain phenomena.
(6) Testing of the theory's predictions and applications of the theory in new situations.

I interpret this strategy of Hodson as follows: As confidence in a particular model grows, it increasingly takes on the status of a fact, that is, an object of scientific inquiry in itself. For example, at junior high school level, the pupil may be sceptical about the particle nature of matter. (He may have heard about it, by watching TV programmes about atoms, and so on. But his out-of-school concept may be at variance with the scientifically accepted view.) Having performed several simple practical activities, such as diffusion of ammonia and hydrochloric acid in a closed glass tube, the pupil builds a tentative model. Being doubtful, this model is usually in theory-free terms. That is, the pupil says "I see a white cloud forming near the middle of the tube". Only after many such illustrations will the pupil's confidence in the idea of particles grow, and he can talk about "particles moving". Eventually he can use this particle model to explain why calcite cleaves so neatly. As the curriculum progresses, the pupil will be introduced to atomic theory. And so theory grows and develops, and his observation language takes on a higher status. He talks about atoms **as if** they exist. No doubt, the notion of their real ontological existence follows very closely.

Similarly, the theory of elecricity develops something like this. In junior high school, the concept of electric charge is introduced, and through various simple practical illustrations, a model is constructed to explain flow of charge (electric current). In later years, experiments with the simple electric circuit demand the construction of a model for resistance. At first, resistance is seen simply as the opposition to current. As resistance increases, current strength decreases. This is a simple model to predict what happens if another resistor is connected in series with the first. Then, the following year, resistance is defined operationally as the ratio of potential difference to current ($R = V/I$), and is used instrumentally. This is a more sophisticated model. In the final year of the science curriculum, the notion of resistance is analysed in terms of atomic theory, that is, the movement of electrons between the atoms of the conductor. This may be done by a thought- experiment or analogy (a person trying to push his way through a crowd). This third model of resistance is far more sophisticated, and its value lies in its explanatory power, and in its consistency with electrical theory as a whole, as well as with a wider scientific theory, namely, atomic theory. This is not only intellectually far more satisfying than instrumental models, but it will, in my view, lead to the notion of real existence of the theoretical entities concerned.

My own view, therefore, concurs with those of Selley and Hodson. The instrumentalism present in our textbooks must be used to our advantage. Wherever possible, the constructivist nature of certain concepts should be highlighted, as well as the notion that we choose between rival theories. However, the aim should not be to encourage an instrumentalist attitude *per se*, but rather to use instrumentalism to reach a critical realism. Instrumentalism in textbooks, together with a constructivist approach, and restrained by both the critical community and a sound empirical base, should lead to critical realism. By a feedback process, a growing critical realist attitude will encourage a constructivist approach.

It is vitally important to emphasise the critical attitude and the social aspect of model-building. In other words, if a constructivist approach is adopted in order to encourage the 'proliferation of theories', it is important to emphasise to the pupil that this should be done critically and tested against the physical world. A full-blooded critical realism involves a proper perspective of the notion of objectivity. Therefore pupils should not read in their textbooks that any part of a theory could be changed, not necessarily through refutation by newly discovered phenomena, but simply because another theory works better. We must retain the empirical base.

If textbooks were to adopt a critical realist position, it would assist in closing the gap between the student's common-sense beliefs and scientific knowledge. It would make feasible a science curriculum designed to develop the student's personal exploratory model gradually, through clarification, comparison with data, and evaluation against suggested improvements. This would be a radical shift from the present transmission mode, which ignores the student's out-of-school understanding of the subject.

However, this must be done with care, for two reasons. Firstly, it would be disastrous to undermine a child's confidence in his thought processes before they are fully capable of handling such tenuous questions. Secondly, if a textbook author adopts a constructivist approach in one section of the book, it should be sustained in subsequent sections. For example, consider a textbook inviting pupils to make a guess in order to explain their observations in Brownian motion, and saying that scientists can never be sure about their guesses about atoms. But by the next chapter, atoms and their motions are regarded as real. The original doubts are forgotten, because now we need to **use** the model to explain other observations. Is the student to infer, therefore, that atoms really exist? Not quite, says Selley. He is meant to accept their existence **for the sake of the argument**. He is asked to suspend his judgement. For it is not helpful to raise questions about real existence at this point. This approach is instrumentalist.

On the one hand, this is a good tactic, for it leaves the pupil to get on with the science. Yet on the other, says Selley, it leaves the pupil in an awkward predicament, for when the detailed structure of matter is under discussion, the tentative nature of the basic model becomes an encumbrance, and dogmatic assertions begin to clash with make-believe.

The question arises whether this is indeed a problem for the pupil. In my experience most pupils are naive realists, and would accept the reality of atoms without question. And surely any attempt to make guesses (conjectures) and then to decide which is the best (comparison of rival theories) must be put to two tests: one to test the consequences of the guess, and the other to obtain the ratification of the scientific community. In this case, the latter is the textbook author. In other words, while maintaining a critical attitude, there are times, perhaps many, when the pupil must rely on the authority of the teacher (or textbook author). After all, there **is** a 'hard core' of scientific knowledge. The pupil must be shown that there is no way that he can find out about the whole of scientific knowledge on his own. As Popper said, we can never make a fresh start. We build on what has gone before.

So the problem is not to try to get the pupil to accept the reality of atoms, but rather to try to bring him to the notion that they are intellectually constructed entities. Perhaps, as Selley suggests, textbooks ought to distinguish between their presentation of theoretical (inferred) entities and that of conventions and constructs. **On the other hand, an explicit treatment of theoretical entities might do more harm than good to an immature mind.** It might be counterproductive to teach a pupil the 'Particle Model of Matter' or 'Atomic Theory', and then proceed to undermine the foundations by saying that electrons are 'only' intellectual constructs. The way for textbooks to treat this, in my view, is to offer material of theory-building simulations which require the active involvement of the reader.

Something which I have successfully used in class, which a textbook might include is as follows:

A model-building exercise: Rutherford's Scattering Experiment

The square in *figure A* below represents a piece of stiff cardboard or masonite, about 500 mm x 500 mm. It is placed on a smooth floor, and supported at each corner so that it lies horizontally about 50 mm above the floor.

You are told that there is a solid object hidden under the cardboard, and that you want to find out its shape without looking. All you are allowed to do is roll the marbles along the floor (ABCDEF) and watch the way they emerge after colliding with the hidden object (A'B'C'D'E'F'). From the pattern of emerging marbles, you can guess the shape of the object.

Determine the shape of the object under the cardboard in Figure A below:

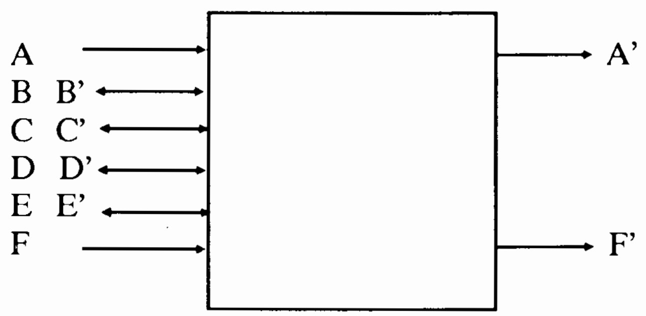


Fig.A

Make a guess about the object.
What is its shape?
Are you sure?
Is this the only explanation?
How could you find out if there is more than one possible answer?

One possible way to find out more about the object's shape is to roll the marbles from another direction. Suppose we roll them as shown in *Figure B*, and obtain the pattern shown below.

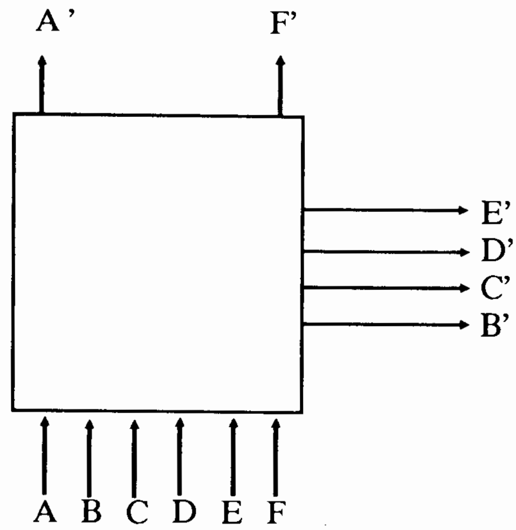


Fig. B

Has your theory about the shape of the object changed?
What shape do you now think it is ?
Is this your final answer, or could there still be another possible shape there?

Look what you have done. You came to the problem with the knowledge that under the cardboard was a solid object of unknown shape, and that marbles would bounce off it. So, before you started, you had a simple idea or theory. After the first experiment, a picture began to form. Perhaps you guessed that the object was square. If you were content to stop experimenting further, that theory would have remained in your mind.

But after the next experiment, you might have been surprised to see the resulting pattern. Your theory that it was a square was demolished ! Yet you could not ignore the results of the first experiment. Indeed, you had to adjust your theory to fit the new evidence. You had to choose the better theory.

Each theory you invented added a little more to the picture building up in your mind. Each theory was only a mental picture that you constructed. That is, the object was 'only' a theory for you. But what a powerful thing a theory is! It was almost as if you began to know **exactly** what was hidden under that cardboard.

Of course, there is still much you do **not** know about the object (for example, its mass, or colour, or whether it is iron or copper). Perhaps you can think up ways of finding this out, without looking under the cardboard.

As you gather more information, the theory you are building up about the object will grow and develop, and the object will seem to become more and more real to you. Eventually your confidence in your theory will be so great that you might talk about it as if you had actually seen the object. You might say "There is a rectangular, copper block there" and not just "There is a solid object there".

> Remember, theories are inventions you make up in your mind about what you think is going on in the world. Theories grow and change, until you trust them so well that you **know** they actually exist the way you think. Have you ever heard somebody say about scientific theories: "Oh well, you don't have to believe it. It's **only** a theory." Beware! That object under the cardboard is **only** a theory! But you would certainly hurt your foot if you had accidentally kicked it! Theories are real!

It is very important, when trying to lead children to a critical realism, to emphasise and reinforce the positive aspects of theory-construction, that is, **confidence in one's cognitive faculties, and trust in one's corroborated theories**. Avoid any reference to relativism or subjectivity. Of course, to obtain the greatest benefit from the above exercise, it should be done in groups, so that the pupil can experience the criticisms and discussions of the social group around him.

6.3.2 Practicals, laboratory inquiries, experiments

The way most current textbooks deal with laboratory practical work causes some confusion in the mind of the pupil. They tend to call such pupil-performed practical activities 'experiments'. These are rarely hypothesis-testing procedures at all. Rather they are demonstrations of the 'see-for-yourself' type. Although there is a place for these, perhaps it would be more honest to drop the pretence that they are 'experiments', and leave the term 'experiment' only to describe a few student investigations which are truly open-ended hypothesis-testing procedures. I believe, with Selley, that the major purpose of practical work is not to prove or test any propositions, but to give operational definitions to the concepts involved, that is, to clarify the meaning of the theoretical terms involved. As mentioned before, it is tempting to regard this as a naive realist stance on the part of the author. However, as Selley rightly states, it is possible to read into school science an instrumentalist interpretation.

According to Hodson (1989), children ought to know the role played by experiments in science. We should therefore take active steps to avoid reinforcing several prevalent myths about experiments. Such myths include the idea that all science results from experiment; that experimentation is completely objective; and that theory is built up from experiments. Such myths should, in my view, be pointed out explicitly in every school science textbook.

Textbooks should inform pupils that all experiments are conducted within some sort of theoretical framework, be it weak or strong. But it should be pointed out that many major theoretical advances in science did not arise from experimentation. Science does not always use experiments. For example, in astronomy, meteorology and geology, much theory-creating work is done through computer simulations and modelling, rather than by direct experimentation.

A note should be provided in the textbooks for teachers (and **perhaps** also for students) to the effect that observation is never objective. Observation is loaded with prior theory. Otherwise the prevalent view that observation has priority will be strengthened, and the generation of theory will be seen as a process of looking for regularities and patterns by making simple guesses. The type of approach taken in the textbooks reviewed in this study suggests that children can refute a major theory by means of a single experiment. No theory can be refuted by a single experiment. The decision to judge between competing theories is a complex one. Pupils should be made aware of this.

Pupils could be exposed to activities designed to make them aware of the unreliability and theory-dependency of observations. This may be done using optical illusions, and can be great fun for pupils. Indeed, for most pupils, it is simply of great interest, but brighter pupils recognise the relevance to scientific inquiry. However, it must be done with care, and not overemphasised, for it must not result in loss of confidence in one's cognitive faculties. It could then be counterproductive.

As Hodson (1989, p.57) rightly observes, children should be encouraged to regard theory and experiment as being inter-dependent: experiments assist theory building; and theory, in turn, determines the kind of experiments that should be carried out. In theory construction, experimentation has a two-fold significance. Firstly, in testing the empirical adequacy of the developing theory and providing retrospective evidence for theoretical propositions. Secondly, in guiding the continued development of theory towards coherence and completeness. For example, says Hodson, experiments assist the refinement of concepts and the quantification of conceptual relationships, and establish the limits of applicability of a theory. Thus, experiment is seen to be an integral part of the decision-making of theory construction. In turn, theory has a two-fold role in experimentation. First, in the generation of questions to be investigated and problems that require theoretical elucidation and explanation. Second, as a guiding factor in the precise design of experiments to answer those questions and solve those problems. This holistic, interactive view of the experiment-theory relationship provides a fruitful model for concept development in individuals.

Textbooks help sustain the myth that the path in science from experiment to theory is linear, simple and clear-cut. Hodson suggests that part of learning about science should involve reading actual accounts of experiments.

6.3.3 Instrumentalism and realism in school science

In order to bring about a proper understanding of science, it is necessary that the role of theory be made apparent to school pupils. That role is essentially to **explain** phenomena. Merely to learn theory without examining how it works is little better than rote memorisation. This is why I advocate the use of such exercises as the one presented in section 6.3.1 above (Rutherford's Scattering Simulation) when dealing with Atomic Theory.

In school science, unfortunately, theories are often represented as simple statements open to straightforward tests based on observation. A more appropriate and philosophically sounder view is that they are **imaginative guesses which stand or fall on their ability to explain and predict, without being dependent on any single observation.** In practice, theories are seldom, if ever, refuted by a single anomalous observation or experiment. It is only when these anomalies are long-standing, socially significant, and strike at the fundamental assumptions of the theory that the theory comes under threat of falsification.

Pupils should also recognise that theories grow and develop in order better to accommodate observational evidence. This process of growth and development should be recognised in the science curriculum and in textbooks. In teaching science, therefore (says Hodson), the degree of theoretical sophistication at any particular stage should be determined by the capacity of the theory to explain phenomena the learners will encounter. It need not go beyond. Do not introduce a theory until the phenomena that the pupil is dealing with demands it. Thus, year by year during the school science curriculum, theories will grow and develop, perhaps along similar lines to their historical development.

The process does not end here, for it is imperative to show to the pupil the social aspect of theory growth. Science, says Hodson (1985), proceeds in three distinct phases: **creation**, **validation**, and the **incorporation** into the body of knowledge. Scientific knowledge is the result of a complex social activity. The work of an individual must withstand the criticism of his fellow practitioners. The criteria of truth and objectivity are derived from the validation by the scientific community. In this way, the community of scientists exerts "quality control" over the activities of individual scientists. This is usually done in practice by free discussion and creative criticism in the 'private language' of individual scientists. When this work is presented in written form, in journal papers, it becomes 'public science', and is again subjected to ruthless testing and criticism. Eventually, this public knowledge becomes incorprated in condensed form in textbooks.

I agree with Hodson that the pupil should be **explicitly told** about these phases. Also, it should be **implicit** in textbooks, in the form of problem-solving exercises. Such exercises (as, for example, given in 6.3.1 above) will expose the pupil to (i) hypothesis generation (by creative speculation), (ii) hypothesis testing (by critical experimentation), and by (iii) the social processes of acceptance and recording of scientific knowledge. In this way, many of the problems of mismatch between school science, real science, and the philosophy of science, would be minimised.

Our science textbooks tend to emphasise the acquisition and understanding of concepts and theories and the methods and processes of science. Relatively little attention is given to individual phases of scientific creativity (hypothesis generation, experimental design etc.), and even less to the community phase of criticism, validation and the achievement of concensus. According to Hodson, in order to obtain a philosophically more valid approach to science, textbooks should take account of the following activities:

(1) The exploration of children's existing views, contemporary scientific views, and new theories of science education.
(2) Experimental work, using procedures accepted and validated by the scientific community to test the adequacy of various alternative theories.
(3) Recording and reporting of findings and ideas, using language styles approved by the community and the achievement of consensus by discussion and criticism.

It is the first and third of these activities which are neglected in school. Fortunately, there is rapidly growing research into children's alternative views of science. Thus the first neglect is being addressed. But the third needs to be emphasised. It should be a goal of science education that children are brought to an awareness that science is pre-eminently a social activity. Children must be made aware that, for theories to be accepted as valid scientific knowledge, they must be recognised and approved by the scientific community. If this procedure is followed in the classroom, children will not perceive the scientist as dispassionate, unbiassed and independent, with little or no interest in ethical or social concerns. Rather they will begin to see that science is a very human activity.

Further, they will get rid of the commonly-accepted notion that reality is 'the world already out there' and objectivity as a subject-free view of the world out there. They will (hopefully) gradually evolve from an instrumentalist approach to a full-blooded, critical realist view. This may take years, and may only be fully achieved after school. Perhaps the naive realist stage of childhood must evolve, through an instrumentalist approach, to a fuller realism in which there is a growing awareness that reality is constructed, and is not already out there. As this notion matures, it will be seen that relativism is avoided by the critical, open-minded attitude. The objectivity of science is ensured, not by requiring individuals to be free from personal preferences or interests, but by insisting that hypotheses be open to experimental testing and are made available for testing by fellow practitioners. This, as Hodson rightly points out, is a far more appropriate and realistic view of scientific open-mindedness than the traditional inductivist view that scientists have no pre-existing theoretical views or expectations.

6.3.4 Recommendations for textbooks

Historical case studies, the reading of actual experiments done by scientists, as well as explicit discussions of the role of theory as seen by realists or instrumentalists, might be useful in helping children to be more aware of the contemporary view of science.

For this reason, a few examples have been assembled which are the sort of material I believe textbooks should contain in order to attempt to portray a more correct view of the nature of scientific theory. Using theory as a starting point, this approach may hopefully lead to a better notion of the nature of science and scientific method in general. Finally, perhaps children may be led, through such readings, to a richer, more full-blooded type of realism.

The textbook material presented below consists of:

(1) Two or three (not more) good case studies, such as the phlogiston theory of heat, to be included in an appendix in every textbook. This would not take up much space in the textbook, and each need not require more than one lesson. Suggestions are provided in 6.4 below.

(2) A short journal article, suitably edited to reduce conceptual and linguistic complexity, should be presented in every textbook. An example is given in 6.5 below.

(3) Every textbook should contain, in a preface or introduction, a short treatment of the now out-dated traditional view of scientific theory and scientific method, followed by the contemporary view. A possible outline is provided in 6.6 below. This preface should also briefly discuss the instrumentalist versus the realist views of theory, and the constructivist nature of scientific knowledge. The important role of theory must be emphasised. Perhaps the critical realist view of science may be raised. (See the example in 6.6 below).

(4) Several "compulsory" enrichment readings should be encouraged. Popular books or articles dealing with the personal accounts of the work of particular scientists should be read. For example:

The Double Helix by J.D. Watson (1970)
The Sleepwalkers (perhaps only the part called *'The Watershed'*) by A. Koestler (1959)
Lucy: the Beginnings of Humankind by D.C. Johanson and M.A. Edey (1981)
The Voyage of the Beagle by Charles Darwin
Adventures with the missing link by Dr R. Dart.
The panda's thumb by J.S. Gould (1983), pp.105-111
The Piltdown forgery by J.S.Weiner (1955)
Also the articles such as that in *Sky and Telescope* (January 1988, pp.38-43) on the 'Halton Arp controversy'.

These books and readings describe how theories grow in the realities of everyday scientific intercourse.

What is presented below in Sections 6.4, 6.5, 6.6, and 6.7 is the kind of material which textbooks might include in order to try to portray a more up-to-date philosophy of science. Of these, Section 6.6 is regarded as a *sine qua non* for textbooks, and should be incorporated in a preface or introduction in every senior school textbook. This could be aimed at both students and teachers. In order to overcome the dangers of an increasing tendency towards instrumentalism in recent textbooks, the focus of attention should be on the role played by **scientific theory**.

6.4 Historical case studies

By emphasising that current scientific views are no more than the latest in a series of views shaped and influenced by personal and social conditions and attitudes, historical studies would reinforce the notion that scientific knowledge is created rather than discovered. But we must not present the history of science in contemporary terms, otherwise pupils may see the past as simply quaint and ill-conceived. Historical case studies must as far as possible be seen from the perspective of the time. Pupils need to see the various fruitless routes that were followed, "the reasons, subterfuges, and lucky hazards which led me to my discoveries" (Kepler), and to appreciate the part played by personal ambition and social pressures. Many writers, such as J.B. Conant, have encouraged the use of historical case studies, but their calls for inclusion of materials into textbooks have largely gone unheeded. There seems to be a scarcity of resource materials.

6.4.1 Galileo versus Aristotle

The following condensation of a section in the Harvard *Project Physics* (Concepts of Motion) could perhaps be included in a textbook in order to highlight the notion of theory change.

Galileo's theory of free fall versus Aristotle's

Galileo was brought up on a science which believed that all terrestrial matter was made up of a mixture of four 'elements': Earth, Water, Air, and Fire. Each of these four elements was thought to have a natural place in the terrestrial region. The highest belonged to Fire, below which was Air, then Water, and bottom-most was Earth. Each was thought to seek its own place. Thus, if fire were displaced below its natural position, it would tend to rise through Air. Similarly, Earth would tend to fall through both Air and Water. So a stone, for example, would fall through Fire, Air and Water in order to reach Earth, its natural place.

The medieval thinkers also believed that the stars, planets, and other celestial bodies, were made up of a fifth element called the quintessence. The natural motion of celestial bodies was not rising or falling, but endless revolutions in perfect circles. For a circle is the perfect shape. Heavenly bodies, though moving, were at all times in their natural places.

A falling stone has 'natural' motion, because it is moving towards its natural place. But a stone moving upwards is undergoing 'violent' motion, because it is moving away from its natural position. To maintain this upward motion, a force had to be continuously supplied to the stone. Anyone lifting a large stone is very much aware of this as he strains to raise the stone higher. It is common-sense. Also, a falling stone does not have any force on it.

Now, a theory 'explains' an observation if the latter is consistent with the theory. The Aristotelian ideas were consistent with many common-sense observations. But there were difficulties. Take, for example, an arrow shot into the air. Aristotelian physics required that the arrow be continuously propelled by a force. Otherwise, if the force were removed, the arrow should fall directly to the ground in 'natural' motion. But the arrow does not fall immediately to the ground after losing contact with the bow-string. What then is the force that propels it? Here the Aristotelian offered an ingenious explanation: the motion of the arrow through the air was maintained by the air itself! As the arrow starts to move, the air is pushed aside, and the rush of air to fill the space being vacated by the arrow maintains it in its flight.

So in all motion, a force was required to sustain uniform motion. It was sometimes difficult finding a suitable force. Consider accelerated motion. How is acceleration explained? As a falling body approached its natural place, it speeded up, just as a tired horse returning to its stable starts galloping.

When a falling body reaches its natural place, it stops. Rest was regarded as the natural state, and required no further explanation.

This theory, which Galileo studied at the University of Pisa, was originally put forward by the Greek philosopher Aristotle in the fourth century B.C. It seemed perfectly plausible in the societies in which Aristotle and Galileo lived, where rank and order were dominant in human experience.

Galileo was born in Pisa in 1564, the same year as Shakespeare's birth. He was a medical student at the University of Pisa, but was lured to physical science. At the age of 26 he was appointed Professor of Mathematics at Pisa. He specialised in mechanics and astronomy, and in 1638 he wrote his second book, *Two New Sciences.*

In this, he states that both a heavy and a light body, falling freely, reach the ground at slightly different times. Aristotle had explained this in terms of the heavier body having a greater need to find its natural place. Galileo, however, suggested that, because the times were so slightly different, perhaps we should change our point of view of the problem. Perhaps all falling bodies actually reach the ground at the same time, and the slight difference is due to air resistance. He took a brand-new, refreshing perspective on an old problem.

He tried to imagine what would happen if there were no air. This may be easy for us, but in Galileo's day it was almost inconceivable to think like this. Air is always present. Galileo's imaginative guess went against common-sense.

Similarly, Galileo realised that, in horizontal motion, it is friction that stops a moving body. Take away friction, and the body will move forever. (This eternal motion was, for Galileo, circular. It was Newton who later modified the axiom into straight-line motion.) The point again is that Galileo went againt sensory experience. He said that constant motion is the natural state of a moving body, and coming to a stop required another explanation. This was exactly contrary to the Aristotelian view. Galileo's guess was a bold conjecture, whose consequences were confirmed by thought-experiments as well as observations.

See if you can think up logical arguments to refute Aristotle or Galileo. Try to put yourself in the world of Galileo, and argue against Galileo. (Modelled after Harvard *Project Physics*)

Note the following few points:

(1) Aristotle's theory was not stupid. It accounted well for many observed phenomena.

(2) Galileo's evidence did not immediately refute Aristotle's.

(3) It was only after Galileo had constructed a new theory, which enabled him to look at old questions in a new way, that the old theory began to be refuted.

(4) Long after the old theory had been refuted, it was still believed in simultaneously with the new theory. Even today, hundreds of years later, many people still think along the lines of Aristotle's theory. We often hold two opposing theories, working with one on one occasion, and the other on

another occasion. For example, we still use Newton's theory to launch Space Shuttles, even though it has been superceded by Einstein's theory.

6.4.2 Kepler's Laws

Another example, taken from Koestler's *The Sleepwalkers*, shows how scientific theory is constructed in a very human way.

Kepler's Laws: A sleepwalker's road to theory-construction

In his book *The Sleepwalkers,* Arthur Koestler describes how Kepler arrived at his laws of planetary motion. The following consists of brief extracts from this, in order to show the very human way in which scientific theories grow:

The manner in which Kepler arrived at his new cosmology is fascinating. Fortunately, Kepler did not cover up his tracks as Copernicus, Galileo and Newton did. Kepler was incapable of exposing his ideas methodically, in textbook fashion. He had to describe them in the order they came to him, including all the errors, detours, and the traps into which he had fallen. His book, *The New Astronomy*, is a unique revelation of the ways in which a creative mind works. Kepler writes:

> "What matters to me is not merely to impart to the reader what I have to say, but above all to convey to him the reasons, subterfuges, and lucky hazards which led me to my discoveries."

When he arrived in Prague in 1601, he found the world-renowned astronomer Tycho Brahe's senior assistant, Longomontanus, trying to unravel the orbit of Mars.

> "I believe (writes Kepler) it was an act of Divine Providence that I arrived just at the time when Longomontanus was occupied with Mars. For Mars alone enables us to penetrate the secrets of astronomy which otherwise would remain forever hidden from us."

The reason for this key position of Mars is that, among the outer planets, its orbit is the most elliptical.

He first attacked the problem of trying to find the shape of Mars's orbit on traditional lines. When he failed, he began to get rid of the whole load of ancient beliefs on the nature of the universe and replace it with a new science.

As a preliminary, he made several revolutionary innovations. Kepler did not know as yet that the orbit was an ellipse. He still regarded it as a circle. He asked himself the question that, although the sun was not at the centre, why did the planet insist on turning around the centre? He answered this by assuming that the planet was subject to two forces, one from the sun, and the other located in the planet itself. Today we know these forces are gravity and inertia. But gravity had not yet been invented to explain this.

A second innovation was his assumption that the plane of the orbit of Mars does not oscillate (as Copernicus had suggested), but forms a fixed angle with the plane of the Earth's orbit. He confirmed this by many observations, remarking somewhat smugly that

> "the observations took the side of my preconceived ideas, as they often did before".

The third innovation was the most radical. To get away from the traditional idea of 'uniform motion in perfect circles', he let circular motion stand, but he threw out uniform speed. This bold conjecture was guided by mainly physical considerations. If the sun ruled the motion, then its force must act more strongly when the planet is closer to the source, making the planet move faster.

These three bold moves cleared away a considerable amount of rubbish that had obstructed progress since Ptolemy. Kepler felt confident that victory was just around the corner.

Kepler's first attack on the problem is described in great detail in the *New Astronomy*. The task before him was to define the orbit of Mars by determining the radius of the orbit and the direction of Mars on a given date relative to the fixed stars. He used four observed positions of Mars. It was a problem involving many trial-and-error procedures. Kepler's draft calculations, preserved in manuscripts to this day, covered nine-hundred folio pages in small handwriting!

At times he was despairing. He felt, he says, that a demon was knocking his head against the ceiling. He wrote:

> "If you (dear reader) are bored with this wearisome method of calculation, take pity on me who had to go through with at least seventy repetitions of it, at very great loss of time; nor will you be surprised that by now the fifth year is nearly past since I took on Mars..."

Now, at the very beginning of the hair-raising computations, Kepler absentmindedly put three erroneous figures for three vital longitudes of Mars and happily went on from there, never noticing the error. Yet the correct results differ little from Kepler's. The reason is, that toward the end of the chapter, Kepler committed several mistakes in simple arithmetic - errors in division which would bring bad marks to any schoolboy - and these errors very nearly cancelled out his earlier mistakes.

After seventy trials, he arrived at values which gave the correct position of Mars for all ten oppositions recorded by Tycho Brahe. The problem seemed to have been conquered. But then a major problem arose. Said Kepler:

> "Who would have thought it possible? This hypothesis, which so closely agrees with the observed oppositions, is nevertheless false..."

In the following chapters, Kepler explains, with great thoroughness and an almost masochistic delight, how he discovered that the hypothesis is false, and why it must be rejected. In order to prove it by a further test, he had selected a further two of Tycho's observations, but they did not fit. And when he tried to adjust his model to them, this made things even worse, for now the observed positions of Mars differed from those which his theory demanded by magnitudes up to eight minutes arc.

This was a catastrophe. Ptolemy, and even Copernicus, could afford to neglect a difference of eight minutes, because their observations were only accurate within a margin of ten minutes of arc, anyway. But Kepler felt that he had to acknowledge Tycho's greater degree of precision. Kepler writes:

> "Since it was not permissible to ignore them, those eight minutes point the road to a complete reformation of astronomy..."

It was the final capitulation of an adventurous mind before irreducible, obstinate facts. Earlier on, if a minor detail had not fit into a major hypothesis, it was cheated away or shrugged away. Now, this time-hallowed indulgence of saving the appearances at any cost (that is, treating facts instrumentally) had ceased to be permissible. A new era had begun in the history of thought: an era of austerity and rigour.

In Kepler's previous work, facts had been forced to fit the theory. In the *New Astronomy*, a theory, built on years of labour and torment, was instantly thrown away because of a discord of eight miserable minutes arc. What caused this change of heart in him? It was his introduction of physical causality into the formal geometry of the skies which made it impossible for him to ignore the eight minutes of arc. So long as cosmology was guided by purely geometrical rules of the game, regardless of physical causes, discrepancies between theory and fact could be overcome by inserting another wheel into the system. In a universe moved by real, physical forces, this was no longer possible. The revolution which freed thought from the stranglehold of ancient dogma, immediately created its own, rigorous discipline.

Kepler closes the Second Book of the *New Astronomy* with these words:

> "And thus the edifice which we erected on the foundation of Tycho's observations, we have now again destroyed ... This was our punishment for having followed some plausible, but in reality false, axioms of the great men of the past."

But the shape of Mars's orbit still eluded him. The final assault took him two years. At first, he once again returned to the old idea that the orbit was circular, but failed. He writes:

> "The conclusion is quite simply that the planet's path is not a circle - it curves inward on both sides and outward again at opposite ends. Such a figure is called an oval. The orbit is not a circle, but an oval."

But now a dreadful thing happened, and the next six chapters of his book are a nightmare journey through another labyrinth. This oval orbit is a wild, frightening new departure for him. To mock the Aristotelian circle is one thing; but to opt for an entirely new, lopsided path for planets is quite another.

Why indeed an oval? He **must** find a physical cause, and invents the idea that, while the sun's force sweeps the planet around its orbit, a second antagonistic force, seated in the planet itself, resulted in an oval path.

He tried for a year to make the oval hypothesis work, but could not. In despair, he even tried repudiating his own Second Law - to no avail. Finally, a kind of snowblindness seemed to descend on him: he held the solution in his hand without seeing it. On 4 July 1603, he wrote to a friend that he was unable to solve the problem using the oval; but

"if only the shape were a perfect ellipse all the answers could be found..."

A full eighteen months later, he again wrote to the same correspondent that the truth must lie somewhere halfway between an oval and a circle "just as if the Martian orbit were a perfect ellipse".

Then an amazing breakthrough occurred. He was comparing the difference between a circle and an oval, and noticed than the greatest difference was 0,00429 of the radius. Then Kepler noticed that the secant of a particular angle when Mars is halfway along the oval is precisely 0,00429. Suddenly he felt as though he had been awakened from a sleep. Now at last, after years of work, he held the secret of the Martian orbit. He was able to express the distance of the planet from the sun in a simple mathematical formula. But he still did not recognise the shape as being an ellipse. He had reached his goal, but did not realise that he had reached it.

He went off on one last wild goose chase. He tried to construct an orbit that would correspond with his newly-found equation. But he did not know how. He made a mistake in the geometry, and arrived at a wrong answer.

We have now reached the climax of the comedy. In his despair, he threw out his formula (which denoted an elliptical orbit) because he wanted to try out an entirely new hypothesis: to wit, an elliptical orbit. He constructed an ellipse by a different geometrical method. And then, at last, he realised that the two methods produced the same result.

With his usual disarming frankness, he confessed what had happened:

"Why should I mince my words? The truth of Nature, which I had rejected and chased away, returned by stealth through the backdoor, disguising itself to be accepted. That is to say, I laid (the original equation) aside, and fell back on ellipses, believing that this was a quite different hypothesis, whereas the two, as I shall prove in the next chapter, are one and the same ... I thought and searched, until I went nearly mad, for a reason why the planet preferred an elliptical orbit ... Ah, what a foolish bird I have been !"

Note the following:

(1) Kepler's invesigation began with preconceived ideas (or thories), not with observation. Science usually begins with theory, not with observation

and experiment, as we often think.

(2) The long investigation was not a cold, calculating procedure, following a clean-cut, straight line of thought. Rather, it was filled with passion. It went backwards and forwards.

(3) The "lucky hazards" that Kepler refered to were not really lucky, in a gambling sense, although there were some strange coincidences along the way. Rather, Kepler's luck was due to the fact that he was so caught up in his problem, his mind was so filled with the facts, that when some external fact came to his notice, he recognised its relevance immediately.
As Pasteur said: "Chance favours the prepared mind", or in our own day as Gary Player wisely said: "The more I practise, the luckier I get!"

6 .4 .3 The Phlogiston Theory

It is important to point out to pupils that theories which might appear strange to us today were once regarded as sensible. They were quite suitable for their time.

The Phlogiston Theory

A theory which is not refuted when the bold predictions to which it gives rise are tested is said to be corroborated. Such a theory represents new knowledge. All such discoveries (eg Eddington's calculations on the 1919 eclipse observations corroborated Einstein's theory) are corroborations by severe tests - by predictions which were highly improbable in the light of our previous knowledge.

Other important discoveries have also been made while testing a theory, even though they did not lead to its corroboration but in fact to its refutation. Lavoisier's classical experiments which show that the volume of air decreases while a candle burns in a closed space, or that the weight of burning iron filings increases, did not establish the oxygen theory of combustion; yet they tended to refute the phlogiston theory.

In order to explain combustion, a theory was put forward which postulated the existence of a principle or substance of inflammability supposed to exist in combustible bodies. This substance was called 'phlogiston'.

In order to test for the existence of phlogiston, the mass of a piece of copper was measured before combustion. If it lost mass, then it confirmed that phlogiston, which was needed for combustion, had been used up. If it gained mass, then the phlogiston theory was refuted. But another theory was needed to replace it, namely, the oxygen theory. The fact that the copper does indeed gain mass corroborates the oxygen theory, but does not prove it, for there may be another explanation.

It is important for us not to scorn the phlogiston theory as a stupid guess, or simple-minded error, or superstition. It was suitable for its time, and made sense of the facts known then.

Also, as Thomas Kuhn points out, it is simplistic for us to say "Oxygen was discovered". This statement misleads because it suggests that discovery is a single simple act in which the oxygen 'out there' was simply waiting from all eternity for someone to find it. In fact, the concept 'oxygen' resulted from a series of interrelated constructions. It happened like this.

In the early 1770's, several chemists had enriched air in a laboratory without knowing it. The earliest claimant to prepare a relatively pure sample of the gas was the Swedish apothecary C.W. Scheele. We may, however, ignore his work, since it was not published until oxygen's discovery had repeatedly been announced elsewhere. The second in time to establish a claim was the British scientist, Joseph Priestley, who collected the gas released by heated red oxide of mercury as one item in a prolonged investigation of the 'airs' evolved by a number of solid substances. In 1774, he identified the gas thus produced as nitrous oxide and in 1775, led by further tests, as common air with less than its usual quantity of phlogiston. The third claimant, the French scientist Lavoisier, started the work that led him to oxygen after Priestley's experiments of 1774 - possibly as the result of a hint from Priestley. Early in 1775, Lavoisier reported that the gas obtained by heating the red oxide of mercury was "itself entire without alteration (except that) ... it comes out more pure, more respirable." By 1777, Lavoisier had concluded that the gas was a distinct species, one of the two main constituents of the atmosphere, a conclusion that Priestley was never able to accept.

Who, then, 'discovered' oxygen? Priestley isolated a gas that was later recognised as a distinct species. Lavoisier isolated the gas and was able to say what the gas was. He insisted that oxygen was an atomic 'principle of acidity' and was formed only when that 'principle united with 'caloric', the matter of heat. But the principle of acidity was not banished until 1810, and caloric lingered until the 1860's. So can we say that Lavoisier discovered **oxygen**? His concept of oxygen was a primitive one, oxygen-in-the-making, as it were.

More important, did the discovery lead to a change in theoretical structure, that is, a new theory? What Lavoisier announced in his papers of the late 177O's was not so much the discovery of oxygen as the **oxygen theory of combustion.** Long before he played any part in the discovery of oxygen, Lavoisier was convinced both that something was wrong with the phlogiston theory and that burning bodies absorbed some part of the atmosphere. This was recorded in 1772. That theory resulted in a chemical revolution. This earlier work on combustion gave additional form and structure to his growing concept of oxygen.

6.5 A Journal Article

The purpose of showing a simple journal article to pupils is three-fold: firstly, to show the accepted **format** of such an article; secondly, to reinforce the idea that when a theory becomes public and is presented in published form, it takes on a social character which lends it **objectivity**; and thirdly, to use it as a means of **criticising the inductive nature** of scientific inquiry along the lines of Medawar (1963).

The following is an article taken from a journal published by the Geological Society of America, and was shortened and simplified to exclude technical jargon as far as possible.

GEOLOGICAL SOCIETY OF AMERICA BULLETIN December 1974

RELICT AND RECENT BEACHROCK FROM SOUTHERN AFRICA

William G. Siesser
Dept of Geology University of Cape Town

ABSTRACT

Beachrock is a calcium carbonate rock found along beaches in the inter-tidal zone. It is the remains of a larger formation formed during withdrawal of the sea during an ice-age 25000 years ago. This is confirmed by carbon-14 tests.

INTRODUCTION

Previous studies are referred to, all names and sources being given. Its relevance to the present study is briefly described.

SOUTH AFRICAN BEACHROCK

Occurrence: Where is beachrock found in the south-western Cape. Petrography and mineralogy: Its chemical composition and crystalline structure is described.

METHODOLOGY

The aim and method of the present study is described in some detail. This is done so that the logic of the experimental procedure may be criticised by other scientists, also so that the study may be repeated by the reader if he so wishes.

RESULTS

All the results of the study's experiments (eg the radioactive dating) are listed in detail, again not only for the information-content, but also so that other scientists can criticise and evaluate them.

DISCUSSION

These results are now applied to the hypothesis contained in the first part of the paper.

CONCLUSIONS

It is decided from the results whether or not the hypothesis has been supported.

ACKNOWLEDGEMENTS

Thanks to all who funded the research.

REFERENCES

All sources are listed

There are several methods used in science: one is the inductive experimental method of Francis Bacon and John Stuart Mill; another is the hypothesis and deduction method of Karl Popper; a third emphasises the method of comparingcompeting theories. Bacon's method emphasises **verification** of theories; Popper's emphasise **falsification** of theories. (A more detailed account is given in section 6.6 below.)

Which method or combination of methods do you think was used in the above journal article? Give reasons for you answer. Why do you think the scientific community (represented here by the editors of this journal) insist on a particular format? Does the fact that scientists are expected to publish their results and theories in writing, or present them as "papers" at conferences, have any importance for science?

6.6 Traditional and contemporary views of science

The following could be included, either verbatim, or in a shortened summary form, in all high school science textbooks:

Scientific method?

What is scientific method? Most people think that all scientists follow a strict method. This is simply not true. For there are many different scientific methods.

The traditional view of science

Traditionally, it has been supposed that science followed the method put forward by Francis Bacon and elaborated by John Stuart Mill. This goes as follows:

(1) Observation and experiment
(2) Inductive generalisation
(3) Hypothesis
(4) Attempted verification of hypothesis by experiment
(5) Proof or disproof
(6) Knowledge

This is known as the **inductive method**, but it also includes deduction. Induction is the mental process of passing from observations of particular events to universal laws or generalisations. For example, from our observations of thousands of dogs, we make the generalisation that all dogs have four legs. Deduction is the reverse process, that is, the inference of particular conclusions from a general law. For example, if all dogs have four legs, and this animal here is a dog, then it must also have four legs.

Traditionally it has been believed that science begins with objective observations. These observations yield the data in which patterns may be revealed. It is permissible to make such generalisations, provided that the number of observations is large, and the observations must be reproducible under a variety of conditions. Generalisations lead to theories, which, when verified many times over, become laws. These theories and laws enable predictions to be made. If these deductions are confirmed by testing, the theory is affirmed. In this way scientific knowledge is built up.

This rigorous scientific method leads to the following ideas:
(1) Scientific knowledge is proven knowledge.
(2) Scientific knowledge is based on sensory experience.
(3) Scientific theories are derived directly from observations and experiments.
(4) Observation is objective and impersonal.
(5) A scientific theory can be refuted by a single falsifying observation or experiment.
(6) Scientific knowledge is reliable.
(7) Scienctific knowledge leads to absolute truth.

In 1934 Karl Popper, a physicist and philosopher of science, suggested that induction is an invalid process. It is wrong to say, for example, that "All copper objects are good conductors of electricity", because we have never observed **all** copper objects. No number of observations of white swans allows us logically to say "All swans are white", because it is possible that the next swan we observe may be black. If we do come across a black swan, what we **can** say is "Not all swans are white." Hence, generalisations cannot be **verified** by further evidence, but they can be **falsified**. That is, **scientific laws cannot be proved**, but they can be tested by attempts to refute them.

So Popper emphasises **falsification** of theories rather than **verification** of theories. We make an imaginative guess (or conjecture, or hypothesis) about our problem, then seek ways of trying to prove it wrong (falsify or refute it). His **conjecture and refutation** scientific method goes like this:

(1) Problem posed (usually to try to refute an existing theory).
(2) Proposed solution (that is, a new theory).
(3) Deduction of testable consequences of the new theory.
(4) Severe testing, by attempted refutations, through observation and experiment.
(5) Preference established between competing theories.

This is much closer to real scientific practice than the Baconian method, although neither is used exclusively. There are three important differences between them. (a) Science begins with theory, not observation. (b) This means that observations are influenced by prior theory and are not totally objective. Observation is fallible. (c) A single experiment cannot verify a theory, but it can falsify it.

This brings us to the contemporary view of scientific method.

The contemporary view

Popper's scientific method fails because (i) it depends on a single **falsifying** observation, and (ii) observations are fallible. Therefore an observation cannot **conclusively** refute a theory. Hence a new theory is needed **before** falsifying observations can be made. This means that, so long as we think within the confines of a particular theory, we may never be able to think up evidence that would falsify it. So another perspective is needed to highlight the shortcomings of the existing theory. In other words, we need to think laterally and creatively. We need to 'brain-storm'. The more alternative theories we invent, the better.

Scientists work within the current set of accepted theories. This is called 'normal science'. Problems encountered are dealt with in terms of the existing theories. However, if a problem (anomaly) arises which resists being solved in terms of the current theories, a crisis develops, and a new theory may emerge to resolve the difficulties. Such a change of theories is called a 'scientific revolution', because a completely new way of thinking is required. For example, a revolution occurred when Newton's theory could not account for certain phenomena, and Einstein's relativity theory replaced it. However, scientists are reluctant to let go of old theories. So old ones are sometimes retained simultaneously with the new for some time. Indeed, the new one may be used instrumentally for some time until confidence in it grows. The new theory should not be accepted too readily or uncritically.

There is a basic 'hard core' of scientific knowledge which cannot be modified, falsified or rejected. The scientific community agrees on what belongs in this hard core. Any mis-match between a theory and an observation is dealt with by modifying the protective belt of auxiliary hypotheses which surround the hard core. Early work on a theory often takes place in opposition to apparently falsifying observations. An old theory cannot be falsified until we have a new, better theory to replace it. So, for a time, we hold on to both the old and the new theories simultaneously. Time has to be allowed for a theory to develop before it is subjected to rigorous testing. When the new theory has been developed sufficiently to permit rigorous testing, it is **confirmations** rather than falsifications that are significant. A theory is progressing if it predicts some **novel** facts. We must gain new information about the world from our theory.

Theories grow and develop. At first, they may be the result of imaginative guesses. For example, a story is told of a certain village, whose inhabitants were perplexed by two facts: firstly, whenever they wanted to use a pencil, one could never be found; and secondly, if one was found, the pencil sharpener was always found to be full of pencil shavings. A wonderful theory was invented to account for these two observations. At night, while the inhabitants slept, some fairy-like 'Plogglies' emerged, took every pencil in sight, ground them up, and shoved the shavings into the pencil sharpeners. This theory was successful, because it accounted for the two observed facts.

However, inventing 'Plogglies' is too arbitrary. The theory could not be tested, because 'Plogglies' simply do not exist.

Similarly, suppose you watch a ball roll across a table, and see it come to a stop. A friend suggests that friction stopped it. Another friend tells you that small invisible demons brought it to a halt. How do you know it is friction, not demons, that brought the rolling ball to rest? Suggest experiments to test or support your view. This problem, which looks like a joke at first sight, raises the whole question of the nature of scientific explanation. Try to make a logical defence - but remember that an opponent defending demons could claim a variety of properties for them.

As theories grow and our confidence in them grows, a greater degree of reality is given to the guessed object. At first we construct a simple model, possibly a hardware model. Then we might build a more mathematical model which is more informative than the first one. We are content to use our invented models in an instrumental way, simply to **describe** or to **predict**. For example we may say that electrical resistance is like a partial blockage in a water pipe (Model 1). Then, after further experimentation with simple circuits, we **define** resistance as potential difference divided by current (Model 2). We make use of these models quite happily to predict facts about electrical circuits. Our models enable us to treat resistance **as if** it were a real thing. That is, at first, we accept the existence of resistance in a superficial way. But as we investigate further, we build other models (for example, the model that the electrons collide with atoms of the resistance wire - that is, we link our models with the well-established Atomic Theory). As our models develop, they take on the form of a broader, more comprehensive theory. And along the way, we have tied our various models in with another comprehensive theory, namely Atomic Theory. The consistency of our theory of resistance with another well-tried theory, adds strength to our theory.

As our trust in our theories increases even further by constantly criticising and testing their consequences, we acknowledge the reality of the concept which we originally constructed. And so we readily agree that the world of electrons, atoms, resistance, current, and so on, really exist objectively. A scientist working in this way is called a realist.

A realist scientist who is critical can be realist about some theories (those which he believes to be true) and instrumentalist about others (which he finds useful but uncertain about their truth). The latter he calls a **model**. For a realist scientist, a model is different from a theory. A model is less certain than a theory. Scientists who are not realists, but who are instrumentalists, are instrumentalist about all theories.

Many scientists today prefer not to be realists. They hold that it is not the business of science to talk about the real existence of things we cannot see, for example, electrons. For such a scientist, a theory is only an imaginative fiction, a tool for solving a problem. It has no reality. He suspends his judgement about their real existence, and treats such things **as if** they existed.

This procedure works, but does not tell the full story about the physical world. Such a scientist does not have the confidence in his theories he should have. Therefore he does not distinguish between theories and models, since he is equally uncertain about theories and models.

On the other hand, the critical realist scientist does not find it illogical to retain a falsified theory in an instrumentalist capacity, provided that its status is acknowledged. The fact that it is useful does not mean that it is true. It may be that, for certain applications, a falsified theory is more useful than a true one because it is simpler to use. In other words, it has instrumental value. For example, Newton's laws of motion may be quite adequate to solve certain problems, without calling on the more correct theory of relativity. Or Rutherford's model of the atom may be simpler and therefore more useful than the wave-mechanical model, even though the latter is more precise. As Popper puts it: Suppose it is one minute to noon. Then the statement "It is twelve o'clock" is false. Yet, though false, it is far more useful than the true statement "The time is now between ten in the morning and four in the afternoon". Science approaches truth, but can never attain it. Nevertheless, such knowledge can be immensely useful and intellectually satisfying.

So, although there is no one accepted scientific method, contemporary scientists agree about the following points;

(1) Science begins, not with observation, but theory.
(2) Observation is not objective, and is therefore fallible.
(3) Theories are imaginative constructions. They are inventions of the mind, intelligent guesses.
(4) The consequences of our theories are subjected to rigorous testing and criticism. They need time to develop before being tested.
(5) In the meantime, rival theories may be retained in spite of falsifying evidence.
(6) A new theory may have to be introduced to provide evidence for the rejection of an existing theory.
(7) A theory must be criticised and approved by the scientific community. Only then is a theory validated. Once produced publicly, it has an objective existence independent of individual minds.
(8) We have full confidence in our theories. They tell us about the real world. Theories are part of reality.

The role of scientific theory

From the above, it can be seen what a high regard is placed on the role of **theory** in science. The chief role of scientific theory is to **explain**. A scientific theory provides a **context** or **framework** in which various facts are linked together in a logical way in order to give reasons for certain phenomena. The things that theories talk about (for example, forces, electrons, electric current) are regarded by the critical realist type of scientist as actually existing. These scientists take the implications of their theories seriously - which is, of course, is what they should do! But some (instrumentalist) scientists hold that scientific theories are only useful devices for relating their observations. They do not take theories seriously, and can discard them very easily, even arbitrarily, without sufficient experimental evidence. This often occurs when there is still some uncertainty about a phenomenon. But when the theory has been fully accepted and ratified, a theory can become an object of scientific inquiry.

Implications of instrumentalism

Most scientists today use an instrumentalist approach to science. Instrumentalism works, and is very successful. It is a major factor why science has made such wonderful progress.

However, instrumentalism can easily lead to idealism, phenomenalism, agnosticism, relativism, gamesmanship, a spectator attitude, and pragmatism.

1. **Idealism**: If only sensory knowledge is valid, then all we ever know is the experience of our sense impressions. We can never be sure that an independant world lies outside of ourselves. For example, in open-brain surgery, a touch of a probe on a particular part of the brain can trigger off a sensation of smell, even though no external smell is there. To postulate the existence of something outside us is a metaphysical jump, which is not allowed by empiricist philosophy. So we remain forever trapped within ourselves, and our thoughts are the only thing we know. Reality is in the mind. We become idealists, or, at the very least, sceptics.

2. **Phenomenalism**: Our senses experience phenomena directly. What we see is what we get. For the empiricist, the directly observed thing is reality. There is no underlying reality behind appearance. The surface view is all that there is. Things are exactly what they seem. Thus an empiricist/instrumentalist view is superficial.

3. **Agnosticism**: If only sensory knowledge is valid, then the notion of God is seriously undermined. Scepticism and atheism may well follow.

4. **Relativism**: If theoretical knowledge is downgraded into a fiction which has no necessary physical counterpart, it need not be taken seriously. It can be as arbitrary as another cog in the wheel of Ptolemy's epicycles. For most people, truth is a correspondence to reality, but for an instrumentalist, truth is what works. Truth is relative. It depends on the result of inquiry. A statement is not true in itself. It is only true if found to be so.

5 **Gamesmanship**: Because an instrumentalist scientist does not take his theories seriously and regards them only as useful devices for prediction, the whole scientific enterprise becomes a game. Science becomes interested only in that it works, rather than in explanation. If this is all that science is, then it is dishonest. It may indeed be a costly hoax we have played on ourselves.

6. **Passive spectatorship**: If scientific theories are mere fictions with no reference to reality, then science has no sense of commitment. It is content to remain passive and uninvolved. Technology is preferred to front-line research, for there is no incentive to carry out the latter. It simply becomes isolated in time and space, and has no relationship to the user, who is therefore tempted to remain a passive and uninvolved spectator.

7. **Pragmatism**: Instrumentalism emphasises utility: the purpose of science is not to explain but to provide useful predictions. Hence nothing is worth doing unless it is useful. So Space Shuttles are preferable to Voyager probes, because the former have important military and economic spin-offs, whereas there is little obvious use in taking a few pictures of distant planets. Instrumentalism does not encourage the search for truly new knowledge. It appeals to the "instant" success attitude of modern man.

Conclusion: As scientists, we study the natural physical world. We should be realists, and take our theories seriously.

Of course, this synopsis of scientific method and the nature of science can be shortened. School pupils may find the paragraphs dealing with realism and instrumentalism a little too abstract. Yet we should include such material with the **teacher** in mind. This may be the **only** contact most teachers have with contemporary philosophy of science.

6.7 A contemporary example of science in action

The following shortened extract from *Sky and Telescope* (January 1988) illustrates the social nature of scientific theory construction:

The Arp controversy: The social nature of science

Theory-construction is very much a social affair. The scientific community monitors and controls the work of individual scientists, not in a dogmatic, authoritarian way, but by criticism. The editors of scientific journals act as referees, and thus exercise a quality control over what is good science, or whether the scientist is working within the bounds of the current theoretical structures.

In order to illustrate the way the scientific community works, the following is a summary of an article, in the form of a book review with defensive arguments, taken from *Sky and Telescope* (January 1988, pp.38-43). It also reveals the very human foibles of stubbornness, anguish, disappointment, and even partisanship, involved in the scientific decisions which affect theory construction.

Quasers, Redshifts, and Controversies

Halton Arp is a distinguished observational astronomer. In the first part of his career he worked on various aspects of stellar evolution - his Ph.D. thesis at Mount Wilson on the frequency of novae in the Andromeda galaxy was a fundamental contribution in this field. For thirty years he devoted himself to the study of extragalactic astronomy. Arp ranked among the top twenty observational optical astronomers in the world.

In 1966, in collaboration with Fred Hoyle and Geoffrey Burbidge, he found what was believed to be physical associations between some of these galaxies and previously-identified powerful radio sources. He also noted many cases of apparent associations between galaxies and quasars.

All of this would have been completely acceptable if the objects all had the same redshifts, but they did not. A redshift is interpreted as being due to the Doppler effect, in which the wavelength of the light emitted by a body moving away at high speed increases. This suggested that the Universe is expanding. But why, then, did some galaxies not have the same redshift? Yet Arp believed in the reality of the associations. He tried to publish articles about it in scientific journal, and after struggles with the referees, his papers were published. In the 1970's, other astronomers found similar results. Arp claimed that not all galaxy-redshifts were due to the expansion of the Universe. He maintained that redshifts are not always correlated with distances, and that some quasars were localised. However, his theory went against the stream. His standing in astronomy began to drop.

About four years ago, in 1984, came the final blow. His whole field of research was deemed unacceptable by the scientist-committee at the California Institute of Technology in Pasadena. The directors of Mount Wilson and Palomar observatories refused to assign him any more telescope time. After abortive appeals all the way up to the trustees of the Carnegie Institution, he took early retirement and moved to West Germany.

Evidence to support Arp's theory continued to grow. Facts about periodicities and peaks in the redshift distribution were very hard to explain in terms of conventional theory. By the early 1980's, Burbidge and Arp were convinced that the evidence for local quasars was too great for it all to be wrong. At the same time, Burbidge felt that evidence that other quasars did have cosmological redshifts was compelling. So he believed in Arp's hypothesis while trying to accommodate some part of the conventional view.

Yet Arp's treatment by the astronomical community was extremely unpleasant. Perhaps the astronomical community exercised good judgement, but their tactics to try to maintain the *status quo* gave all the appearances of being unfair. These include unending refereeing, blackballing of speakers at meetings, distortion and misquotation of the written word, and denial of telescope time to those who were investigating what some believed was outside of the commonly-accepted theory. Arp suffered all of these.

Arp has recently written a book called *Quasars, Redshifts, and Controversies*, giving an account of his major thesis. Towards the end, he gives a painfully honest account of the way in which he was barred from using the great United States telescopes. He writes, "The six-person telescope allocation committee ... sent me an unsigned letter stating that my research was judged to be without value and that they intended to refuse allocation of further observing time."

Burbidge says: "I remember very well when Arp called and told me this. At the time I was director of Kitt Peak National Obervatory. I told him that in my experience telescope allocation committees were only advisory to directors, and I could not imagine the directors in Pasadena accepting such biassed advice. But they did, and Arp's research career in the United States abruptly ended. No responsible scientist I know, including many astronomers who are strongly opposed to Arp's thesis and many scientists outside the field, believes that justice was served."

How will this episode be seen fifty years from now? Everything depends, of course, on how far astronomy has advanced. If the 'Arp effect' is only the tip of the iceberg, then it will look very similar to the case of Alfred Wegener and Alex du Toit and the theory of continental drift. If not, then all that will be remembered will be the star atlases Arp has compiled for the scientific community.

In the May 1988 edition of *Sky and Telescope*, the following letter appeared:

> "After reading Geoffrey Burbidge's account of how Halton Arp was blacklisted for his unconventional theories about quasar redshifts, I can't help but wonder if astronomy has returned to its pre-Renaissance ways. The severe resistance to Arp's work simply appalls me. Wasn't it the rebel thinkers throughout history who broke our bonds of ignorance and rid us of our dependence on assumption?
>
> I am especially disturbed by Burbidge's remark that, in order to succeed, professional astronomers must agree with the ideas promoted by their more senior colleagues. This seems to parallel the persecution of Galileo by the Catholic Church because his ideas differed from what it wanted the people to believe. Must scientists again fear to challenge convention?
>
> Astronomers must discard their prejudice and be willing to consider new ideas and observations. With time and effort bad theories will be weeded out. Let us not allow what happened to Halton Arp to befall any other astronomers who have insights that don't suit the party line."

What do you think? Do you agree with the letter-writer? Suppose the scientific community had indeed been willing to consider new ideas, but had found Arp's theory just could not be accepted. Is this not a justifiable exercising of the scientific community's right to monitor and control in order to keep a high standard?

The materials presented in Sections 6.4 to 6.7 above are suggestions for textbook authors to consider including in their textbooks in order to try to move away from their inherent empiricist-inductivist and instrumentalist approach, towards a critical realist approach. As mentioned before, in order to do this, **the focus must shift towards the role of theory in scientific inquiry**.

6.8 The danger of science as a modern ideology

There is no doubt that Westernised society is saturated with the materialistic values of our scientific and technological era. In many ways, science today has the same mystique as religion had in medieval times: science has become an ideology (Feyerabend, in Hacking 1981, p.156). Science is being taught at schools as if it were reliable knowledge, absolute truth, and not to be criticised. There is only one scientific method, a method which is based on cold logic and closed to any creative, imaginative influence. Science is seen by many people as the panacea for overcoming all human problems. This perceived ability of science to solve all problems is called the "technological fix" by Factor and Kooser (1980). It is most obviously seen in advertising media, where the marketing of consumer products, from detergents to motor cars, from audio CD players to margarines, depends heavily on appeals to this technological fix.

Paradoxically, it was science which helped liberate mankind from ancient and rigid forms of thought. Yet science has now perhaps become as oppressive as the ideologies it once had to fight. This may to a large extent be due to the inductivist-empiricist and instrumentalist approach taken by science as entrenched in science textbooks and science education. Regretfully, much of the science, both in textbooks and as taught in classrooms, is still saturated by an outmoded view of science. This study has shown that the high school physical science textbooks in use in 1989 still reflect a philosophy of science which was criticised by Popper in 1934 and by Kuhn in 1962. **Our science education is out of line with current thought.**

There is much truth in Feyerabend's claim that modern science inhibits freedom of thought. Thus we must teach our children to think critically, and to be aware that we are immersed in and strongly influenced by the technological materialism of our age.

One concrete way of doing this is to provide guidelines in our textbooks. The textbooks should communicate the notion that science does **not** work simply by collecting facts and inferring theories from them. Theories do not necessarily follow from facts in the strict logical sense. Rather, theories shape and order facts. However, this must be done in terms of the standards agreed upon by the scientific community. But the fact remains that we **can** adopt a theory which may be "pretty lousy", as Feyerabend puts it, and which may still conflict with well-known facts, but still be better than any other theory available at the time. We **can** choose between alternative theories. This forces our mind to make imaginative choices and thus makes it grow. It makes our mind capable of choosing, imagining, and criticising.

This is a contemporary view of science, a view I strongly advocate that authors of school science textbooks should study and communicate to teachers, through their prefaces and Teacher's Guides as well as in their contextual material. For it is vital that we present an up-to-date philosophy of science to our pupils. Only by showing that science is, in fact, "a very human form of knowledge" (Bronowski 1973, p. 374), full of human judgements and creative imagination as well as rationality, will we convey to our pupils that science is worth studying and choosing as a career.

6.9 Scientific realism and science education

As personal thinking matures, the reality of things long held as real, is slowly questioned. What, then, are electrons? What are orbitals? What are photons? Indeed, even at at more elementary level, does Brownian motion "prove" that atoms or molecules exist?

Children, even when they reach the Piagetian stage of formal thought, still retain a strong belief that there is a real world outside of themselves. Of course atoms and electrons exist! Yet at first this is based on the affirmation of authority. As the critical skills of young people develops, we must be very careful not to go too fast too soon. There is a very real danger that pupils could become anxious and insecure if they try to wrestle with questions involving the reliability of their knowledge. So I believe that we must take a (critical) realist stand in science education, simply in order to help our pupils take their first steps along the path of epistemology. I realise that this is a pragmatic reason for realism, but there are more fundamental reasons, as follows.

The best argument in favour of realism in science education that I have found is that of Ian Hacking (1983) when he said: If you can shoot a beam of electrons at a target, then they are real. Photons and quarks, and other 'unobservable' entities, are real if you can actively intervene with them in an experiment in the laboratory. Thus electrons, atoms, photons, and so on, are as real as stones, and toenails, and love and pain. An electron is far more than the instrumentalist's notion that it is only a theoretical **fiction**. It is real, for it collides with my TV screen and makes it work!

Because the instrumentalist attitude in science is so convenient, it is easy to get caught up in its snares. For, in itself, it encourages rote learning, and performing calculations in a mechanical, plug-into-the-formula way. Its attempt to portray observation and experimental method as objective, helps remove science from the real life of the pupil. For children, there are many interpretations to a given observation, yet the textbook gives only one. Thus imagination is all too frequently stifled, and a passive acceptance of facts is encouraged. So instrumentalism must be complemented by a critical constructivism.

As science educators, we should not allow our pupils to leave school as passive spectators, able only to turn switches, adjust voltage levels, or check instruments.

Our pupils should be more than technologists. They should learn to become involved in and care about what they do. They should be full-blooded realists, joining in the fruitful, productive quest for knowledge. They must reject sterile, passive, instrumentalist spectatorship and gamesmanship.

I believe, with Pirsig (1974), that it is somewhere in this strange separation of realist from instrumentalist, of what man is from what man does, that we have a clue as to what has gone wrong in this twentieth century.

6.10 Conclusion

This study has investigated the following problems:

(1) Our science textbooks are instrumentalist, and are becoming increasingly so. This was confirmed by the empirical part of this study.

(2) Instrumentalism was found to be a safe retreat from the problems involving realism. Although its clean-cut method helps science to progress, its limited view of reality obstructs human knowledge.

(3) Constructivism was envisaged as a way out of the impasse caused by instrumentalism. However, constructivism and instrumentalism have the same pragmatic roots, so share in all its shortcomings, such as relativism, subjectivism and anti-realism. Is the prevalent constructivist view therefore the cure for the ills of contemporary science education?

(4) After a detailed examination of the relationship between instrumentalism and constructivism, as well as an appraisal of the characteristics of constructivism in terms of Piaget, it was concluded that the only way to overcome the problems of relativism, subjectivism, and anti-realism inherent in the constructivist approach, was to revise our notions of objectivity and reality. This was done in terms of contemporary philosophy of science, and led to critical realism.

(5) The underlying aim of the study was to try to present to pupils a better view of the nature of science and scientific method than that of the inductivist-empiricist view. The finding that critical realism provides a sound foundation and method suggests several practical strategies with regard to how textbooks can achieve these goals of science education.

Contemporary views on the nature of science differ in many important ways from the traditional views. The point of departure taken in this study was the role of theory in science, the way it is seen by instrumentalists and naive realists, the need to accommodate current views of constructivist psychology, and the resultant notion of **critical realism.**

One way of helping pupils to gain a more correct perspective on the **importance of scientific theory**, its nature, and how it grows, is through textbooks. Contemporary textbooks are empiricist and increasingly instrumentalist. Therefore it is important that pupils (and the large number of teachers who rely on textbooks - particularly in the Third Word) be given an explicit but brief account of the contrast between traditional and contemporary views of science. Also, a practical exercise such as the 'thought-experiment' of the Rutherford scattering experiment described in 6.3.1 above, may be a useful way of illustrating the role of scientific theory. Finally, the social aspect of scientific theory can be gained through the inclusion in all textbooks of one or two short enrichment readings of case studies, a simplified journal article, and a short list of recommended books as suggested in 6.3.4 above.

It is hoped that textbook authors might take some of these points to heart, and include some of them in their next editions.

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APPENDIX A

LEVELS OF INQUIRY TEXTBOOK A: Brink & Jones 8

No.	Prob-lem	Meth-od	Answer	Inqu. Level
1.1	Y	Y	Y	0
1.2	Y	Y	Y	0
2.1	Y	Y	Y	0
2.2	Y	Y	Y	0
2.3	Y	Y	Y	0
2.4	Y	Y	Y	0
2.5	Y	Y	Y	0
3.1	Y	Y	Y	0
3.2	Y	Y	Y	0
3.3	Y	Y	Y	0
4.1	Y	Y	Y	0
4.2	Y	Y	Y	0
4.3	Y	Y	Y	0
4.4	Y	Y	Y	0
4.5	Y	Y	N	1
5.1	Y	Y	Y	0
5.2	Y	Y	Y	0
5.3	Y	Y	Y	0
5.4	Y	Y	Y	0
5.5	Y	Y	Y	0
5.6	Y	Y	Y	0
5.7	Y	Y	Y	0
5.8	Y	Y	Y	0
5.9	Y	Y	Y	0
6.1	Y	Y	Y	0
6.2	Y	Y	Y	0
7.1	Y	Y	Y	0
7.2	Y	Y	Y	0
7.3	Y	Y	Y	0
7.4	Y	Y	Y	0
7.5	Y	Y	Y	0
7.6	Y	Y	Y	0
8.1	Y	Y	Y	0
8.2	Y	Y	Y	0
9.1	Y	Y	Y	0
9.2	Y	Y	Y	0
9.3	Y	Y	N	1
9.4	Y	Y	Y	0
9.5	Y	Y	Y	0
9.6	Y	Y	Y	0
10.1	Y	Y	Y	0
10.2	Y	Y	Y	0
10.3	Y	Y	Y	0
10.4	Y	Y	Y	0
11.1	Y	Y	Y	0
11.2	Y	Y	Y	0
11.3	Y	Y	N	1
15.1	Y	Y	Y	0
15.2	Y	Y	Y	0
15.3	Y	Y	Y	0
15.4	Y	Y	Y	0
15.5	Y	Y	Y	0
15.6	Y	Y	Y	0
16.1	Y	Y	Y	0
16.2	Y	Y	Y	0
16.3	Y	Y	Y	0
16.4	Y	Y	Y	0
17.1	Y	Y	Y	0
17.2	Y	Y	Y	0
18.1	Y	Y	Y	0
18.2	Y	Y	Y	0
19.1	Y	Y	Y	0
19.2	Y	Y	Y	0
19.3	Y	Y	Y	0
20.1	Y	Y	Y	0
20.2	Y	Y	Y	0

(Answers not given in lab inquiry itself, but immediately in following text.)

Level 0: 96%
" 1: 4
" 2: 0
" 3: 0

TOTAL No: 66

No.	Prob-lem	Meth-od	Answ er	Inqu. Level
1.1	Y	Y	Y	0
1.2	Y	Y	Y	0
1.3	Y	Y	Y	0
2.1	Y	Y	Y	0
2.2	Y	Y	Y	0
2.3	Y	Y	Y	0
2.4	Y	Y	Y	0
2.5	Y	Y	Y	0
2.6	Y	Y	Y	0
2.7	Y	Y	Y	0
2.8	Y	Y	Y	0
3.1	Y	Y	Y	0
3.2	Y	Y	Y	0
4.1	Y	Y	Y	0
4.2	Y	Y	N	1
4.3	Y	Y	Y	0
4.4	Y	Y	Y	0
4.5	Y	Y	Y	0
5.1	Y	Y	Y	0
6.1	Y	Y	N	1
6.2	Y	Y	Y	0
6.3	Y	Y	Y	0
6.4	Y	Y	Y	0
6.5	Y	Y	Y	0
7.1	Y	Y	Y	0
7.2	Y	Y	N	1
7.3	Y	Y	Y	0
7.4	Y	Y	Y	0
9.1	Y	Y	Y	0
9.2	Y	Y	Y	0
9.3	Y	Y	Y	0
9.4	Y	Y	Y	0
9.5	Y	Y	Y	0
9.6	Y	Y	Y	0
10.1	Y	Y	Y	0
10.2	Y	Y	Y	0
10.3	Y	Y	Y	0
10.4	Y	Y	Y	0
10.5	Y	Y	Y	0
14.1	Y	Y	N	1
14.2	Y	Y	N	1
14.3	Y	Y	Y	0
14.4	Y	Y	Y	0
14.5	Y	Y	Y	0
14.6	Y	Y	Y	0
14.7	Y	Y	Y	0
15.1	Y	Y	N	1
15.2	Y	Y	Y	0
15.3	Y	Y	Y	0
15.4	Y	Y	Y	0
16.1	Y	Y	Y	0
16.2	Y	Y	Y	0
17.1	Y	Y	Y	0
17.2	Y	Y	Y	0
17.3	Y	Y	Y	0
18.1	Y	Y	N	1
18.2	Y	Y	N	1
18.3	Y	Y	N	1
18.4	Y	Y	N	1
19.1	Y	Y	Y	0
19.2	Y	Y	Y	0

(Answers not given in lab inquiry itself, but immediately in following text.)

Level 0: 84%
" 1: 16
" 2: 0
" 3: 0

TOTAL No: 61

Page	Prob-lem	Meth-od	Answer	Inqu. Level
6	Y	Y	Y	0
8	Y	Y	Y	0
9	Y	Y	Y	0
11	Y	Y	Y	0
16	Y	Y	Y	0
19	Y	Y	Y	0
20	Y	Y	Y	0
21	Y	Y	Y	0
21	Y	Y	Y	0
22	Y	Y	Y	0
26	Y	Y	Y	0
27	Y	Y	Y	0
30	Y	Y	Y	0
31	Y	Y	Y	0
32	Y	Y	Y	0
38	Y	Y	Y	0
39	Y	Y	Y	0
44	Y	Y	Y	0
46	Y	Y	Y	0
46	Y	Y	Y	0
47	Y	Y	Y	0
48	Y	Y	Y	0
50	Y	Y	Y	0
51	Y	Y	Y	0
53	Y	Y	Y	0
53	Y	Y	Y	0
57	Y	Y	Y	0
59	Y	Y	Y	0
61	Y	Y	Y	0
63	Y	Y	Y	0
67	Y	Y	Y	0
69	Y	Y	Y	0
70	Y	Y	Y	0
71	Y	Y	Y	0
74	Y	Y	Y	0
80	Y	Y	Y	0
85	Y	Y	Y	0
93	Y	Y	Y	0
95	Y	Y	Y	0
96	Y	Y	Y	0
99	Y	Y	Y	0
100	Y	Y	Y	0
103	Y	Y	Y	0
107	Y	Y	Y	0
111	Y	Y	Y	0
114	Y	Y	Y	0
115	Y	Y	Y	0
136	Y	Y	Y	0
137	Y	Y	Y	0
138	Y	Y	Y	0
139	Y	Y	Y	0

Page	Prob-lem	Meth-od	Answer	Inqu. Level
142	Y	Y	Y	0
143	Y	Y	Y	0
146	Y	Y	N	1
147	Y	Y	N	1
151	Y	Y	Y	0
154	Y	Y	Y	0
155	Y	Y	Y	0
158	Y	Y	Y	0
165	Y	Y	N	1
166	Y	Y	Y	0
168	Y	Y	Y	0
172	Y	Y	Y	0
173	Y	Y	Y	0
178	Y	Y	N	1
179	Y	Y	N	1
183	Y	Y	Y	0
185	Y	Y	Y	0
186	Y	Y	N	1

(Answers not given in lab inquiry itself, but immediately in following text.)

Level 0: 91%
" 1: 9
" 2: 0
" 3: 0

TOTAL No: 69

LEVELS OF INQUIRY TEXTBOOK J: SEP 8

Page	Problem	Method	Answer	Inqu. Level
1	Y	Y	N	1
2	Y	Y	N	1
5	Y	Y	N	1
6	Y	Y	N	1
7	Y	Y	N	1
8	Y	Y	N	1
9	Y	Y	N	1
12	Y	Y	N	1
13	Y	Y	N	1
14	Y	Y	N	1
15	Y	Y	N	1
17	Y	Y	N	1
19	Y	Y	N	1
22	Y	Y	N	1
25	Y	Y	Y	0
28	Y	Y	N	1
30	Y	Y	Y	0
32	Y	Y	N	1
35	Y	Y	N	1
37	Y	Y	N	1
39	Y	Y	N	1
41	Y	Y	N	1
43	Y	Y	N	1
46	Y	Y	N	1
48	Y	Y	N	1
51	Y	Y	N	1
54	Y	Y	N	1
58	Y	Y	N	1
63	Y	Y	N	1
66	Y	Y	N	1
69	Y	Y	N	1
72	Y	Y	N	1
76	Y	Y	N	1
78	Y	Y	N	1
81	Y	Y	N	1
88	Y	Y	N	1
93	Y	Y	N	1
96	Y	Y	N	1
100	Y	Y	N	1
105	Y	Y	N	1
109	Y	Y	N	1
111	Y	Y	N	1
112	Y	Y	N	1
115	Y	Y	Y	0
119	Y	Y	N	1
120	Y	Y	N	1
124	Y	Y	N	1
126	Y	Y	N	1
128	Y	Y	N	1
131	Y	Y	N	1
132	Y	Y	N	1

Page	Problem	Method	Answer	Inqu. Level
135	Y	Y	N	1
137	Y	Y	N	1
141	Y	Y	N	1
146	Y	Y	N	1
150	Y	Y	N	1
153	Y	Y	N	1
159	Y	Y	N	1
161	Y	Y	N	1
166	Y	Y	N	1
168	Y	Y	N	1
170	Y	Y	N	1
172	Y	Y	N	1
174	Y	Y	N	1
179	Y	Y	N	1
183	Y	Y	N	1
186	Y	Y	N	1
191	Y	Y	N	1

Level 0: 4%
" 1: 96
" 2: 0
" 3: 0

TOTAL No: 68

Page	Prob-lem	Meth-od	Answer	Inqu. Level	
10	Y	Y	N	1	
12	Y	Y	Y	0	*
14	Y	Y	Y	0	*
17	Y	Y	Y	0	*
18	Y	Y	N	1	
20	Y	Y	N	1	
23	Y	Y	N	1	
24	Y	Y	Y	0	
26	Y	Y	Y	0	
30	Y	Y	Y	0	
37	Y	Y	Y	0	
41	Y	Y	N	1	
57	Y	Y	N	1	
60	Y	Y	Y	0	*
62	Y	Y	Y	0	
63	Y	Y	N	1	
68	Y	Y	Y	0	
71	Y	Y	Y	0	
74	Y	Y	Y	0	
78	Y	Y	N	1	
80	Y	Y	N	1	
88	Y	Y	Y	0	
100	Y	Y	N	1	
104	Y	Y	Y	0	
108	Y	Y	Y	0	
112	Y	Y	Y	0	
113	Y	Y	N	1	
116	Y	Y	N	1	
128	Y	Y	Y	0	
128	Y	Y	Y	0	
131	Y	Y	N	1	
134	Y	Y	N	1	
134	Y	Y	N	1	
158	Y	Y	Y	0	
160	Y	Y	Y	0	
167	Y	Y	Y	0	
170	Y	Y	Y	0	
173	Y	Y	Y	0	
181	Y	Y	N	1	
185	Y	Y	Y	0	
189	Y	Y	Y	0	
193	Y	Y	Y	0	
199	Y	Y	Y	0	
215	Y	Y	Y	0	
226	Y	Y	Y	0	
238	Y	Y	Y	0	
243	Y	Y	Y	0	
243	Y	Y	Y	0	

* Answers not given in prac, but given immediately after in Text.

Most of the Level 1's were calculations.
Highly computative type of practical work (eg work out your own power)

Many "see-for-yourself" type; confirmations.

Very instrumentalist.

Level 0: 67%
" 1: 33
" 2: 0
" 3: 0

TOTAL No: 48

LEVELS OF INQUIRY **TEXTBOOK R:** **Harvard: Concepts in Motion**

Page	Prob- lem	Meth- od	Answ er	Inqu. Level
134	Y	Y	N	1
142	Y	Y	N	1
144	Y	Y	N	1
145	Y	Y	Y	0
153	Y	Y	Y	0
157	Y	Y	N	1
158	Y	Y	N	1
166	Y	Y	N	1
169	Y	Y	N	1
176	Y	Y	Y	0
179	Y	N	N	2
181	Y	Y	N	1
182	Y	Y	N	1

Level 0: 23%
" 1: 69
" 2: 8
" 3: 0

TOTAL No: 13

LEVELS OF INQUIRY

RANDOM SAMPLING: (Ten pages randomly selected from each Textbook.) (x = no practical inquiry on that page)

A. Brink & Jones 8

Page	Level
9	x
218	x
16	0
189	0
87	x
100	x
15	x
202	0
244	0
240	x

B. Pienaar & Walters 8

Page	Level
188	x
315	x
40	0
319	x
285	x
92	x
147	x
234	x
203	x
326	x

C. Broster & James 8

Page	Level
16	0
189	x
87	x
100	1
15	x
55	x
40	x
79	x
80	0
188	x

D. Brink & Jones 9

Page	Level
204	x
188	0
312	x
40	0
285	x
92	0
146	x
234	x
109	x
85	x

E. Pienaar & Walters 9

Page	Level
316	x
100	0
210	x
19	0
344	0
96	x
338	0
260	0
51	0
50	0

F. Broster & James 9

Page	Level
100	x
15	x
202	0
55	x
40	0
79	0
80	x
77	x
207	0
188	x

G. Brink & Jones 10

Page	Level
204	x
188	x
31	x
40	0
82	x
92	1
146	0
234	1
109	0
89	x

H. Pienaar & Walters 10

Page	Level
12	x
101	x
210	x
22	x
204	x
97	x
110	x
260	0
51	x
50	x

I. Broster & James 10

Page	Level
100	x
14	x
202	x
55	x
42	x
79	1
82	x
64	x
208	1
188	x

J. SEP 8

Page	Level
26	0
11	1
163	1
94	1
8	1
102	1
49	1
17	1
189	2
87	1

K. Duncan: GCSE Physics

Page	Level
50	1
51	x
260	x
96	x
19	0
210	x
99	x
252	x
179	x
80	0

L. Pople & Williams: Sci to 16

Page	Level
82	x
107	x
45	x
116	x
22	x
92	x
218	x
40	x
204	x
187	x

M. Atherton et al

Page	Level
379	x
242	x
204	0
151	x
182	0
240	0
35	1
342	0
252	0
55	0

N. Lewis & Waller

Page	Level
340	x
203	x
326	x
85	x
277	x
140	x
374	x
21	x
42	x
37	x

O. Pople: Explaining Phys

Page	Level
77	x
207	x
240	x
188	x
109	x
114	x
151	x
182	x
51	x
32	x

P. Warren: Physics Alive

Page	Level
21	x
42	0
37	x
189	0
14	0
155	0
137	1
187	1
190	0
221	0

Q. Lambert: Physics

Page	Level
94	0
249	x
26	1
8	x
228	0
218	x
102	2
90	1
49	x
243	0

R. Harvard Project Physics

Page	Level
21	x
43	x
37	x
179	2
14	1
153	1
137	1
177	1
85	x
48	x

S. Chemistry: CHEM Study

Page	Level
448	x
91	1
342	x
9	x
62	1
283	x
218	x
16	x
51	1
150	x

T. Physics: PSSC

Page	Level
109	0
114	x
151	x
182	x
450	x
240	x
487	x
33	0
342	x
252	x

U. Nigerian Physics

Page	Level
10 Bk 1	x
14 "	0
59 "	1
82 Bk 2	x
47 "	0
24 "	x
140 "	x
33 Bk 3	0
42 "	x
52 "	x

V. Kenyan Physics

Page	Level
91 Bk 1	0
14 "	x
51 "	0
82 Bk 2	0
45 "	1
24 "	0
7 Bk 3	0
33 "	x
34 Bk 4	x
25 "	x

W. Jansen & Dekker

Page	Level
18 Std 6	x
14 "	0
51 "	0
82 "	0
45 "	x
24 Std 7	0
7 "	x
75 "	x
114 "	1
59 "	x

SUMMARY OF SAMPLED LABORATORY INQUIRIES

	TEXTBOOK																						
Level	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
0	4	1	2	3	7	4	3	1	0	0	2	0	6	0	0	6	3	0	0	2	3	5	4
1	0	0	1	0	0	0	1	0	2	8	1	0	1	0	0	2	2	4	3	0	1	1	1
2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Level	Total	%
Overall		87	
	0	56	64
	1	28	32
	2	3	4
	3	0	0
South African		38	
	0	25	66
	1	12	31
	2	1	3
	3	0	0
British		24	
	0	17	71
	1	6	25
	2	1	4
	3	0	0
American		10	
	0	2	20
	1	7	70
	2	1	10
	3	0	0
African		15	
	0	12	80
	1	3	20
	2	0	0
	3	0	0

APPENDIX B

Brink & Jones 8 (1)	Lvl	1.1	1.2	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1
		Laboratory Inquiry No.										
1. Recognise & def. problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn.& meas. procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	0	1	1	1	1	1	1	1
8. Transform rslts. to std. forms		0	0	0	0	0	0	0	0	0	0	0
9. Explain		0	1	1	0	1	0	1	1	1	1	1
10. Make inferences		0	1	1	1	1	0	0	1	1	1	0
11. Form generalis-ations, models	1	1	1	1	0	1	1	0	1	1	1	1
12. Define limits, assumptions		0	0	0	0	0	0	1	0	0	0	0
13. Learn technique		0	1	1	0	0	0	1	0	0	0	1
14. Perform quanti-tative work	0	0	1	0	0	0	0	1	0	0	0	0
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0		1.1	1.2	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1
x	0 (Max 5)	2	4	3	1	2	2	4	2	2	2	3
	1 (" 4)	1	3	3	1	3	1	2	3	3	3	2
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
y	0	1	1	1	0	1	1	1	1	1	1	1
	1	0	1	1	0	1	0	1	1	1	1	1
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:		0	1	1	0	1	0	1	1	1	1	1

Brink & Jones 8 (2)	Lvl	4.2	4.3	4.4	4.5	5.1	5.2	5.3	5.4	5.5	5.6	5.7
		Laboratory Inquiry No.										
1. Recognise & def. problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	1	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	1
4. Design observn & meas. procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	0	0	1	0	0	1	1	1	0
8. Transform rslts to std forms		0	1	0	0	0	0	0	0	1	0	0
9. Explain		0	0	0	0	1	0	1	1	0	0	0
10. Make inferences		0	0	0	1	1	0	1	1	1	1	1
11. Form generalis-ations or models	1	0	1	0	1	1	1	1	1	0	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	0	0	0	0	0	1	1	0	0
14. Perform quanti-tative work	0	1	1	0	0	0	0	0	0	1	1	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum.	x 0	(Max 5)	4	5	1	1	2	1	1	3	5	3	1
If x>=0,4 let y=1.	1	(" 4)	0	1	0	2	3	1	3	3	1	2	2
If x<0,4 let y=0	2	(" 4)	0	0	0	0	0	0	0	0	0	0	0
	3	(" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0		1	1	0	0	1	0	0	1	1	1	0
	1		0	0	0	1	1	0	1	1	0	1	1
	2		0	0	0	0	0	0	0	0	0	0	0
	3		0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:			0	0	0	0	1	0	0	1	0	1	0

Brink & Jones 8 (3)	Lvl	Laboratory Inquiry No. 5.8	5.9	6.1	6.2	7.1	7.2	7.3	7.4	7.5	7.6	8.1
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas. procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	1	1	0	0	0	0	0	0	0
9. Explain		0	0	1	0	0	0	0	0	0	0	0
10. Make inferences		1	1	1	1	1	1	1	0	0	0	0
11. Form generalis-ations or models	1	1	1	0	0	1	1	1	1	1	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		0	0	0	0	0	0	0	0	0	0	0
14. Perform quanti-tative work	0	0	0	1	1	1	1	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	2	2	4	4	3	3	2	2	2	2	2
	1 (" 4)	2	2	2	1	2	2	2	1	1	1	1
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	0	1	1	1	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	1	1	1	0	1	1	1	0	0	0	0

Brink & Jones 8 (4)	Lvl	Laboratory Inquiry No. 8.2	9.1	9.2	9.3	9.4	9.5	9.6	10.1	10.2	10.3	10.4
1. Recognise & def. problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas. procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	0	1	1	1	1	1	1	1	1	1
7.Record results	0	1	0	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	0	0	0	0	0	0	0
9. Explain		1	0	0	0	0	0	0	0	0	0	0
10. Make inferences		1	0	0	0	0	0	0	0	1	0	1
11. Form generalis-ations or models	1	1	0	1	1	1	1	1	1	1	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		0	1	1	1	1	1	1	0	1	0	1
14. Perform quanti-tative work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	2	1	3	3	3	3	3	2	3	2	3
	x 1 (" 4)	3	0	1	1	1	1	1	1	2	1	2
	x 2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0	1	0	1	1	1	1	1	1	1	1	1
	y 1	1	0	0	0	0	0	0	0	1	0	1
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	1	0	0	0	0	0	0	0	1	0	1

Brink & Jones 8 (5)	Lvl	Laboratory Inquiry No. 11.1	11.2	11.3	15.1	15.2	15.3	15.4	15.5	15.6	16.1	16.2
1. Recognise & def problem	2	0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas. procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	0	0	0	1	1	1	1	1	1	1	1
7. Record results		1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	0	0	0	0	0	0	0
9. Explain	1	0	0	0	0	0	0	0	0	0	0	1
10. Make inferences		1	1	1	1	0	0	0	0	1	1	1
11. Form generalis- ations or models		0	0	0	1	1	1	1	1	0	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	0	0	0	1	0	0	0	1	1	0	1
14. Perform quanti- tative work		0	0	0	0	0	0	0	0	1	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

		11.1	11.2	11.3	15.1	15.2	15.3	15.4	15.5	15.6	16.1	16.2
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	1	1	1	3	2	2	2	3	4	2	3
	x 1 (" 4)	1	1	1	2	1	1	1	1	1	2	3
	x 2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0	0	0	0	1	1	1	1	1	1	1	1
	y 1	0	0	0	1	0	0	0	0	0	1	1
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	0	0	1	0	0	0	0	0	1	1

Brink & Jones 8 (6)	Lvl	16.3	16.4	17.1	17.2	18.1	18.2	19.1	19.2	19.3	20.1	20.2
		Laboratory Inquiry No.										
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	1	0	1	0	0	0	1	0
9. Explain		1	0	0	0	1	1	0	0	0	1	0
10. Make inferences		1	1	0	1	1	1	1	1	0	1	0
11. Form generalis-ations, models	1	1	0	1	1	0	0	1	1	0	0	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		0	1	0	0	0	0	0	0	0	0	0
14. Perform quanti-tative work	0	0	0	0	0	0	1	1	1	1	1	1
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

Divide each	x 0 (Max 5)	2	3	2	3	2	4	3	3	3	4	3
total by	x 1 (" 4)	3	1	1	2	2	2	2	2	0	2	0
maximum.	x 2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
let y=1.												
If x<0,4	y 0	1	1	1	1	1	1	1	1	1	1	1
let y=0	y 1	1	0	0	1	1	1	1	1	0	1	0
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
Result A:	LEVEL:	1	0	0	1	1	1	1	1	0	1	0

RESULTS: TASK ANALYSIS OF LABORATORY INQUIRIES — Textbook A

Brink & Jones 8	Lvl	Totals across 66	%	Collective Totals B
1. Recognise and define	2	0	0	1
2. Formulate hypothesis		1	2	
3. Predict		0	0	
4. Design observation and measurement procedures		0	0	
5. Design experiments	3	0	0	0
6. Carry out observations, measurements, experiments	0	62	94	127
7.Record results, describe		58	88	
8. Transform results into standard forms		7	11	
9. Explain	1	18	27	106
10. Make inferences		39	59	
11. Formulate generalisations or models		48	73	
12. Define limitations or assumptions		1	2	
13. Learn techniques	0	21	32	38
14. Perform quantitative work		17	26	
15. Perform "dry" lab inquiries	3	0	0	0
16. Work according to own design		0	0	

RESULT A: (Columns)

	Number	Total	%
Level 0:	36	66	55
Level 1:	30	66	45
Level 2:	0	66	0
Level 3:	0	66	0

RESULT B: (Rows)

	Number	Total	%
Level 0:	165	330	50
Level 1:	106	264	40
Level 2:	1	264	0
Level 3:	0	198	0

Pienaar & W. 8 (1)	Lvl	Laboratory Inquiry No. 1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	0	0	1	1	1	1	1
7.Record results	0	1	1	1	1	0	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	1	1	1	0	0	0	0
9. Explain		0	0	0	0	0	1	0	1	1	0	0
10. Make inferences		0	1	1	0	0	0	0	1	0	0	1
11. Form generalis- ations, models	1	1	0	0	1	0	1	0	0	0	0	0
12. Define limits, assumptions		0	0	1	0	0	0	0	0	0	0	0
13. Learn technique		0	1	0	0	1	1	1	0	0	0	0
14. Perform quanti- tative work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. x 0	(Max 5)	2	4	2	1	2	3	4	2	2	2	2
x 1	(" 4)	1	1	2	1	0	2	0	2	1	0	1
x 2	(" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4 let y=1. x 3	(" 3)	0	0	0	0	0	0	0	0	0	0	0
If x<0,4 let y=0 y 0		1	1	1	0	1	1	1	1	1	1	1
y 1		0	0	1	0	0	1	0	1	0	0	0
y 2		0	0	0	0	0	0	0	0	0	0	0
y 3		0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:		0	0	1	0	0	1	0	1	0	0	0

Pienaar & W. 8 (2)	Lvl	3.1	3.2	4.1	4.2	4.3	4.4	4.5	5.1	6.1	6.2	6.3
		Laboratory Inquiry No.										
1. Recognise & def problem	2	0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict	2	0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures	2	0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms	0	0	1	0	0	1	0	0	0	0	0	0
9. Explain	1	0	0	0	1	0	0	1	0	0	0	0
10. Make inferences	1	0	1	1	1	0	1	1	0	1	1	1
11. Form generalis-ations, models	1	0	0	1	1	0	1	0	1	0	1	1
12. Define limits, assumptions	1	0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	0	1	0	0	1	1	0	1	0	0	1
14. Perform quanti-tative work	0	0	0	0	0	1	0	0	0	0	0	0
15. Perform "dry" inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0

		3.1	3.2	4.1	4.2	4.3	4.4	4.5	5.1	6.1	6.2	6.3
x	0 (Max 5)	2	4	2	2	5	3	2	3	2	2	2
x	1 (" 4)	0	1	2	3	0	2	2	1	1	2	2
x	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
x	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0

		3.1	3.2	4.1	4.2	4.3	4.4	4.5	5.1	6.1	6.2	6.3
y	0	1	1	1	1	1	1	1	1	1	1	1
y	1	0	0	1	1	0	1	1	0	0	1	1
y	2	0	0	0	0	0	0	0	0	0	0	0
y	3	0	0	0	0	0	0	0	0	0	0	0
LEVEL:		0	0	1	1	0	1	1	0	0	1	1

Pienaar & W. 8 (3)	Lvl	6.4	6.5	7.1	7.2	7.3	7.4	9.1	9.2	9.3	9.4	9.5
		Laboratory Inquiry No.										
1. Recognise & def problem	2	0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7.Record results		1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	0	0	0	0	0	0	0
9. Explain	1	0	0	1	0	0	0	0	0	0	0	0
10. Make inferences		1	1	1	1	1	0	0	0	0	0	0
11. Form generalis-ations, models		1	0	1	1	0	1	1	1	1	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	0	0	0	0	0	0	1	1	1	1	1
14. Perform quanti-tative work		0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0

		6.4	6.5	7.1	7.2	7.3	7.4	9.1	9.2	9.3	9.4	9.5
x	0 (Max 5)	2	2	2	2	2	2	3	3	3	3	3
	1 (" 4)	2	1	3	2	1	1	1	1	1	1	1
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
y	0	1	1	1	1	1	1	1	1	1	1	1
	1	1	0	1	1	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
LEVEL:		1	0	1	1	0	0	0	0	0	0	0

Pienaar & W. 8 (4)	Lvl	Laboratory Inquiry No. 9.6	10.1	10.2	10.3	10.4	10.5	14.1	14.2	14.3	14.4	14.5
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	0	0	0	0	0	0	0
9. Explain		0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	0	0	0	0	0	0	0	0	0	0
11. Form generalis-ations, models	1	1	1	1	1	1	1	1	1	1	0	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	0	0	1	0	0
14. Perform quanti-work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0		9.6	10.1	10.2	10.3	10.4	10.5	14.1	14.2	14.3	14.4	14.5
x	0 (Max 5)	3	3	3	3	3	3	2	2	3	2	2
	1 (" 4)	1	1	1	1	1	1	1	1	1	0	0
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
y	0	1	1	1	1	1	1	1	1	1	1	1
	1	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
LEVEL:		0	0	0	0	0	0	0	0	0	0	0

Pienaar & W. 8 (5)	Lvl	14.6	14.7	15.1	15.2	15.3	15.4	16.1	16.2	17.1	17.2	17.3
		Laboratory Inquiry No.										
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7. Record results	0	1	1	1	1	1	1	1	1	0	0	1
8. Transform rslts to std forms		0	0	0	0	0	0	0	0	0	0	0
9. Explain		0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	0	0	0	0	0	1	0	0	0	1
11. Form generalis-ations, models	1	0	0	1	1	0	0	1	1	1	1	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		0	0	0	0	0	0	0	0	0	0	0
14. Perform quanti-tative work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

		14.6	14.7	15.1	15.2	15.3	15.4	16.1	16.2	17.1	17.2	17.3
Divide each total by maximum.	x 0 (Max 5)	2	2	2	2	2	2	2	2	1	1	2
If x>=0,4	x 1 (" 4)	0	0	1	1	0	0	2	1	1	1	1
let y=1.	x 2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x<0,4	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
let y=0	y 0	1	1	1	1	1	1	1	1	0	0	1
	y 1	0	0	0	0	0	0	1	0	0	0	0
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	0	0	0	0	0	1	0	0	0	0

Pienaar & Walters 8 (6)	Lvl	18.1	18.2	18.3	18.4	19.1	19.2
		Laboratory Inquiry No.					
1. Recognise and define problem	2	0	0	0	0	0	0
2. Formulate hypothesis		0	0	0	0	0	0
3. Predict		0	0	0	0	0	0
4. Design observation and measurement procedures		0	0	0	0	0	0
5. Design experiments	3	0	0	0	0	0	0
6. Carry out observations, measurements, experiments	0	1	1	1	1	1	1
7. Record results, describe		1	1	1	1	1	1
8. Transform results into standard forms		0	0	1	1	1	1
9. Explain	1	0	0	0	0	1	0
10. Make inferences		1	1	0	0	1	0
11. Formulate generalisations or models		1	1	0	0	1	0
12. Define limitations or assumptions		0	0	0	0	0	0
13. Learn techniques	0	0	0	1	1	1	1
14. Perform quantitative work		0	0	1	1	0	1
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0
16. Work according to own design		0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0		18.1	18.2	18.3	18.4	19.1	19.2
x	{ 0 (Max 5)	2	2	5	5	4	5
	{ 1 (" 4)	2	2	0	0	3	0
	{ 2 (" 4)	0	0	0	0	0	0
	{ 3 (" 3)	0	0	0	0	0	0
y	{ 0	1	1	1	1	1	1
	{ 1	1	1	0	0	1	0
	{ 2	0	0	0	0	0	0
	{ 3	0	0	0	0	0	0
Results A:	LEVEL:	1	1	0	0	1	0

RESULTS: TASK ANALYSIS OF LABORATORY INQUIRIES   Textbook B

Pienaar & Walters 8	Lvl	Totals across 61	%	Collective Totals B
1. Recognise and define	2	0	0	0
2. Formulate hypothesis		0	0	
3. Predict		0	0	
4. Design observation and measurement procedures		0	0	
5. Design experiments	3	0	0	0
6. Carry out observations, measurements, experiments	0	59	97	126
7.Record results, describe		58	95	
8. Transform results into standard forms		9	15	
9. Explain	1	7	11	66
10. Make inferences		22	36	
11. Formulate generalisations or models		36	59	
12. Define limitations or assumptions		1	1	
13. Learn techniques	0	24	39	29
14. Perform quantitative work		5	8	
15. Perform "dry" lab inquiries	3	0	0	0
16. Work according to own design		0	0	

RESULT A: (Columns)

	Number	Total	%
Level 0:	45	61	74
Level 1:	16	61	26
Level 2:	0	61	0
Level 3:	0	61	0

RESULT B: (Rows)

	Number	Total	%
Level 0:	155	305	51
Level 1:	66	244	27
Level 2:	0	244	0
Level 3:	0	183	0

Broster & J. 8 (1)	Lvl	6	8	9	11	16	19	20	21	21	22	26
		Laboratory Inquiry Page No.										
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict	2	0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	0	0	1	0	0	0	0
9. Explain		0	0	0	0	0	0	0	1	1	1	0
10. Make inferences		0	0	0	0	1	1	0	0	0	1	0
11. Form generalis-ations, models	1	0	0	0	0	1	1	1	0	0	0	1
12. Define limits assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	0	1
14. Perform quanti-tative work	0	1	1	0	0	0	0	1	0	0	0	0
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. x 0	(Max 5)	4	4	3	3	3	3	4	3	3	2	3
x 1	(" 4)	0	0	0	0	2	2	1	1	1	2	1
x 2	(" 4)	0	0	0	0	0	0	0	0	0	0	0
x 3	(" 3)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4 let y=1. If x<0,4 let y=0. y 0		1	1	1	1	1	1	1	1	1	1	1
y 1		0	0	0	0	1	1	0	0	0	1	0
y 2		0	0	0	0	0	0	0	0	0	0	0
y 3		0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:		0	0	0	0	1	1	0	0	0	1	0

Broster & J. 8 (2)	Lvl	Laboratory Inquiry No. 27	30	31	32	38	39	44	46	46	47	48
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	0	0	0	0	1	1
8. Transform rslts to std forms		0	1	1	1	0	0	0	0	0	1	0
9. Explain		0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	1	0	0	0	0	0	0	0	0	0
11. Form generalis-tions, models	1	1	0	0	0	1	1	1	1	1	0	1
12. Define limit or assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-tative work	0	0	0	1	1	0	0	0	0	0	1	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. x 0 (Max 5)		3	4	5	5	3	2	2	2	2	5	3
x 1 (" 4)		1	1	0	0	1	1	1	1	1	0	1
x 2 (" 4)		0	0	0	0	0	0	0	0	0	0	0
If x>=0,4 let y=1. x 3 (" 3)		0	0	0	0	0	0	0	0	0	0	0
If x<0,4 let y=0 y 0		1	1	1	1	1	1	1	1	1	1	1
y 1		0	0	0	0	0	0	0	0	0	0	0
y 2		0	0	0	0	0	0	0	0	0	0	0
y 3		0	0	0	0	0	0	0	0	0	0	0
LEVEL:		0	0	0	0	0	0	0	0	0	0	0

Broster & J. 8 (3)	Lvl	Laboratory Inquiry No. 50	51	53	53	57	59	61	63	67	69	70
1. Recognise & def problem	2	0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7. Record results		1	1	1	1	1	1	1	1	0	1	1
8. Transform rslts to std forms		0	0	0	0	0	1	1	1	0	0	1
9. Explain	1	0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	0	0	0	0	0	0	0	1	0	0
11. Form generalis-ations, models		1	0	1	1	1	1	1	1	0	0	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	1	1	1	1	1	1	1	1	1	1	0
14. Perform quanti-tative work		0	0	0	0	0	1	1	1	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. x 0 (Max 5)		3	3	3	3	3	5	5	5	2	3	3
x 1 (" 4)		1	1	1	1	1	1	1	1	0	1	1
x 2 (" 4)		0	0	0	0	0	0	0	0	0	0	0
x 3 (" 3)		0	0	0	0	0	0	0	0	0	0	0
If x>=0,4 let y=1. If x<0,4 let y=0. y 0		1	1	1	1	1	1	1	1	1	1	1
y 1		0	0	0	0	0	0	0	0	0	0	0
y 2		0	0	0	0	0	0	0	0	0	0	0
y 3		0	0	0	0	0	0	0	0	0	0	0
LEVEL:		0	0	0	0	0	0	0	0	0	0	0

Broster & J. 8 (4)	Lvl	71	74	80	85	93	95	96	99	100	103	107
		Laboratory Inquiry Page No.										
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts lab std forms		0	0	0	0	1	0	1	0	0	1	1
9. Explain		0	0	0	0	0	0	1	0	0	0	1
10. Make inferences		0	0	0	0	0	0	0	0	0	0	1
11. Form generalis-ations, models	1	1	1	1	1	0	1	1	1	0	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		0	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-tative work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

			71	74	80	85	93	95	96	99	100	103	107
Divide each		0 (Max 5)	2	3	3	3	4	3	4	3	3	4	4
total by	x	1 (" 4)	1	1	1	1	0	1	2	1	0	1	3
maximum.		2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4		3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
let y=1.													
If x<0,4		0	1	1	1	1	1	1	1	1	1	1	1
let y=0	y	1	0	0	0	0	0	0	1	0	0	0	1
		2	0	0	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0	0	0
		LEVEL:	0	0	0	0	0	0	1	0	0	0	1

Broster & J. 8 (5)	Lvl	Laboratory Inquiry Page No. 111	114	115	136	137	138	139	142	143	146	147
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	1	0	1	1	0	0	1	1	0
9. Explain		1	1	1	0	1	0	0	1	1	1	1
10. Make inferences		0	0	1	1	1	0	0	1	1	1	0
11. Form generalis- ations, models	1	1	0	1	1	1	1	0	1	1	1	0
12. Define limits assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti- tative work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum.	x 0 (Max 5)	3	3	4	3	4	4	3	3	4	4	3
	1 (" 4)	2	1	3	2	3	1	0	3	3	3	1
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4 let y=1.	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
If x<0,4 let y=0	y 0	1	1	1	1	1	1	1	1	1	1	1
	1	1	0	1	1	1	0	0	1	1	1	0
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	1	0	1	1	1	0	0	1	1	1	0

		Laboratory Inquiry Page No.										
Broster & J. 8 (6)	Lvl	151	154	155	158	165	166	168	172	173	178	179
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	1	1	0	0	0	1	1	1	1
9. Explain		1	0	1	0	0	0	0	0	0	0	0
10. Make inferences		0	0	1	1	0	0	0	1	1	1	1
11. Form generalis-ations, models	1	0	0	1	0	0	0	0	1	1	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-tative work	0	0	0	0	0	0	0	0	1	1	1	1
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each	x	0 (Max 5)	3	3	4	4	3	3	3	5	5	5	5
total by		1 (" 4)	1	0	3	1	0	0	0	2	2	2	2
maximum.		2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4		3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
let y=1.													
If x<0,4	y	0	1	1	1	1	1	1	1	1	1	1	1
let y=0		1	0	0	1	0	0	0	0	1	1	1	1
		2	0	0	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:			0	0	1	0	0	0	0	1	1	1	1

Broster & James 8 (7)	Lvl	Lab Inq Pg No. 183	185	186
1. Recognise and define problem	2	0	0	0
2. Formulate hypothesis		0	0	0
3. Predict		0	0	0
4. Design observation and measurement procedures		0	0	0
5. Design experiments	3	0	0	0
6. Carry out observations, measurements, experiments	0	1	1	1
7.Record results, describe		1	1	1
8. Transform results into standard forms		1	1	1
9. Explain	1	1	0	0
10. Make inferences		1	0	1
11. Formulate generalisations or models		0	0	1
12. Define limitations or assumptions		0	0	0
13. Learn techniques	0	1	1	1
14. Perform quantitative work		0	0	1
15. Perform "dry" lab inquiries	3	0	0	0
16. Work according to own design		0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0

		183	185	186
x	0 (Max 5)	4	4	5
	1 (" 4)	2	0	2
	2 (" 4)	0	0	0
	3 (" 3)	0	0	0
y	0	1	1	1
	1	1	0	1
	2	0	0	0
	3	0	0	0
OVERALL LEVEL:		1	0	1

RESULTS: TASK ANALYSIS OF LABORATORY INQUIRIES Textbook C

Broster & James 8	Lvl	Totals across 69	%	Collective Totals B
1. Recognise and define		0	0	
2. Formulate hypothesis		0	0	
3. Predict	2	0	0	0
4. Design observation and measurement procedures		0	0	
5. Design experiments	3	0	0	0
6. Carry out observations, measurements, experiments		53	77	
7. Record results, describe	0	44	64	109
8. Transform results into standard forms		12	17	
9. Explain		16	23	
10. Make inferences		22	32	
11. Formulate generalisations or models	1	43	62	81
12. Define limitations or assumptions		0	0	
13. Learn techniques		66	96	
14. Perform quantitative work	0	14	20	80
15. Perform "dry" lab inquiries		0	0	
16. Work according to own design	3	0	0	0

RESULT A: (Columns)

	Number	Total	%
Level 0:	50	69	73
Level 1:	19	69	27
Level 2:	0	69	0
Level 3:	0	69	0

RESULT B: (Rows)

	Number	Total	%
Level 0:	189	345	55
Level 1:	81	276	29
Level 2:	0	276	0
Level 3:	0	138	0

SEP 8 (1)	Lvl	1	2	5	6	7	8	9	12	13	14	15
		Laboratory Inquiry Page No.										
1. Recognise & def problem		0	0	0	0	0	0	1	1	1	1	1
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	1	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	0	1	1	0
7.Record results	0	1	1	1	1	1	1	1	0	1	1	0
8. Transform rslts to std forms		0	0	0	0	0	0	0	1	0	0	1
9. Explain		1	0	0	0	0	0	0	0	0	1	0
10. Make inferences		1	1	1	1	1	1	1	1	1	1	1
11. Form generalis-ations, models	1	0	0	0	0	0	0	0	0	0	0	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	0	1	1	1	0
14. Perform quanti-tative work	0	0	1	1	1	0	1	1	0	0	1	1
15. Perform "dry" lab inquiries		0	0	0	0	0	0	1	0	0	1	1
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0		1	2	5	6	7	8	9	12	13	14	15
x	0 (Max 5)	3	4	4	4	3	4	3	2	3	4	2
	1 (" 4)	2	1	1	1	1	1	1	1	1	2	1
	2 (" 4)	0	0	0	0	0	0	1	1	1	2	1
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
y	0	1	1	1	1	1	1	1	1	1	1	1
	1	1	0	0	0	0	0	0	0	0	1	0
	2	0	0	0	0	0	0	0	0	0	1	0
	3	0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:		1	0	0	0	0	0	0	0	0	2	0

SEP 8 (2)	Lvl	17	19	22	25	28	30	32	35	37	39	41
		Laboratory Inquiry Page No.										
1. Recognise & def problem		1	1	1	1	0	1	0	1	1	1	1
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	1	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		0	1	1	1	1	1	1	1	1	1	1
7.Record results	0	0	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		1	0	0	0	0	0	1	0	0	0	1
9. Explain		0	0	1	0	0	0	0	0	0	0	1
10. Make inferences		1	0	0	0	0	0	1	1	1	0	1
11. Form generalis-ations, models	1	0	0	0	0	0	0	0	0	0	0	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		0	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-tative work	0	1	0	0	0	0	0	1	0	0	0	0
15. Perform "dry" lab inquiries	3	1	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	2	3	3	3	3	3	5	3	3	3	3
	x 1 (" 4)	1	0	1	0	0	0	1	1	1	0	3
	x 2 (" 4)	1	1	1	1	0	1	0	1	1	1	1
	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0	1	1	1	1	1	1	1	1	1	1	1
	y 1	0	0	0	0	0	0	0	0	0	0	1
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	0	0	0	0	0	0	0	0	0	1

SEP 8 (3)	Lvl	43	46	48	51	54	58	63	66	69	72	76
		Laboratory Inquiry Page No.										
1. Recognise & def problem	2	1	1	1	1	1	1	1	0	0	1	1
2. Form hypothesis	2	1	0	1	0	0	0	0	0	0	1	0
3. Predict	2	0	0	0	0	0	0	1	0	0	0	0
4. Design observn & meas procedures	2	0	0	0	0	0	0	1	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7. Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms	0	0	1	0	0	0	1	1	0	1	1	0
9. Explain	1	1	1	1	0	0	0	1	0	0	1	1
10. Make inferences	1	1	1	1	0	0	1	1	0	0	1	0
11. Form generalis-ations, models	1	0	0	0	0	0	0	0	0	0	0	0
12. Define limits, assumptions	1	0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-tative work	0	0	0	0	0	0	1	1	0	0	1	1
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0		43	46	48	51	54	58	63	66	69	72	76
x	0 (Max 5)	3	4	3	3	3	5	5	3	4	5	4
x	1 (" 4)	2	2	2	0	0	1	2	0	0	2	1
x	2 (" 4)	2	1	2	1	1	1	3	0	0	2	1
x	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
y	0	1	1	1	1	1	1	1	1	1	1	1
y	1	1	1	1	0	0	0	1	0	0	1	0
y	2	1	0	1	0	0	0	1	0	0	1	0
y	3	0	0	0	0	0	0	0	0	0	0	0
LEVEL:		2	1	2	0	0	0	2	0	0	2	0

SEP 8 (4)	Lvl	78	81	88	93	96	100	105	109	111	112	115
		Laboratory Inquiry Page No.										
1. Recognise & def problem		1	0	1	1	1	1	1	1	1	1	1
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	1	1	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	1	0	0	0	0	1	0
5. Design expts	3	0	0	0	0	1	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		1	0	0	0	1	0	0	1	1	0	1
9. Explain		1	0	0	0	0	1	1	0	0	1	0
10. Make inferences		1	0	1	1	1	1	1	0	0	0	1
11. Form generalis-ations, models	1	0	0	1	1	1	0	0	1	1	0	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	0	0	1	1
14. Perform quanti-tative work	0	1	0	0	0	1	0	0	0	0	0	0
15. Perform "dry" lab inquiries		0	0	0	0	0	0	0	0	0	0	0
16. Work to own design	3	0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0		78	81	88	93	96	100	105	109	111	112	115
x	0 (Max 5)	5	3	3	3	5	3	3	3	3	3	4
	1 (" 4)	2	0	2	2	1	2	2	1	1	1	1
	2 (" 4)	0	0	2	2	2	1	1	1	1	1	1
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
y	0	1	1	1	1	1	1	1	1	1	1	1
	1	1	0	1	1	1	1	1	0	0	0	0
	2	0	0	1	1	1	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	1	0	2	2	2	1	1	0	0	0	0

SEP 8 (5)	Lvl	119	120	124	126	128	131	132	135	137	141	146
		Laboratory Inquiry Page No.										
1. Recognise & def problem		1	1	1	1	1	1	1	1	1	1	1
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		1	0	1	1	1	1	1	1	0	0	1
9. Explain		0	0	0	0	0	0	0	0	1	0	1
10. Make inferences		1	1	0	0	1	1	1	1	1	1	1
11. Form generalis-ations, models	1	0	1	0	0	0	0	0	0	1	0	1
12. Define limits, assumptions		0	1	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-tative work	0	0	0	0	0	0	0	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	1	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each	x 0 (Max 5)	4	3	4	4	4	4	4	4	3	3	4
total by	x 1 (" 4)	1	3	0	0	1	1	1	1	3	1	3
maximum.	x 2 (" 4)	1	1	1	1	1	1	1	1	1	1	1
If x>=0,4	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
let y=1.												
If x<0,4	y 0	1	1	1	1	1	1	1	1	1	1	1
let y=0	y 1	0	1	0	0	0	0	0	0	1	0	1
	y 2	0	0	0	0	0	0	0	0	0	1	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	1	0	0	0	0	0	0	1	0	1

SEP 8 (6)	Lvl	150	153	159	161	166	168	170	172	174	179	183
		Laboratory Inquiry Page No.										
1. Recognise & def problem	2	1	1	1	1	1	1	1	1	1	1	1
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	1	0	0	0	0	1	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	1	0	0	0
5. Design expts	3	1	0	0	0	0	0	0	1	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7.Record results		1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	1	0	0	0	1	1	1	1
9. Explain	1	1	1	1	0	0	0	0	1	0	0	1
10. Make inferences		1	1	1	1	0	0	0	1	1	1	1
11. Form generalis-ations, models		0	0	0	1	0	0	0	0	1	1	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti-work		0	0	0	0	0	0	0	0	1	1	1
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0 — x 0	(Max 5)	3	3	3	4	3	3	3	4	5	5	5
x 1	(" 4)	2	2	2	2	0	0	0	2	2	2	3
x 2	(" 4)	1	1	2	1	1	1	1	3	1	1	1
x 3	(" 3)	1	0	0	0	0	0	0	1	0	0	0
y 0		1	1	1	1	1	1	1	1	1	1	1
y 1		1	1	1	1	0	0	0	1	1	1	1
y 2		0	0	1	0	0	0	0	1	0	0	0
y 3		1	0	0	0	0	0	0	1	0	0	0
LEVEL:		2	1	2	0	0	0	2	1	1	1	1

SEP 8 (7)	Level	Lab Inq Page No 186	191
1. Recognise & define problem		1	1
2. Formulate hypothesis	2	0	0
3. Predict		0	0
4. Design observation and measurement procedures		0	0
5. Design experiments	3	0	0
6. Carry out observations, measurements, experiments		1	1
7. Record results, describe	0	1	1
8. Transform results into standard forms		1	1
9. Explain		1	0
10. Make inferences		1	0
11. Formulate generalisations or models	1	1	0
12. Define limitations or assumptions		0	0
13. Learn techniques		1	1
14. Perform quantitative work	0	1	1
15. Perform "dry" lab inquiries		0	0
16. Work according to own design	3	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x { 0 (Max 5)	5	5
	x { 1 (" 4)	3	0
	x { 2 (" 4)	1	1
	x { 3 (" 3)	0	0
	y { 0	1	1
	y { 1	1	0
	y { 2	0	0
	y { 3	0	0
	OVERALL LEVEL:	1	0

SEP 8	Lvl	Totals across 68	%	Collective Totals B
1. Recognise and define	2	57	84	68
2. Formulate hypothesis		3	4	
3. Predict		5	7	
4. Design observation and measurement procedures		3	4	
5. Design experiments	3	3	4	3
6. Carry out observations, measurements, experiments	0	65	96	160
7. Record results, describe		65	96	
8. Transform results into standard forms		30	44	
9. Explain	1	22	32	83
10. Make inferences		47	69	
11. Formulate generalisations or models		14	21	
12. Define limitations or assumptions		0	0	
13. Learn techniques	0	63	93	83
14. Perform quantitative work		20	29	
15. Perform "dry" lab inquiries	3	4	6	4
16. Work according to own design		0	0	

RESULT A: (Columns)

	Number	Total	%
Level 0:	42	68	62
Level 1:	15	68	22
Level 2:	11	68	16
Level 3:	0	68	0

RESULT B: (Rows)

	Number	Total	%
Level 0:	243	340	71
Level 1:	83	272	31
Level 2:	68	272	25
Level 3:	7	204	3

Duncan: Physics (1)	Lvl	Laboratory Inquiry Page No. 10	12	14	17	18	20	23	24	26	30	37
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	1	0	0	0	0	0	0
9. Explain		0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	1	1	1	0	0	0	0	0	0	0
11. Form generalis-ations, models	1	0	1	0	0	0	0	0	0	0	0	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti- work	0	0	0	0	0	1	0	0	0	0	0	0
15. Perform "dry" inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	3	3	3	3	5	3	3	3	3	3	3
	1 (" 4)	0	2	1	1	0	0	0	0	0	0	0
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0	1	1	1	1	1	1	1	1	1	1	1
	1	0	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:		0	1	0	0	0	0	0	0	0	0	0

Duncan: Physics (2)	Lvl	Laboratory Inquiry Page No. 41	57	60	62	63	68	71	74	78	80	88
1. Recognise & def problem	2	0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn meas procedures		0	0	0	0	0	0	1	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7.Record results		1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		1	0	1	0	1	1	0	1	0	1	1
9. Explain	1	0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	1	1	0	1	1	0	0	0	0	0
11. Form generalis-ations, models		0	0	1	0	1	1	0	1	0	0	1
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	1	1	1	1	1	1	1	1	1	1	0
14. Perform quanti-work		1	0	1	0	1	1	0	1	1	1	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	5	3	5	3	5	5	3	5	4	5	3
	x 1 (" 4)	0	1	2	0	2	2	0	1	0	0	1
	x 2 (" 4)	0	0	0	0	0	0	1	0	0	0	0
	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
	y 0	1	1	1	1	1	1	1	1	1	1	1
	y 1	0	0	1	0	1	1	0	0	0	0	0
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	0	1	0	1	1	0	0	0	0	0

Duncan: Physics (3)	Lvl	Laboratory Inquiry Page No. 100	104	108	112	113	116	128	128	131	134	134
1. Recognise & def problem		0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7.Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		1	0	1	1	0	1	1	1	1	1	1
9. Explain		0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	0	1	1	1	1	1	1	0	0	0
11. Form generalis-ations, models	1	0	0	1	1	0	0	1	1	0	0	0
12. Define limits, assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti- work	0	1	0	1	1	1	1	1	1	1	1	1
15. Perform "dry" inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0

Divide each	x 0 (Max 5)	5	3	5	5	4	5	5	5	5	5	5
total	x 1 (" 4)	0	0	2	2	1	1	2	2	0	0	0
maximum.	x 2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4	x 3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
let y=1. If x<0,4	y 0	1	1	1	1	1	1	1	1	1	1	1
let y=0	y 1	0	0	1	1	0	0	1	1	0	0	0
	y 2	0	0	0	0	0	0	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	0	1	1	0	0	1	1	0	0	0

Duncan: Physics (4)	Lvl	158	160	167	170	173	181	185	189	193	199	215
		Laboratory Inquiry Page No.										
1. Recognise & def problem	2	0	0	0	0	0	0	0	0	0	0	0
2. Form hypothesis		0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	0
4. Design observn & meas procedures		0	0	0	0	0	0	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	0	0	0	0	0	0
6. Carry out obsvns measurements, expts	0	1	1	1	1	1	1	1	1	1	1	1
7.Record results		1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		0	0	0	0	0	1	0	0	0	0	1
9. Explain	1	0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	0	1	1	1	0	0	0	0	0	0
11. Form generalis-ations, models		0	0	0	0	0	0	0	0	0	1	1
12. Define limits assumptions		0	0	0	0	0	0	0	0	0	0	0
13. Learn technique	0	1	1	1	1	1	1	1	1	1	1	0
14. Perform quanti-work		0	0	0	0	0	1	0	0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum.	x 0 (Max 5)	3	3	3	3	3	5	3	3	3	3	3
	1 (" 4)	0	0	1	1	1	0	0	0	0	1	1
	2 (" 4)	0	0	0	0	0	0	0	0	0	0	0
If x>=0,4 let y=1.	3 (" 3)	0	0	0	0	0	0	0	0	0	0	0
If x<0,4 let y=0	y 0	1	1	1	1	1	1	1	1	1	1	1
	1	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0
	LEVEL:	0	0	0	0	0	0	0	0	0	0	0

Duncan: GCSE Physics (5)	Level	Lab Inq Page No. 226	238	243	243
1. Recognise & define problem	2	0	0	0	0
2. Formulate hypothesis		0	0	0	0
3. Predict		0	0	0	0
4. Design observation and measurement procedures		0	0	0	0
5. Design experiments	3	0	0	0	0
6. Carry out observations, measurements, experiments	0	1	1	1	1
7.Record results, describe		1	1	1	1
8. Transform results into standard forms		0	0	0	0
9. Explain	1	0	0	0	0
10. Make inferences		0	0	0	0
11. Formulate generalisations or models		0	0	0	0
12. Define limitations or assumptions		0	0	0	0
13. Learn techniques	0	1	1	1	1
14. Perform quantitative work		0	0	0	0
15. Perform "dry" lab inquiries	3	0	0	0	0
16. Work according to own design		0	0	0	0

Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0					
x	{ 0 (Max 5)	3	3	3	3
	{ 1 (" 4)	0	0	0	0
	{ 2 (" 4)	0	0	0	0
	{ 3 (" 3)	0	0	0	0
y	{ 0	1	1	1	1
	{ 1	0	0	0	0
	{ 2	0	0	0	0
	{ 3	0	0	0	0
	OVERALL LEVEL:	0	0	0	0

Duncan: GCSE Physics	Lvl	Totals across 48	%	Collective Totals B
1. Recognise and define	2	0	0	1
2. Formulate hypothesis		0	0	
3. Predict		0	0	
4. Design observation and measurement procedures		1	2	
5. Design experiments	3	0	0	0
6. Carry out observations, measurements, experiments	0	48	100	115
7. Record results, describe		48	100	
8. Transform results into standard forms		19	40	
9. Explain	1	0	0	28
10. Make inferences		16	33	
11. Formulate generalisations or models		12	25	
12. Define limitations or assumptions		0	0	
13. Learn techniques	0	46	96	65
14. Perform quantitative work		19	40	
15. Perform "dry" lab inquiries	3	0	0	0
16. Work according to own design		0	0	

RESULT A: (Columns)

	Number	Total	%
Level 0:	40	48	83
Level 1:	8	48	17
Level 2:	0	48	0
Level 3:	0	48	0

RESULT B: (Rows)

	Number	Total	%
Level 0:	180	240	75
Level 1:	28	192	15
Level 2:	1	192	1
Level 3:	0	144	0

Harvard Physics (1)	Lvl	Laboratory Inquiry Page No. 134	142	144	145	153	157	158	166	169	176	179
1. Recognise & def problem		0	0	0	0	1	1	1	1	1	1	0
2. Form hypothesis	2	0	0	0	0	0	0	0	0	0	0	0
3. Predict		0	0	0	0	0	0	0	0	0	0	1
4. Design observn & meas procedures		0	0	0	0	0	1	0	0	0	0	0
5. Design expts	3	0	0	0	0	0	1	0	0	0	0	0
6. Carry out obsvns measurements, expts		1	1	1	1	1	1	1	1	1	1	1
7. Record results	0	1	1	1	1	1	1	1	1	1	1	1
8. Transform rslts to std forms		1	1	1	1	1	1	1	1	0	1	1
9. Explain		0	0	0	0	0	0	0	0	0	0	0
10. Make inferences		0	0	0	1	1	1	0	1	1	1	1
11. Form generalis-ations, models	1	0	0	0	1	1	1	0	1	0	1	0
12. Define limits, assumptions		0	0	1	1	1	1	1	1	0	1	1
13. Learn technique		1	1	1	1	1	1	1	1	1	1	1
14. Perform quanti- work	0	0	0	0	1	1	1	1	1	0	1	1
15. Perform "dry" inquiries	3	1	0	0	0	0	0	0	0	0	0	0
16. Work to own design		0	0	0	0	0	0	0	0	0	0	0
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x 0 (Max 5)	4	4	4	5	5	5	5	5	3	5	5
	x 1 (" 4)	0	0	1	3	3	3	1	3	1	3	2
	x 2 (" 4)	0	0	0	0	1	2	1	1	1	1	1
	x 3 (" 3)	1	0	0	0	0	0	0	0	0	0	0
	y 0	1	1	1	1	1	1	1	1	1	1	1
	y 1	0	0	0	1	1	1	0	1	0	1	1
	y 2	0	0	0	0	0	1	0	0	0	0	0
	y 3	0	0	0	0	0	0	0	0	0	0	0
OVERALL LEVEL:		0	0	0	1	1	2	0	1	0	1	1

Harvard Project Physics(2)	Level	Lab Inq Page No. 181	182
1. Recognise & define problem	2	1	0
2. Formulate hypothesis		0	0
3. Predict		0	0
4. Design observation and measurement procedures		0	0
5. Design experiments	3	0	0
6. Carry out observations, measurements, experiments	0	1	1
7.Record results, describe		1	1
8. Transform results into standard forms		0	0
9. Explain	1	0	0
10. Make inferences		1	0
11. Formulate generalisations or models		1	1
12. Define limitations or assumptions		0	0
13. Learn techniques	0	1	1
14. Perform quantitative work		1	0
15. Perform "dry" lab inquiries	3	0	0
16. Work according to own design		0	0

		181	182
Divide each total by maximum. If x>=0,4 let y=1. If x<0,4 let y=0	x { 0 (Max 5)	4	3
	x { 1 (" 4)	2	1
	x { 2 (" 4)	1	0
	x { 3 (" 3)	0	0
	y { 0	1	1
	y { 1	1	0
	y { 2	0	0
	y { 3	0	0
	OVERALL LEVEL:	1	0

RESULTS: TASK ANALYSIS OF LABORATORY INQUIRIES Textbook R

Harvard Project Physics	Lvl	Totals across 13	%	Collective Totals B
1. Recognise and define	2	7	54	9
2. Formulate hypothesis		0	0	
3. Predict		1	8	
4. Design observation and measurement procedures		1	8	
5. Design experiments	3	1	8	1
6. Carry out observations, measurements, experiments	0	13	100	36
7. Record results, describe		13	100	
8. Transform results into standard forms		10	77	
9. Explain	1	0	0	23
10. Make inferences		8	62	
11. Formulate generalisations or models		7	54	
12. Define limitations or assumptions		8	62	
13. Learn techniques	0	13	100	21
14. Perform quantitative work		8	62	
15. Perform "dry" lab inquiries	3	1	8	1
16. Work according to own design		0	0	

RESULT A: (Columns)

	Number	Total	%
Level 0:	6	13	46
Level 1:	6	13	46
Level 2:	1	13	8
Level 3:	0	13	0

RESULT B: (Rows)

	Number	Total	%
Level 0:	57	65	88
Level 1:	23	52	44
Level 2:	9	52	17
Level 3:	2	39	5

APPENDIX C

TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT

Textbook: Brink & Jones 8 **Textbook A**
(Random pages:21 115 151 67 227 208 190 202 55 20)
No. of Sentences: 220 No. of Questions: 20
Ratio S/Q: 11,00 (Q/S: 0,09)

A. Non-experiential

1.Rhetorical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
0	3 **(15%)**	0	0	0

B. Experiential

	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
a. Observing	3 **(15%)**	5 **(25%)**	0	0
b. Communicating	0	0	0	0
c. Comparing	1 **(5%)**	2 **(10%)**	1 **(5%)**	0
d. Organising	0	0	0	0
e. Experimenting	0	0	0	0
f. Inferring	0	2 **(10%)**	3 **(15%)**	0
g. Applying	0	0	0	0

C. Position of Questions

Initiatory	Contextual	Terminal	Captional
8 **(40%)**	0	12 **(60%)**	0

* % of Total Questions

TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT

Textbook: Pienaar & Walters 8 **Textbook B**
(Random pages:21 115 152 69 229 208 187 202 55 20)
No. of Sentences: 160 No. of Questions: 11
Ratio S/Q: 14,55 (Q/S: 0,09)

A. Non-experiential

1.Rhetorical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
0	2 **(18%)**	0	0	0

B. Experiential

	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
a. Observing	2 **(18%)**	2 **(18%)**	0	0
b. Communicating	0	0	0	0
c. Comparing	0	2 **(18%)**	0	0
d. Organising	0	0	0	0
e. Experimenting	0	0	0	0
f. Inferring	0	1 **(9%)**	2 **(19%)**	0
g. Applying	0	0	0	0

C. Position of Questions

Initiatory	Contextual	Terminal	Captional
1 **(9%)**		10 **(91%)**	

* % of Total Questions

TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT

Textbook: Broster & James 8 **Textbook C**
(Random pages:21 115 151 67 190 12 55 20 188 140)
No. of Sentences: 251 No. of Questions: 23
Ratio S/Q: 10,91 (Q/S: 0,09)

A. Non-experiential

1.Rhetorical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
0	4 **(17%)**	2 **(9%)**	0	0

B. Experiential

	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
a. Observing	5 **(22%)**	0	0	0
b. Communicating	0	0	0	0
c. Comparing	3 **(13%)**	2 **(9%)**	0	0
d. Organising	0	0	0	0
e. Experimenting	0	0	0	0
f. Inferring	3 **(13%)**	3 **(13%)**	1 **(4%)**	0
g. Applying	0	0	0	0

C. Position of Questions

Initiatory	Contextual	Terminal	Captional
4 **(17%)**	0	19 **(83%)**	

* % of Total Questions

TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT

Textbook: SEP 8 **Textbook J**
(Random pages:21 115 151 67 190 12 55 20 140 18)
No. of Sentences: 74 No. of Questions: 15
Ratio S/Q: 4,93 (Q/S: 0,20)

A. Non-experiential

1.Rhetorical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
0	1 **(7%)**	0	0	0

B. Experiential

	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
a. Observing	4 **(25%)**	2 **(13%)**	1 **(7%)**	0
b. Communicating	0	0	0	0
c. Comparing	1 **(7%)**	0	0	0
d. Organising	1 **(7%)**	0	0	0
e. Experimenting	0	0	0	0
f. Inferring	1 **(7%)**	0	4 **(27%)**	0
g. Applying		0	0	0

C. Position of Questions

Initiatory	Contextual	Terminal	Captional
3 **(20%)**	3 **(20%)**	9 **(60%)**	

* % of Total Questions

TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT

Textbook: Duncan GCSE Physics **Textbook K**
(Random pages:21 119 149 66 227 208 191 202 12 221)
No. of Sentences: 217 No. of Questions: 27
Ratio S/Q: 8,04 (Q/S: 0,12)

A. **Non-experiential**

1.Rhetor-ical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
0	3 **(25%)**	2 **(15%)**	2 **(15%)**	0

B. **Experiential**

	2.Direct Information	3.Focus-ing	4.Open-Ended	5.Valuing
a. Observing	0	0	0	0
b. Communicating	0	0	0	0
c. Comparing	0	0	0	0
d. Organising	0	0	0	0
e. Experimenting	0	0	0	0
f. Inferring	2 **(15%)**	0	0	0
g. Applying	2 **(15%)**	2 **(15%)**	0	0

C. **Position of Questions**

Initiatory	Contextual	Terminal	Captional
0	0	13 **(100%)**	

* % of Total Questions

TEXTBOOK QUESTIONING STRATEGIES ASSESSMENT INSTRUMENT

Textbook: Harvard Project Physics **Textbook R**
(Random pages:21 115 151 67 190 12 54 20 138 18)
No. of Sentences: 225 No. of Questions: 27
Ratio S/Q: 8,33 (Q/S: 0,12)

A. Non-experiential

1.Rhetorical	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
1 **(4%)**	1 **(4%)**	5 **(19%)**	3 **(11%)**	0

B. Experiential

	2.Direct Information	3.Focusing	4.Open-Ended	5.Valuing
a. Observing	1 **(4%)**	2 **(7%)**	2 **(7%)**	0
b. Communicating	0	0	0	0
c. Comparing	1 **(4%)**	2 **(7%)**	1 **(4%)**	0
d. Organising	0	0	0	0
e. Experimenting	0	0	2 **(7%)**	0
f. Inferring	2 **(7%)**	1 **(4%)**	2 **(7%)**	0
g. Applying	0	0	1 **(4%)**	0

C. Position of Questions

Initiatory	Contextual	Terminal	Captional
7 **(26%)**	8 **(30%)**	12 **(44%)**	

* % of Total Questions

D. Comparison of Questioning Style in Reading Content

TEXTBOOK:	Brink	Pien.	Brost.	SEP	Duncan	Harv.
No. of Questions	20	11	23	15	27	27
No. of Sentences	220	160	251	74	217	225
% of Ques. per Sent.	9%	7%	9%	20%	12%	12%
% of Experientl. Qu.	85%	82%	74%	93%	45%	66%
% of Non-Expertl.Qu.	15%	18%	26%	7%	55%	34
% of Initiatory Qu.	40%	9%	17%	20%	0%	26%
% of Contextual Qu.	0%	0%	0%	20%	0%	30%
% of Terminal Ques.	60%	91%	83%	60%	100%	44%
% of Captional Ques.	0%	0%	0%	0%	0%	0%

APPENDIX D

TEXT ANALYSIS Take 25 sentences, assigning each to category below.
Textbook A: Brink & Jones 8

Random Page Number:	20	193	140	18	204	128	38	237	142	56	250	Tot %
a. Facts	9	13	7	13	13	13	3	7	24	21	123	49
b. Conclusions	2	1	0	1	0	0	1	0	0	0	5	2
c. Definitions	4	0	0	3	0	0	0	0	0	0	7	3
d. Ques. asked but answd immediately	0	0	0	0	0	0	0	0	0	0	0	0
e. Questions requrng stud. to analyse data	2	2	7	2	1	3	6	3	0	0	26	10
f. Statements requrng pupil to form concln	0	0	0	0	0	0	0	0	0	0	0	0
g. Dir. to pupil to perform& analyse act.	7	6	10	5	8	5	15	12	1	0	69	28
h.Ques to arouse intr -not answered immdtly	0	0	0	0	2	1	0	1	0	0	4	2
i. Sentence directing student to figure	1	3	0	1	1	1	0	2	0	3	12	5
j. Rhetorical questns	0	0	1	0	0	1	0	0	0	1	3	1

Overall Involvement Index for Text $= \frac{(e + f + g + h)}{(a + b + c + d)} = \frac{26 + 1 + 69 + 4}{123 + 5 + 7 + 0} =$ **0,74**

ANALYSIS OF QUESTIONS AT CHAPTER ENDS
Textbook: Brink & Jones 8

	Chapter																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
a.(*)	5	8	3	5	2	4	2	2	1	4	1	3	2	0	0	2	0	0	7	1
b.	2	2	2	3	0	1	2	0	0	2	1	3	1	0	0	0	1	1	0	0
c.	2	2	4	0	5	3	0	4	1	0	2	1	4	4	4	7	4	4	1	5
d.	5	0	0	4	2	4	2	2	2	0	3	4	0	4	1	0	0	0	7	1
e.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(*) a. Answer in text
b. Definition
c. Requires pupil to apply learning to new situation
d. Requires pupil to solve a problem
e. None of the above

Totals across rows: a. 52
b. 21
c. 56
d. 41

Overall Index for Questions $= \frac{(c + d)}{(a + b)} = \frac{56 + 41}{52 + 21} =$ **1,33**

TEXT ANALYSIS Take 25 sentences, assigning each to category below.
Textbook B: Pienaar & Walters 8

Random Page Number:	208	38	268	106	212	283	155	317	303	203	250	%
a. Facts	22	14	10	18	13	15	20	7	21	24	164	66
b. Conclusions	0	1	0	2	0	1	0	1	1	1	7	3
c. Definitions	0	0	0	2	0	0	0	1	0	0	3	1
d. Ques asked but answd immedtly	0	2	0	1	1	1	0	0	1	0	6	2
e. Questions requrng stud. to analyse data	0	1	3	0	0	1	0	0	0	0	5	2
f. Statements requrng pupil to form concl.	0	0	0	0	0	0	0	0	0	0	0	0
g. Dir. to pupil to perform & analyse act	0	5	6	1	4	0	3	16	1	0	36	14
h. Ques to arouse int -not answered immdtly	0	0	1	0	2	0	0	0	0	0	3	1
i. Sentence directing student to figure	3	1	5	1	5	7	2	0	0	0	24	10
j. Rhetorical questns	0	1	0	0	0	0	0	0	1	0	2	1

Overall Involvement Index for Text $= \dfrac{(e + f + g + h)}{(a + b + c + d)} = \dfrac{5 + 0 + 36 + 3}{164 + 7 + 3 + 6} = 0{,}24$

ANALYSIS OF QUESTIONS AT CHAPTER ENDS
Textbook: Pienaar & Walters 8

	Chapter																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	T
a.(*)	12	7	10	6	5	6	5	-	5	3	2	3	2	10	3	2	5	3	5	94
b.	1	0	1	0	0	0	1	-	1	0	2	0	0	0	2	0	2	3	3	16
c.	0	6	4	7	0	0	1	-	4	3	2	4	3	7	3	3	2	4	4	57
d.	4	6	7	9	5	1	2	-	2	3	2	5	1	10	3	1	3	3	1	68
e.	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0

(*) a. Answer in text.
b. Definition.
c. Requires pupil to apply learning to new situation.
d. Requires pupil to solve a problem.
e. None of the above.

Overall Index for Questions $= \dfrac{(c + d)}{(a + b)} = \dfrac{57 + 68}{94 + 16} = 1{,}14$

TEXT ANALYSIS Take 25 sentences, assigning each to category below.
Textbook C: Broster & James 8

Random Page Number:	38	104	155	21	115	151	67	12	52	20	Tot 250	%
a. Facts	19	13	4	2	15	18	21	9	3	11	115	46
b. Conclusions	0	0	9	0	3	0	2	0	3	2	19	8
c. Definitions	0	0	0	0	0	0	0	0	0	0	0	0
d. Quest asked but answd immediately	0	2	0	0	0	0	0	6	0	0	8	3
e. Questions requrng stud. to analyse data	0	0	0	0	0	0	0	0	4	0	4	2
f. Statements requrng pupil to form concl	0	0	0	5	0	0	0	0	5	0	10	4
g. Dir. to pupil to perform & analyse act	6	8	12	12	6	7	2	9	10	11	83	33
h. Ques to arouse int -not answered immdtly	0	2	0	5	1	0	0	1	0	1	10	4
i. Sentence directing student to figure	0	0	0	1	0	0	0	0	0	0	1	0
j. Rhetorical questns	0	0	0	0	0	0	0	0	0	0	0	0

Overall Involvement Index for Text $= \frac{(e + f + g + h)}{(a + b + c + d)} = \frac{4 + 10 + 83 + 10}{115 + 19 + 0 + 8} = 0{,}75$

ANALYSIS OF QUESTIONS AT CHAPTER ENDS
Textbook: Broster & James 8

	Chapter										
	1	2	3	4	5	6	7	8	9	10	Total
a.(*)	4	7	7	3	1	2	2	4	0	4	34
b.	2	2	0	5	2	3	2	2	2	2	22
c.	1	3	2	0	4	2	0	2	0	2	18
d.	5	0	3	4	5	5	4	4	10	2	42
e.	0	0	0	0	0	0	0	0	0	0	0

(*) a. Answer in text
b. Definition
c. Requires pupil to apply learning to new situation
d. Requires pupil to solve a problem
e. None of the above

Overall Index for Questions $= \frac{(c + d)}{(a + b)} = \frac{18 + 42}{34 + 22} = 1{,}07$

TEXT ANALYSIS Take 25 sentences, assigning each to category below.
Textbook J: SEP 8

Random Page Number:	190	48	17	174	179	102	20	96	54	50	Tot 250	%
a. Facts	2	4	0	0	0	0	3	0	0	3	12	5
b. Conclusions	0	0	0	0	0	0	0	0	0	0	0	0
c. Definitions	0	0	0	0	0	0	0	0	0	0	0	0
d. Ques asked but answd immediately	0	0	0	0	0	0	0	0	0	0	0	0
e. Questions requrng stud. to analyse data	2	3	8	5	1	6	5	6	8	1	45	18
f. Statements requrng pupil to form concl	3	5	7	3	5	5	2	2	2	4	38	15
g. Dir. to pupil to perform & analyse act	12	12	7	13	16	14	13	13	13	15	128	51
h. Ques to arouse int -not answered immdtly	1	1	3	3	1	1	2	4	2	2	20	8
i. Sentence directing student to figure	5	0	0	1	2	0	0	0	0	0	8	3
j. Rhetorical questns	0	0	0	0	0	0	0	0	0	0	0	0

Overall Involvement Index for Text $= \dfrac{(e + f + g + h)}{(a + b + c + d)} = \dfrac{45 + 38 + 128 + 20}{12 + 0 + 0 + 0} = 19{,}3$

ANALYSIS OF QUESTIONS AT CHAPTER ENDS
Textbook: SEP 8

	Chapter
a. Answer in text	Not applicable to SEP 8.
b. Definition	(No Question at ends of Chapters.)
c. Requires pupil to apply learning to new situation	
d. Requires pupil to solve a problem	
e. None of the above	

Overall Index for Questions $= \dfrac{(c + d)}{(a + b)} =$

TEXT ANALYSIS Take 25 sentences, assigning each to category below.
Textbook K: Duncan: GCSE Physics

Random Page Number:	175	41	149	81	203	134	71	99	138	51	Tot 256	%
a. Facts	2	11	0	16	24	14	12	13	25	17	134	54
b. Conclusions	0	0	0	0	0	0	0	0	0	0	0	0
c. Definitions	0	1	1	1	1	1	1	0	0	0	6	2
d. Ques asked but answd immediately	0	0	0	0	0	0	0	0	0	0	0	0
e. Questions requrng stud. to analyse data	9	0	9	5	0	0	1	4	0	5	33	13
f. Statements requrng pupil to form concl.	9	3	13	3	0	0	4	2	0	2	36	14
g. Dir. to pupil to perform & analyse act	5	10	3	0	0	10	7	5	0	1	41	16
h. Ques to arouse int -not answered immdtly	0	0	0	0	0	0	0	0	0	0	0	0
i. Sentence directing student to figure	0	0	0	0	0	0	0	0	0	0	0	0
j. Rhetorical questns	0	0	0	0	0	0	0	0	0	0	0	0

Overall Involvement Index for Text $= \dfrac{(e + f + g + h)}{(a + b + c + d)} = \dfrac{33 + 36 + 41 + 0}{134 + 0 + 6 + 0} = 0{,}79$

ANALYSIS OF QUESTIONS AT CHAPTER ENDS
Textbook: Duncan: GCSE Physics

	Chapter																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
a.(*)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	1	5
b.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c.	2	0	1	1	3	0	1	2	2	2	2	12	3	3	0	1	1	36
d.	2	3	2	0	3	2	3	2	1	1	1	0	2	2	1	5	0	30
e.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(*) a. Answer in text
b. Definition
c. Requires pupil to apply learning to new situation
d. Requires pupil to solve problem
e. None of the above

Overall Index for Questions $= \dfrac{(c + d)}{(a + b)} = \dfrac{36 + 30}{5 + 0} = 13{,}2$

TEXT ANALYSIS Take 25 sentences, assigning each to category below.
Textbook R: Harvard Project Physics

Random Page Number:	139	1	160	64	99	67	81	87	38	106	Tot 250	%
a. Facts	1	0	10	0	12	22	24	15	25	19	128	51
b. Conclusions	0	0	2	0	0	0	0	0	0	0	2	1
c. Definitions	0	0	0	0	0	0	0	0	0	0	0	0
d. Ques asked but answd immediately	0	0	0	0	0	0	0	0	0	0	0	0
e. Questions requrng stud. to analyse data	0	0	1	16	0	0	0	1	0	0	18	7
f. Statements requrng pupil to form concl	9	0	1	8	0	0	0	4	0	4	26	10
g. Dir. to pupil to perform & analyse act	12	0	11	0	0	0	0	1	0	0	24	10
h. Ques to arouse int -not answered immdtly	0	25	0	0	13	3	1	4	0	2	48	19
i. Sentence directing student to figure	3	0	0	1	0	0	0	0	0	0	4	2
j. Rhetorical questns	0	0	0	0	0	0	0	0	0	0	0	0

Overall Involvement Index for Text $= \dfrac{(e + f + g + h)}{(a + b + c + d)} = \dfrac{18 + 26 + 24 + 48}{128 + 2 + 0 + 0} = 0{,}89$

ANALYSIS OF QUESTIONS AT CHAPTER ENDS
Textbook: Harvard Project Physics

	Chapter 1	2	3	4	Total
a. Answer in text	1	0	0	0	1
b. Definition	0	0	0	0	0
c. Requires pupil to apply learning to new situation	5	5	5	2	17
d. Requires pupil to solve a problem	6	7	7	10	30
e. None of the above	0	0	0	0	0

Overall Index for Questions $= \dfrac{(c + d)}{(a + b)} = \dfrac{17 + 30}{1 + 0} = 47$

PHILOSOPHY CHECKLIST **TEXT A**

Textbook: Brink & Jones 8	Instance										
Random Page Number:	9	218	16	189	87	100	15	202	244	240	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	0	1	1	1	0	0	1	1	0	5
b. "Observation" mentioned	0	0	1	1	0	0	0	1	1	0	4
c. Observation objective	0	0	1	1	1	0	0	1	1	0	5
2. Inductive generalisations											
a. Inductive gnrlstns made	1	0	0	1	0	0	0	1	0	0	3
b. No. of instances few	0	0	0	1	0	0	0	1	0	0	2
c. Verification	0	0	0	1	0	0	0	1	0	0	2
3. Laws and theories											
a. "Law", "theory" mentnd	1	0	1	1	0	1	1	0	0	0	5
b. Obs. leads rig. to laws	1	0	0	1	0	1	1	0	0	0	4
c. Laws mature theories	0	0	0	0	0	0	1	0	0	0	1
d. Data yield unique concl	0	0	1	1	1	0	0	0	0	0	3
4. Proven knowledge											
a. Proven knowledge	1	0	1	1	1	1	1	0	0	0	6
b. Sci "discovers" facts	0	0	1	1	1	0	1	1	0	0	5
c. Tone is "factual"	1	0	1	1	1	1	1	1	0	0	7
d. Questions answd immedly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	1	0	0	0	0	1
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	1	0	1	0	0	0	2
h. Science always logical	0	0	0	0	1	0	1	0	0	0	2
i. Science leads to abs tr	0	0	0	0	1	0	1	0	0	0	2

59 / 190 = 31 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	0	1	1	1	0	0	0	1	0	4
Phenomenal	0	0	0	0	0	0	1	0	0	0	1
2. Computative predictions	1	1	0	0	0	1	0	0	0	1	4
Predictions "expected"	1	1	0	1	0	1	0	0	0	1	5
Recipe-like procedures	0	1	0	0	0	1	0	0	0	1	3
Only terms in an equatn	0	1	0	0	0	1	0	0	0	0	2
3. Definition: Nominalistic	1	0	0	0	1	0	0	1	0	0	3
Operational	1	0	1	0	0	1	0	0	0	1	4
4. Theories: Fictions	0	1	1	0	0	0	1	0	1	1	5
Rules of thumb	0	1	0	1	1	1	0	0	0	1	5
Convenient, prag	1	1	0	0	0	1	0	0	1	1	5

41 / 110 = 37 %

PHILOSOPHY CHECKLIST **TEXT B**

Textbook: Pienaar & Walt. 8	Instance										
Random Page Number:	188	315	40	319	285	92	147	234	203	326	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science bgns with obs	1	1	1	0	1	0	0	0	1	0	5
b. "Observation" mentnd	1	1	1	0	1	0	0	0	1	0	5
c. Observation objective	1	1	1	0	1	0	0	0	1	0	5
2. Inductive generalisation											
a. Inductive gnrlstns	0	0	1	0	1	0	0	0	0	0	2
b. No. of instances few	0	0	1	0	1	0	0	0	0	0	2
c. Verification	0	0	1	0	1	0	0	0	0	0	2
3. Laws and theories											
a. "Law", "theory" mntnd	0	0	0	0	1	0	0	0	1	0	2
b. Obs leads rig to laws	0	0	0	0	0	0	0	0	1	0	1
c. Laws mature theories	0	0	0	0	0	0	0	0	1	0	1
d. Data yield unique con	1	0	1	0	1	0	0	0	1	0	4
4. Proven knowledge											
a. Proven knowledge	1	1	1	0	1	0	0	1	1	0	6
b. Sci "discovers" facts	0	0	1	0	1	0	0	0	1	0	3
c. Tone is "factual"	1	0	1	0	1	0	0	1	1	1	6
d. Question answd immdly	1	0	1	0	0	0	0	0	0	0	2
e. Science is reliable	0	1	0	0	0	0	0	0	1	0	2
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	0	0	0	1	0	1
h. Science always logicl	0	0	0	0	0	0	0	0	1	0	1
i. Sci leads to abs tru	0	0	0	0	0	0	0	1	1	0	2

52 / 190 = 27 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	1	1	0	1	0	0	0	1	0	5
Phenomenal	0	0	0	0	0	0	0	0	0	0	0
2. Computative predictions	0	1	0	1	0	1	1	0	0	0	4
Predictions "expected"	1	1	1	1	1	0	0	0	0	0	5
Recipe-like procedurs	0	1	0	1	0	1	1	0	0	0	4
Only terms in an equn	0	1	0	1	0	0	0	0	0	0	2
3. Definition: Nominalistic	0	0	1	0	0	0	1	1	0	1	4
Operational	1	1	0	1	1	0	0	0	1	0	5
4. Theories: Fictions	0	0	0	0	0	0	0	1	0	1	2
Rules of thumb	1	1	1	1	1	0	0	0	0	0	5
Convent, pragm	0	1	0	1	1	1	1	0	0	0	5

41 / 110 = 37 %

PHILOSOPHY CHECKLIST **TEXT C**

Textbook: Broster & James 8	Instances										
Random Page Number:	16	189	87	100	15	55	40	79	80	188	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	0	0	1	1	0	0	0	1	0	4
b. "Observation" mentioned	1	0	0	1	1	0	0	0	1	0	4
c. Observation objective	1	0	0	1	1	0	0	0	1	0	4
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	1	1	0	0	0	1	0	3
b. No. of instances few	1	0	0	1	0	0	0	0	1	0	3
c. Verification	0	0	0	1	0	0	0	0	1	0	2
3. Laws and theories											
a. "Law", "theory" mentnd	1	0	0	0	0	0	0	0	1	0	2
b. Obs. leads rig to laws	0	0	0	0	0	0	0	0	1	0	1
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	1	0	0	0	0	0	0	0	1	0	2
4. Proven knowledge											
a. Proven knowledge	0	0	0	0	0	1	1	1	1	0	4
b. Sci "discovers" facts	1	0	0	1	1	0	0	0	1	0	4
c. Tone is "factual"	1	1	1	0	0	0	0	0	1	0	4
d. Questions answd immedly	1	0	0	0	0	0	0	0	1	0	2
e. Science is reliable	0	0	0	0	0	0	1	1	0	0	2
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	1	0	0	0	0	0	0	0	0	0	1
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	0	0	0	0	0	0	0	0	1	0	1

43 / 190 = 23 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	0	0	1	1	0	0	0	1	0	4
Phenomenal	0	0	1	0	0	0	0	0	0	0	1
2. Computative predictions	0	1	1	0	1	1	0	0	0	1	5
Predictions "expected"	0	1	0	0	1	1	0	0	0	0	3
Recipe-like procedures	0	1	1	0	1	1	0	0	0	0	4
Only terms in an equatn	0	1	1	0	1	1	0	0	0	0	4
3. Definition: Nominalistic	1	0	1	0	0	1	1	1	1	0	6
Operational	0	0	0	0	0	0	0	0	0	1	1
4. Theories: Fictions	0	0	0	0	0	0	0	0	0	1	1
Rules of thumb	0	1	1	0	0	0	1	1	1	1	6
Convenient, prag	0	1	1	0	1	1	0	0	0	1	5

40 / 110 = 36 %

PHILOSOPHY CHECKLIST **TEXT D**

Textbook: Brink & Jones 9 — Instance

Random Page Number:	204	188	312	40	285	92	146	234	109	85	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with ob	0	1	0	1	0	1	0	0	0	1	4
b. "Observation" mentiond	0	1	0	1	0	0	0	0	0	0	2
c. Observation objective	0	1	0	1	0		0	0	0	0	2
2. Inductive generalisations											
a. Inductive gnrlstn made	0	1	0	0	0	1	0	0	0	0	2
b. No. of instances few	0	1	0	0	0	1	0	0	0	0	2
c. Verification	0	1	0	1	0	1	0	0	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	0	1	0	1	0	1	0	0	0	0	3
b. Obs. leads rig to laws	0	1	0	0	0	0	0	0	0	1	2
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique conc	0	1	0	0	0	0	0	0	0	1	2
4. Proven knowledge											
a. Proven knowledge	0	0	1	1	1	1	1	0	0	0	5
b. Sci "discovers" facts	1	0	1	1	1	0	0	0	0	0	4
c. Tone is "factual"	0	1	0	1	1	0	1	1	0	1	6
d. Questions answd immdly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	1
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	0	0	0	0	1	1
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs t	0	0	0	0	0	0	1	0	0	0	1

40 / 190 = 21 %

B. INSTRUMENTALISM:	204	188	312	40	285	92	146	234	109	85	T
1. Observation: Assumed obj	0	1	1	0	0	1	0	0	0	1	4
Phenomenal	0	0	0	0	0	0	0	0	0	0	0
2. Computative predictions	1	1	0	1	0	0	0	1	1	0	5
Predictions "expected"	1	1	0	1	0	1	0	1	1	1	7
Recipe-like procedures	1	1	0	1	0	0	0	1	1	0	5
Only terms in an equatn	1	1	1	0	0	0	0	1	1	0	5
3. Definition: Nominalistic	0	0	0	0	0	1	0	0	1	0	2
Operational	1	0	0	0	0	0	0	0	0	0	1
4. Theories: Fictions	1	1	0	0	1	1	1	0	0	0	5
Rules of thumb	1	1	0	0	1	0	0	0	0	1	4
Convenient, prg	1	1	0	0	1	0	1	0	1	0	5

43 / 110 = 39 %

PHILOSOPHY CHECKLIST **TEXT E**

Textbook: Pienaar & Walters 9	Instance										
Random Page Number:	316	100	210	19	344	96	338	260	51	50	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	1	0	1	1	1	0	1	0	1	6
b. "Observation" mentioned	0	1	0	1	0	1	1	1	0	1	6
c. Observation objective	1	1	0	0	1	1	1	1	0	1	7
2. Inductive generalisations											
a. Inductive gnrlstns made	0	1	0	0	1	1	1	0	0	0	4
b. No. of instances few	0	1	0	0	1	1	0	1	0	0	4
c. Verification	0	0	0	0	1	0	1	1	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	1	0	0	1
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	1	0	0	1
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	1	0	0	1	1	1	0	0	0	4
4. Proven knowledge											
a. Proven knowledge	1	1	1	0	1	0	1	1	0	0	6
b. Sci "discovers" facts	1	1	0	0	1	1	0	1	0	0	5
c. Tone is "factual"	1	1	1	1	0	1	1	1	0	0	7
d. Questions answd immedly	0	0	0	0	1	0	0	1	0	0	2
e. Science is reliable	0	0	0	0	0	0	0	1	0	0	1
f. Technological fix	0	0	1	0	0	0	0	0	0	0	1
g. Linear accretion	1	1	0	0	0	0	0	0	0	0	2
h. Science always logical	0	1	0	0	0	0	0	0	0	0	1
i. Science leads to abs tr	0	1	0	0	0	0	0	1	0	0	2

63 / 190 = 33 %

B. INSTRUMENTALISM:	316	100	210	19	344	96	338	260	51	50	T
1. Observation: Assumed obj	1	1	0	1	1	1	1	1	0	1	8
Phenomenal	0	1	0	0	0	0	0	0	0	0	1
2. Computative predictions	0	0	0	0	0	1	0	1	1	1	4
Predictions "expected"	0	0	0	0	1	1	1	1	1	0	5
Recipe-like procedures	0	1	0	0	1	0	0	1	1	0	4
Only terms in an equatn	0	0	0	0	0	0	0	1	1	0	2
3. Definition: Nominalistic	1	1	1	0	1	0	0	0	0	0	4
Operational	0	0	0	0	0	1	0	1	0	0	2
4. Theories: Fictions	0	0	0	0	0	1	0	1	0	0	2
Rules of thumb	1	0	1	0	1	0	1	1	1	0	6
Convenient, prag	0	0	0	1	0	0	0	1	1	0	3

41 / 110 = 37 %

PHILOSOPHY CHECKLIST **TEXT F**

Textbook: Broster & James 9

Random Page Number:	100	15	202	55	40	79	80	77	207	188	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	0	1	0	1	1	0	1	1	0	5
b. "Observation" mentioned	0	0	1	1	0	1	0	1	1	0	5
c. Observation objective	0	0	1	1	1	0	0	1	1	0	5
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	1	0	1	1	0	1	1	0	5
b. No. of instances few	0	0	0	0	1	1	0	1	1	0	4
c. Verification	0	0	1	0	1	1	0	1	0	0	4
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	1	0	1	1	0	0	0	0	3
4. Proven knowledge											
a. Proven knowledge	1	0	1	0	1	1	1	1	1	1	8
b. Sci "discovers" facts	0	0	1	0	1	1	0	1	1	0	5
c. Tone is "factual"	1	0	1	0	1	1	1	1	1	1	8
d. Questions answd immedly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	1	1
f. Technological fix	0	1	0	0	0	0	0	0	0	0	1
g. Linear accretion	0	0	0	0	0	0	0	0	0	1	1
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	0	0	0	0	0	0	0	0	0	0	0

Instance

55 / 190 = 29 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	0	1	0	1	1	1	0	1	0	5
Phenomenal	0	0	0	0	0	0	0	0	0	0	0
2. Computative predictions	1	1	0	1	0	0	0	0	0	0	3
Predictions "expected"	0	1	1	1	1	0	1	0	1	0	6
Recipe-like procedures	0	1	1	1	1	0	1	0	1	0	6
Only terms in an equatn	0	1	1	1	1	0	1	0	1	0	6
3. Definition: Nominalistic	1	0	0	0	0	1	0	0	0	1	3
Operational	1	0	0	0	0	0	1	0	0	0	2
4. Theories: Fictions	0	0	0	1	0	1	0	0	0	0	2
Rules of thumb	0	1	1	1	1	0	0	0	1	0	5
Convenient, prag	1	1	0	1	0	0	1	0	0	0	4

42 / 110 = 38 %

PHILOSOPHY CHECKLIST **TEXT G**

Textbook: Brink & Jones 10	Instance										
Random Page Number:	204	188	31	40	82	92	146	234	109	84	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	1	0	1	0	1	1	1	1	1	7
b. "Observation" mentioned	0	1	0	1	0	0	0	0	0	0	2
c. Observation objective	0	1	0	1	0	1	1	1	1	1	7
2. Inductive generalisations											
a. Inductive gnrlstns made	0	1	0	1	0	1	0	0	1	0	4
b. No. of instances few	0	1	0	1	0	1	1	0	0	0	4
c. Verification	0	1	0	1	0	1	0	0	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig. to laws	0	0	1	0	0	0	0	0	0	1	2
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	1	0	1	0	0	1	0	1	0	1	5
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	1	0	0	0	1	1	7
b. Sci "discovers" facts	1	1	0	1	0	0	0	0	1	1	5
c. Tone is "factual"	1	1	1	1	1	0	0	0	1	1	7
d. Questions answd immedly	0	0	0	0	0	0	1	1	0	0	2
e. Science is reliable	0	0	0	0	1	0	0	0	0	0	1
f. Technological fix	0	0	0	0	0	0	0	1	0	0	1
g. Linear accretion	0	1	1	1	0	0	1	0	0	1	5
h. Science always logical	0	0	1	0	1	0	0	0	0	0	2
i. Science leads to abs tr	1	1	1	0	0	0	0	0	0	1	4

68 / 190 = 36 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	1	0	1	0	1	1	1	1	1	7
Phenomenal	1	0	1	0	0	1	0	1	0	0	4
2. Computative predictions	1	0	1	0	1	0	0	0	0	1	4
Predictions "expected"	1	0	1	0	0	1	0	0	1	1	5
Recipe-like procedures	0	0	1	0	1	0	0	0	0	1	3
Only terms in an equatn	1	0	0	0	1	0	0	0	1	1	4
3. Definition: Nominalistic	0	0	1	0	1	0	0	0	0	0	2
Operational	1	1	0	0	1	0	1	0	1	1	6
4. Theories: Fictions	1	1	1	0	0	0	0	0	0	0	3
Rules of thumb	1	0	0	1	1	0	0	0	0	1	4
Convenient, prag	0	0	0	1	0	1	0	1	1	1	4

46 / 110 = 42 %

PHILOSOPHY CHECKLIST **TEXT H**

Textbook: Pienaar & Walt. 10	Instance										
Random Page Number:	12	101	210	22	204	97	110	260	51	50	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	0	0	1	1	0	0	1	0	0	3
b. "Observation" mentioned	0	0	0	0	0	0	0	1	0	0	1
c. Observation objective	0	0	0	1	1	0	0	1	0	0	3
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	1	0	0	0	1	0	0	2
b. No. of instances few	0	0	0	0	0	0	0	1	0	0	1
c. Verification	0	0	0	0	0	0	0	1	0	0	1
3. Laws and theories											
a. "Law", "theory" mentnd	1	0	0	1	0	0	0	0	0	0	2
b. Obs. leads rig. to laws	0	0	1	1	0	0	0	0	0	0	2
c. Laws mature theories	1	0	0	0	0	0	0	0	0	0	1
d. Data yield unique concl	1	1	1	1	0	1	1	1	0	0	7
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	0	1	1	1	0	1	8
b. Sci "discovers" facts	1	1	0	0	0	1	0	1	0	0	4
c. Tone is "factual"	1	1	1	1	1	1	1	1	1	0	9
d. Questions answd immedly	0	0	0	0	0	0	0	1	0	0	1
e. Science is reliable	0	0	0	1	0	0	1	1	1	1	5
f. Technological fix	0	0	0	0	0	0	0	1	0	0	1
g. Linear accretion	1	1	0	0	0	0	0	1	0	0	3
h. Science always logical	1	1	1	0	0	1	1	0	1	1	7
i. Science leads to abs tr	1	1	0	0	0	0	0	1	0	0	3

64 / 190 = 34 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	0	0	1	1	0	0	1	0	0	3
Phenomenal	0	0	1	0	1	0	1	0	1	1	4
2. Computative predictions	1	1	0	0	0	0	1	0	1	1	5
Predictions "expected"	1	1	0	0	1	0	0	0	1	1	5
Recipe-like procedures	1	1	0	0	0	0	1	0	1	1	5
Only terms in an equatn	1	1	1	0	0	0	0	0	1	1	5
3. Definition: Nominalistic	1	1	1	0	0	0	0	0	0	1	4
Operational	0	0	0	1	0	0	1	0	0	0	2
4. Theories: Fictions	0	0	1	1	0	1	0	0	1	1	5
Rules of thumb	1	0	1	0	0	1	0	0	1	1	5
Convenient, prag	1	0	0	1	1	0	0	1	0	0	4

47 / 110 = 43 %

PHILOSOPHY CHECKLIST **TEXT I**

Textbook: Broster & James 10	Instance										
Random Page Number:	100	14	202	55	42	79	82	64	208	188	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	0	0	1	0	1	1	1	1	0	5
b. "Observation" mentioned	0	0	0	1	0	1	0	0	1	0	3
c. Observation objective	0	0	0	1	0	1	1	1	1	0	5
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	1	0	1	1	0	1	0	4
b. No. of instances few	0	0	0	0	0	1	0	0	1	0	2
c. Verification	0	0	0	1	0	1	0	0	1	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	1	0	0	0	0	0	0	1
b. Obs. leads rig. to laws	0	0	0	1	0	0	0	0	0	0	1
c. Laws mature theories	0	0	0	1	0	0	0	0	0	0	1
d. Data yield unique concl	0	0	0	1	1	1	0	0	1	0	4
4. Proven knowledge											
a. Proven knowledge	0	0	1	1	1	1	0	1	1	1	7
b. Sci "discovers" facts	0	0	1	1	1	1	0	1	1	0	6
c. Tone is "factual"	0	0	1	1	1	1	0	1	1	1	7
d. Questions answd immdtly	0	0	0	0	0	1	0	1	0	0	2
e. Science is reliable	0	0	1	1	1	0	0	0	0	1	4
f. Technological fix	1	1	1	0	0	1	0	0	0	0	4
g. Linear accretion	0	0	1	1	0	0	0	1	1	1	5
h. Science always logical	0	0	1	0	1	1	0	0	0	1	4
i. Science leads to abs tr	1	0	1	1	0	0	1	1	1	0	6

74 / 190 = 39 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	0	0	1	0	1	1	1	1	0	5
Phenomenal	0	1	1	0	0	1	1	0	0	0	4
2. Computative predictions	0	1	0	1	1	0	1	0	0	1	5
Predictions "expected"	0	1	0	1	1	0	1	0	0	1	5
Recipe-like procedures	0	1	0	1	1	0	1	0	0	0	4
Only terms in an equatn	0	1	0	1	1	0	1	0	0	0	4
3. Definition: Nominalistic	1	0	0	0	1	0	0	1	0	0	3
Operational	0	1	0	1	0	0	1	0	0	0	3
4. Theories: Fictions	1	0	1	0	0	0	1	0	0	0	3
Rules of thumb	1	0	1	0	0	0	1	0	0	0	3
Convenient, prag	0	0	1	0	0	1	1	0	1	1	5

44 / 110 = 40 %

PHILOSOPHY CHECKLIST **TEXT J**

Textbook: SEP 8	Instance										
Random Page Number:	26	11	163	94	8	102	49	17	189	87	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	0	1	1	1	1	1	0	0	1	7
b. "Observation" mentioned	1	0	0	1	1	0	0	0	0	0	3
c. Observation objective	1	0	1	0	1	1	1	0	0	1	6
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	0	0	0	0	0	0	0	0
b. No. of instances few	0	0	0	0	0	0	0	0	0	0	0
c. Verification	0	0	0	0	0	0	0	0	0	0	0
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	1	0	0	0	0	1
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	0	0	0	0	0	0	0	0	0	0	0
b. Sci "discovers" facts	0	0	1	1	1	1	1	1	0	1	7
c. Tone is "factual"	0	0	1	0	0	0	0	0	0	0	1
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	0	0	0	0	0	0
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	0	0	[illegible]	0	0	0	0	0	0	0	0

25 / 190 = 13 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	0	1	1	1	1	1	0	0	1	7
Phenomenal	0	0	0	1	1	1	1	0	0	1	5
2. Computative predictions	0	1	0	1	0	0	0	1	1	0	4
Predictions "expected"	0	1	0	0	0	0	0	1	0	0	2
Recipe-like procedures	0	0	0	0	0	0	0	1	0	0	1
Only terms in an equatn	0	1	0	0	0	0	0	1	0	0	2
3. Definition: Nominalistic	0	0	0	0	0	0	0	0	0	0	0
Operational	0	0	0	0	0	0	0	0	0	0	0
4. Theories: Fictions	0	0	0	0	0	1	0	0	0	0	1
Rules of thumb	0	0	0	0	0	0	0	0	0	0	0
Convenient, prag	0	1	0	0	0	0	0	1	0	0	2

24 / 110 = 22 %

APPENDIX E

PHILOSOPHY CHECKLIST **TEXT K**

Textbook: Duncan: Physics — Instance

Random Page Number:	50	51	260	101	19	210	99	252	179	80	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	0	0	0	1	1	0	0	0	0	3
b. "Observation" mentioned	1	0	0	0	1	0	0	0	0	0	2
c. Observation objective	1	0	0	0	1	1	0	0	0	0	3
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	0	1	1	0	0	0	0	2
b. No. of instances few	0	0	0	0	1	0	0	0	0	0	1
c. Verification	1	0	0	0	1	1	0	0	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	1	1	0	0	1	1	0	0	0	0	4
b. Sci "discovers" facts	0	0	0	0	1	1	0	0	0	0	2
c. Tone is "factual"	0	1	0	0	1	1	0	0	0	0	3
d. Questions answd immedly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	1	0	0	0	0	0	1	0	0	0	2
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	1	0	0	0	0	1
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	0	0	0	0	0	1	0	0	0	0	1

27 / 190 = 14 %

B. INSTRUMENTALISM:	50	51	260	101	19	210	99	252	179	80	T
1. Observation: Assumed obj	1	0	0	0	1	1	1	0	0	0	4
Phenomenal	1	0	0	1	0	1	0	0	0	0	3
2. Computative predictions	0	1	1	1	1	0	1	1	1	1	8
Predictions "expected"	0	1	1	1	1	0	1	1	1	1	8
Recipe-like procedures	0	1	1	1	1	0	1	0	0	1	6
Only terms in an equatn	0	1	1	1	1	0	1	0	0	1	6
3. Definition: Nominalistic	1	1	0	1	0	0	0	0	0	0	3
Operational	0	0	0	1	1	0	1	0	0	0	3
4. Theories: Fictions	1	0	1	1	0	0	0	1	1	0	5
Rules of thumb	0	0	1	1	0	0	0	1	1	0	4
Convenient, prag	1	1	0	1	1	1	1	0	0	1	7

57 / 110 = 52 %

PHILOSOPHY CHECKLIST **TEXT L**

Textbook: Pople: Sci to 16	Instance										
Random Page Number:	82	107	45	116	22	218	92	40	204	187	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	0	1	0	1	1	1	1	0	0	6
b. "Observation" mentioned	0	0	0	0	0	0	0	0	0	0	0
c. Observation objective	1	1	1	0	1	1	1	1	1	0	8
2. Inductive generalisations											
a. Inductive gnrlstns made	1	0	0	0	1	1	1	0	0	0	4
b. No. of instances few	1	0	0	0	1	1	1	0	0	0	4
c. Verification	1	1	0	0	1	0	0	0	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	1	0	0	0	0	1	0	0	0	0	2
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	1	1	1	0	1	1	1	1	1	0	8
b. Sci "discovers" facts	1	0	1	0	1	1	1	1	1	0	7
c. Tone is "factual"	1	1	1	0	1	1	1	1	1	0	8
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	1	0	0	1	0	0	0	0	2
f. Technological fix	0	0	1	0	0	0	0	0	0	0	1
g. Linear accretion	0	0	0	0	0	0	0	0	0	0	0
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	1	0	0	0	0	0	0	0	0	0	1

54 / 190 = 28 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	1	1	0	1	1	1	1	1	0	8
Phenomenal	0	0	0	0	0	0	1	0	0	0	1
2. Computative predictions	1	1	1	1	0	1	1	1	1	1	9
Predictions "expected"	0	1	1	1	0	0	0	0	0	1	4
Recipe-like procedures	0	1	0	1	0	0	0	0	0	1	3
Only terms in an equatn	1	0	0	0	0	0	0	0	0	1	2
3. Definition: Nominalistic	0	0	0	0	1	0	0	0	1	0	2
Operational	1	1	0	0	0	0	0	0	0	1	3
4. Theories: Fictions	1	0	0	0	0	0	0	0	0	1	2
Rules of thumb	0	1	0	1	1	1	1	1	1	0	7
Convenient, prag	0	1	1	1	1	1	1	1	1	1	9

50 / 110 = 45 %

PHILOSOPHY CHECKLIST **TEXT M**

Textbook: Atherton, et al.:	Instance										
Random Page Number:	379	242	204	151	182	240	35	342	252	55	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science bgns with obs	1	0	1	0	1	1	1	1	1	1	8
b. "Observation" mentned	0	0	1	0	1	1	1	0	1	0	5
c. Observation objective	1	0	1	0	1	1	1	1	1	1	8
2. Inductive generalisation											
a. Inductive gnrlstns	0	0	1	0	1	1	1	1	0	1	6
b. No. of instances few	0	0	1	0	1	1	1	1	0	1	6
c. Verification	0	0	0	0	1	1	1	1	0	1	5
3. Laws and theories											
a. "Law", "theory" mntnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs leads rig to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique con	1	0	1	0	1	1	0	0	0	1	5
4. Proven knowledge											
a. Proven knowledge	1	0	0	0	1	1	1	1	0	1	6
b. Sci "discovers" facts	1	0	0	0	0	0	1	1	1	1	5
c. Tone is "factual"	1	1	1	0	1	1	1	1	0	1	8
d. Question answ immdtly	0	0	1	0	0	0	0	0	0	0	1
e. Science is reliable	0	0	0	0	0	0	0	0	1	0	1
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	1	0	0	0	0	0	0	0	0	0	1
h. Science always logicl	0	0	0	0	0	0	0	0	0	0	0
i. Sci leads to abs tru	0	0	0	0	0	0	0	0	0	0	0

65 / 190 = 34 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	0	0	1	1	1	1	1	1	1	8
Phenomenal	1	0	1	1	0	0	1	0	0	1	5
2. Computative predictions	1	0	0	1	0	0	1	0	0	1	4
Predictions "expected"	0	0	1	1	0	0	1	0	0	1	4
Recipe-like procedures	0	0	0	1	0	1	1	0	0	1	4
Only terms in an equtn	0	0	0	1	0	1	1	0	0	1	4
3. Definition: Nominalistic	0	0	1	0	1	0	0	1	0	0	3
Operational	0	0	0	1	0	1	1	0	0	0	3
4. Theories: Fictions	0	1	1	1	0	0	0	0	0	0	3
Rules of thumb	1	1	1	1	0	1	0	0	0	0	5
Convennt, prag	1	1	0	1	0	1	1	0	1	1	7

50 / 110 = 45 %

PHILOSOPHY CHECKLIST **TEXT N**

Text: Lewis & Waller:

Instance — Random Page Number:	340	203	326	47	277	140	374	31	42	37	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	0	1	1	1	1	1	1	1	1	8
b. "Observation" mentioned	0	0	0	0	1	0	1	0	0	0	2
c. Observation objective	0	0	1	1	1	1	1	1	0	0	6
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	1	0	1	1	1	1	1	1	7
b. No. of instances few	0	0	1	0	0	0	1	0	0	0	2
c. Verification	0	0	1	1	0	1	1	0	0	0	4
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	1	0	0	0	0	0	1
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	1	0	1	0	1	1	0	1	0	0	5
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	1	0	1	1	1	1	9
b. Sci "discovers" facts	1	1	1	0	0	1	1	1	1	1	8
c. Tone is "factual"	1	1	1	1	1	1	1	1	1	0	9
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	1	0	0	1	0	0	0	0	0	0	2
f. Technological fix	1	0	0	0	0	0	0	0	0	0	1
g. Linear accretion	1	0	1	0	0	1	1	1	0	1	6
h. Science always logical	0	0	0	1	0	0	0	0	0	0	1
i. Science leads to abs tr	1	0	1	0	1	1	1	1	0	0	6

77 / 190 = 41 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	0	1	1	1	1	1	1	0	0	6
Phenomenal	1	1	1	1	1	1	1	1	0	0	8
2. Computative predictions	0	0	1	1	0	0	0	0	0	0	2
Predictions "expected"	0	0	1	1	0	0	0	0	0	0	2
Recipe-like procedures	0	1	0	1	1	1	1	0	0	0	5
Only terms in an equatn	0	0	0	1	0	0	0	0	0	0	1
3. Definition: Nominalistic	0	0	0	0	1	0	0	0	0	0	1
Operational	0	1	0	1	0	0	0	0	0	0	2
4. Theories: Fictions	1	1	1	1	1	0	0	0	0	0	5
Rules of thumb	1	1	1	1	1	1	1	0	0	0	7
Convenient, prag	1	1	1	1	1	1	1	0	0	0	7

46 / 110 = 42 %

PHILOSOPHY CHECKLIST **TEXT O**

Textbook: Pople: Explg Phys	Instance										
Random Page Number:	77	207	240	188	109	114	151	182	51	32	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with ob	1	1	1	1	1	1	1	1	0	1	9
b. "Observation" mentiond	0	0	0	0	0	0	0	0	0	0	0
c. Observation objective	1	1	1	1	1	1	1	0	0	1	8
2. Inductive generalisations											
a. Inductive gnrlstn made	0	0	0	0	0	0	0	0	0	0	0
b. No. of instances few	0	0	0	0	0	0	0	0	0	0	0
c. Verification	0	0	0	0	0	0	0	0	0	0	0
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique conc	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	1	1	1	1	0	1	9
b. Sci "discovers" facts	1	1	1	1	1	1	1	1	0	1	9
c. Tone is "factual"	1	1	1	1	1	1	1	1	0	1	9
d. Question answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	1	1	1	1	1	1	1	1	0	1	9
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs t	1	1	1	1	1	1	1	1	0	1	9

62 / 190 = 33 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	1	1	1	1	1	1	0	0	1	8
Phenomenal	0	0	0	0	0	1	0	0	0	0	1
2. Computative predictions	1	1	1	1	1	1	0	0	1	0	7
Predictions "expected"	1	1	1	1	1	1	0	0	1	0	7
Recipe-like procedures	1	1	1	1	1	1	0	0	1	0	7
Only terms in an equatn	0	0	0	0	0	1	0	0	1	0	2
3. Definition: Nominalistic	0	0	0	0	0	0	0	0	0	0	0
Operational	1	1	1	0	0	0	0	0	1	0	4
4. Theories: Fictions	1	1	1	0	0	0	0	0	1	0	4
Rules of thumb	1	1	1	0	0	1	0	1	1	0	6
Convenient, prg	1	1	1	0	0	0	0	0	1	0	4

50 / 110 = 45 %

PHILOSOPHY CHECKLIST **TEXT P**

Textbook: Warren: Phys Alive	Instance										
Random Page Number:	21	42	37	189	14	168	137	169	190	221	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	1	1	1	1	1	1	1	1	1	9
b. "Observation" mentioned	0	1	0	0	0	0	0	1	1	1	4
c. Observation objective	0	1	1	1	1	1	1	1	1	1	9
2. Inductive generalisations											
a. Inductive gnrlstns made	0	1	1	1	1	1	1	1	1	1	9
b. No. of instances few	0	0	0	0	0	0	0	0	1	0	1
c. Verification	1	0	0	1	1	1	1	0	1	1	7
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	0	1	0	1	1	1	1	1	1	0	7
b. Sci "discovers" facts	0	1	0	1	1	1	1	1	1	1	8
c. Tone is "factual"	0	1	0	1	1	1	1	1	1	0	7
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	1	0	1	1	1	1	1	1	0	7
h. Science always logical	0	0	0	0	1	0	1	0	0	0	2
i. Science leads to abs tr	0	1	0	1	1	1	1	1	1	0	7

77 / 190 = 41 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	1	1	1	1	1	1	1	1	1	9
Phenomenal	1	0	0	0	0	1	0	1	0	0	3
2. Computative predictions	1	0	0	0	0	1	1	1	0	1	5
Predictions "expected"	1	0	0	0	0	1	0	1	1	1	5
Recipe-like procedures	1	0	0	0	0	1	0	1	0	0	3
Only terms in an equatn	1	0	0	0	0	1	0	1	0	0	3
3. Definition: Nominalistic	0	0	0	0	0	0	0	0	0	1	1
Operational	0	0	0	0	0	1	0	1	0	0	2
4. Theories: Fictions	0	0	0	0	0	0	0	0	1	1	2
Rules of thumb	1	0	1	1	1	1	0	1	0	1	7
Convenient, prag	1	1	1	1	1	1	1	1	0	0	8

48 / 110 = 44 %

PHILOSOPHY CHECKLIST **TEXT Q**

Textbook: Lambert: Physics — Instance

Random Page Number:	94	249	26	8	228	218	102	90	49	243	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	1	1	1	1	1	1	1	0	1	9
b. "Observation" mentioned	1	0	1	1	1	0	0	1	0	0	5
c. Observation objective	1	0	1	1	1	1	1	1	0	0	7
2. Inductive generalisations											
a. Inductive gnrlstns made	1	0	1	0	1	1	1	1	0	1	7
b. No. of instances few	1	0	1	0	0	0	0	1	0	0	3
c. Verification	1	0	1	0	0	0	0	1	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	1	0	1	0	0	0	0	0	0	0	2
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	1	1	1	0	0	1	8
b. Sci "discovers" facts	1	1	1	0	0	0	1	1	0	0	5
c. Tone is "factual"	1	0	1	1	1	1	1	0	0	0	6
d. Questions answd immdtly	1	0	0	0	1	0	0	0	0	0	2
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	1	0	1	0	1	1	1	1	0	1	7
h. Science always logical	0	0	0	0	1	0	1	0	0	0	2
i. Science leads to abs tr	1	0	1	0	1	1	1	1	0	1	7

73 / 190 = 38 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	0	1	1	1	1	1	1	0	0	7
Phenomenal	1	1	1	0	0	0	0	0	0	0	3
2. Computative predictions	0	0	0	0	0	0	0	1	0	0	1
Predictions "expected"	0	0	0	0	0	0	1	1	0	0	2
Recipe-like procedures	1	0	0	0	1	0	1	1	1	1	6
Only terms in an equatn	0	0	0	0	0	0	1	1	0	0	2
3. Definition: Nominalistic	1	1	1	0	0	0	1	1	0	0	5
Operational	0	0	0	0	0	0	1	1	0	0	2
4. Theories: Fictions	0	0	0	0	0	0	1	1	0	1	3
Rules of thumb	1	1	1	0	1	0	1	1	1	1	8
Convenient, prag	1	1	0	0	1	1	0	1	1	1	7

46 / 110 = 42 %

PHILOSOPHY CHECKLIST **TEXT R**

Textbook: Harvard Physics

Random Page Number:	21	43	37	179	14	153	137	177	85	48	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	0	0	0	1	0	1	1	0	0	3
b. "Observation" mentioned	0	0	0	0	1	0	1	1	0	0	3
c. Observation objective	0	0	0	0	0	0	1	1	0	0	2
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	0	1	1	1	1	0	0	4
b. No. of instances few	0	0	0	0	0	0	0	1	0	0	1
c. Verification	0	0	0	0	1	0	1	1	0	0	3
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	1	0	1
4. Proven knowledge											
a. Proven knowledge	0	0	0	0	0	0	0	0	1	0	1
b. Sci "discovers" facts	0	0	0	0	0	0	0	1	0	0	1
c. Tone is "factual"	0	0	0	0	0	0	0	0	0	0	0
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	0	0	0	0	0	0
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	0	0	0	0	0	0	0	0	0	0	0

19 / 190 = 10 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	0	0	0	0	0	1	1	0	0	2
Phenomenal	0	0	0	0	0	0	0	0	0	0	0
2. Computative predictions	1	0	0	1	0	0	0	0	1	1	4
Predictions "expected"	1	0	0	1	0	0	0	0	0	0	2
Recipe-like procedures	1	0	0	1	0	0	0	0	0	1	3
Only terms in an equatn	1	0	0	1	0	0	0	0	0	0	2
3. Definition: Nominalistic	0	0	0	0	0	0	0	0	0	0	0
Operational	0	0	0	0	0	0	0	0	1	1	2
4. Theories: Fictions	0	0	0	1	0	0	1	0	1	1	4
Rules of thumb	0	0	0	0	0	0	0	0	0	0	0
Convenient, prag	0	0	0	0	0	0	0	0	0	0	0

19 / 110 = 17 %

PHILOSOPHY CHECKLIST **TEXT S**

Textbook: CHEM Study

	Instance										
Random Page Number:	448	91	342	9	62	283	218	16	51	150	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	1	1	1	1	1	1	1	1	0	9
b. "Observation" mentioned	1	1	1	1	1	1	1	1	1	0	9
c. Observation objective	1	1	1	1	1	1	1	1	1	0	9
2. Inductive generalisations											
a. Inductive gnrlstns made	1	1	1	0	1	1	1	1	1	1	9
b. No. of instances few	0	1	0	0	1	0	0	0	1	0	3
c. Verification	0	1	0	1	1	0	0	0	1	0	4
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	1	1	2
b. Obs. leads rig. to laws	0	0	0	0	0	0	0	0	0	0	0
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	1	0	1	1	0	1	0	0	1	0	5
b. Sci "discovers" facts	1	1	1	0	1	1	1	0	1	0	7
c. Tone is "factual"	1	0	1	1	0	1	0	0	0	1	5
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	0	0	0	0	0	0
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	0	0	0	0	0	0	0	0	0	0	0

62 / 190 = 33 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	1	1	1	1	1	1	1	1	0	9
Phenomenal	0	0	0	0	0	0	0	0	0	1	1
2. Computative predictions	0	1	0	0	1	0	1	1	1	1	6
Predictions "expected"	0	1	0	0	0	1	0	1	0	1	4
Recipe-like procedures	0	0	0	0	0	0	0	0	0	0	0
Only terms in an equatn	0	0	0	0	0	0	1	0	0	0	1
3. Definition: Nominalistic	0	0	0	0	0	0	0	0	0	0	0
Operational	0	0	0	0	0	0	0	0	0	0	0
4. Theories: Fictions	0	1	0	0	0	0	1	1	0	1	4
Rules of thumb	0	0	0	0	0	0	1	0	0	0	1
Convenient, prag	0	0	0	0	0	0	0	0	0	0	0

26 / 110 = 24 %

Textbook: Physics: PSSC

Random Page Number:	109	114	151	182	450	240	487	33	342	252	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science bgn with obs	1	1	0	1	1	1	1	1	0	1	8
b. "Observation" mentnd	1	1	0	1	1	0	1	0	0	1	6
c. Observation objectiv	1	1	1	1	1	0	1	1	0	1	8
2. Inductive generalistns											
a. Inductive gnrlstns	1	1	0	0	1	0	1	0	0	1	5
b. No. of instances few	1	1	0	0	0	0	1	0	0	0	3
c. Verification	1	1	0	0	1	0	1	0	0	0	4
3. Laws and theories											
a. "Law", "theory" mntd	0	0	1	0	0	0	0	0	0	1	2
b. Obs lead rig to laws	0	0	1	0	0	0	0	0	0	0	1
c. Laws mature theories	0	0	1	0	0	0	0	0	0	0	1
d. Data yield unique cn	0	0	0	0	0	0	0	0	0	0	0
4. Proven knowledge											
a. Proven knowledge	0	0	1	1	0	0	1	0	0	1	4
b. Sci "discovers" fact	1	1	1	1	0	0	1	1	0	1	7
c. Tone is "factual"	0	0	0	1	0	0	0	0	0	1	2
d. Questions answd immd	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	0	0	0	0	0	0	0	0	0	0
h. Science always logcl	0	0	0	0	0	0	0	0	0	0	0
i. Sci leads to abs tr	0	0	0	0	0	0	0	0	0	0	0

51 / 190 = 27 %

B. INSTRUMENTALISM:	109	114	151	182	450	240	487	33	342	252	T
1. Observation: Assumd obj	1	1	0	1	1	1	1	1	0	1	8
Phenomenal	0	0	0	0	0	0	0	0	0	0	0
2. Computative predictions	1	1	0	0	0	1	0	0	1	0	4
Prediction "expected"	0	0	0	0	0	1	0	0	1	0	2
Recipe-like procedure	0	0	0	0	0	1	0	0	1	0	2
Only terms in an equn	0	0	0	0	0	1	0	0	1	0	2
3. Definition: Nominalistc	0	0	0	0	0	0	0	0	0	0	0
Operational	0	0	0	0	0	1	0	0	0	0	1
4. Theories: Fictions	0	0	1	0	0	1	0	0	1	0	3
Rule of thumb	0	0	1	0	0	1	0	0	1	0	3
Convnnt, prag	0	0	0	0	0	1	0	0	1	0	2

27 / 110 = 25 %

PHILOSOPHY CHECKLIST **TEXT U**

Textbook: Physics: Nigerian	Instance										
	Book 1			Book 2				Book 3			
Random Page Number:	10	14	59	82	47	24	140	33	42	52	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	0	1	0	1	1	1	0	0	1	1	6
b. "Observation" mentioned	0	0	0	0	0	0	0	0	0	0	0
c. Observation objective	0	1	0	1	1	1	0	0	1	1	6
2. Inductive generalisations											
a. Inductive gnrlstns made	0	0	0	1	0	0	0	0	1	1	3
b. No. of instances few	0	0	0	0	0	0	0	0	0	0	0
c. Verification	0	1	0	1	0	0	0	0	1	1	4
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	1	0	0	0	0	1	1	3
b. Obs. leads rig. to laws	0	0	0	1	0	0	0	0	1	1	3
c. Laws mature theories	0	0	0	0	0	0	0	0	0	0	0
d. Data yield unique concl	0	1	0	1	1	0	0	0	1	1	5
4. Proven knowledge											
a. Proven knowledge	0	1	1	1	1	1	1	0	1	1	8
b. Sci "discovers" facts	1	1	1	1	0	0	0	0	0	0	4
c. Tone is "factual"	1	1	1	1	1	1	1	1	1	0	9
d. Questions answd immdtly	0	1	0	0	0	0	0	0	0	0	1
e. Science is reliable	0	0	0	1	1	0	0	0	0	0	2
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	0	1	1	1	0	0	0	1	1	1	6
h. Science always logical	1	0	1	0	1	0	1	1	0	0	5
i. Science leads to abs tr	0	1	0	1	0	1	1	1	1	1	7

72 / 190 = 38 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	0	1	0	0	1	1	0	0	1	1	5
Phenomenal	1	0	1	0	1	0	1	0	0	0	4
2. Computative predictions	1	0	1	0	1	1	1	1	0	0	6
Predictions "expected"	1	0	1	1	1	0	1	1	0	0	6
Recipe-like procedures	1	0	1	1	1	0	1	1	0	0	6
Only terms in an equatn	1	0	1	1	1	0	1	1	0	0	6
3. Definition: Nominalistic	0	1	1	1	0	0	0	0	0	0	3
Operational	1	0	0	0	0	1	1	1	0	0	4
4. Theories: Fictions	1	0	0	1	0	0	0	1	0	0	3
Rules of thumb	0	1	1	0	0	0	1	1	0	0	4
Convenient, prag	1	1	0	0	0	0	1	1	1	0	5

52 / 110 = 47 %

PHILOSOPHY CHECKLIST **TEXT V**

Textbook: Physics: Kenyan	Instance										
	Book 1			Book 2			Bk 3		Bk 4		-
Random Page Number:	91	14	51	82	45	24	7	33	34	25	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	1	0	1	1	1	1	1	0	1	8
b. "Observation" mentioned	0	1	0	1	1	0	1	0	0	0	4
c. Observation objective	1	1	1	1	1	0	1	1	0	1	8
2. Inductive generalisations											
a. Inductive gnrlstns made	1	1	0	0	1	0	1	1	0	0	5
b. No. of instances few	0	1	0	0	0	0	1	0	0	0	2
c. Verification	1	1	0	0	1	0	1	0	0	0	4
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	1	0	0	0	0	0	0	0	1
b. Obs. leads rig. to laws	0	0	1	0	0	0	0	0	0	0	1
c. Laws mature theories	0	0	1	0	0	0	0	0	0	0	1
d. Data yield unique concl	1	1	0	1	1	0	1	0	0	1	6
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	0	1	1	1	0	1	8
b. Sci "discovers" facts	1	1	1	1	0	0	1	1	0	0	6
c. Tone is "factual"	0	0	0	1	0	0	1	0	0	1	3
d. Questions answd immdtly	0	0	0	0	0	0	0	0	0	0	0
e. Science is reliable	0	0	0	0	0	0	0	0	0	0	0
f. Technological fix	0	0	0	0	0	0	0	0	0	0	0
g. Linear accretion	1	0	1	1	0	1	1	0	0	0	5
h. Science always logical	0	0	0	0	0	0	0	0	0	0	0
i. Science leads to abs tr	1	1	1	1	0	1	0	0	0	1	6

68 / 190 = 36 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	1	0	1	1	1	1	1	0	1	8
Phenomenal	1	0	0	1	1	0	1	0	0	0	4
2. Computative predictions	1	1	0	1	0	1	0	0	1	0	5
Predictions "expected"	1	0	0	1	0	1	0	0	1	0	4
Recipe-like procedures	1	0	0	1	0	1	0	0	1	0	4
Only terms in an equatn	1	0	0	1	0	1	0	0	1	0	4
3. Definition: Nominalistic	1	0	0	1	0	0	0	0	1	0	3
Operational	0	1	0	0	0	1	0	0	0	0	2
4. Theories: Fictions	0	0	1	0	0	1	0	0	1	0	3
Rules of thumb	0	0	1	0	0	1	0	0	1	0	3
Convenient, prag	1	0	0	0	0	1	0	0	1	0	3

43 / 110 = 39 %

PHILOSOPHY CHECKLIST **TEXT W**

Textbook: Jansen & Dekker

	Instance										
	Standard 6					Standard 7					
Random Page Number:	18	14	51	82	45	24	7	75	114	59	T
A. INDUCTIVIST-EMPIRICISM:											
1. Observation											
a. Science begins with obs	1	1	1	1	1	1	0	0	1	1	8
b. "Observation" mentioned	0	1	0	0	0	0	0	0	1	0	2
c. Observation objective	1	1	1	1	1	1	0	0	1	1	8
2. Inductive generalisations											
a. Inductive gnrlstns made	1	1	0	0	1	1	0	0	1	0	5
b. No. of instances few	0	1	0	0	0	1	0	0	1	0	3
c. Verification	1	1	0	0	1	1	0	0	1	0	5
3. Laws and theories											
a. "Law", "theory" mentnd	0	0	0	0	0	0	0	0	0	0	0
b. Obs. leads rig. to laws	0	1	1	1	0	0	0	0	0	0	3
c. Laws mature theories	0	0	1	1	1	0	0	0	0	0	3
d. Data yield unique concl	1	1	0	0	0	1	0	0	1	0	4
4. Proven knowledge											
a. Proven knowledge	1	1	1	1	1	1	1	1	1	0	9
b. Sci "discovers" facts	1	1	1	1	1	0	0	0	0	0	5
c. Tone is "factual"	1	1	1	1	1	1	0	0	1	1	8
d. Questions answd immdtly	0	0	0	0	0	1	0	0	1	1	3
e. Science is reliable	1	1	1	1	0	0	0	0	0	1	5
f. Technological fix	1	1	1	0	0	0	0	0	0	1	4
g. Linear accretion	0	0	0	0	0	1	0	0	0	0	1
h. Science always logical	0	0	0	0	0	0	1	1	0	0	2
i. Science leads to abs tr	1	1	0	0	1	1	0	0	1	0	5

83 / 190 = 44 %

B. INSTRUMENTALISM:											T
1. Observation: Assumed obj	1	1	1	1	1	1	0	0	1	1	8
Phenomenal	0	1	0	0	1	0	1	1	0	1	5
2. Computative predictions	0	0	0	0	0	0	1	1	1	1	4
Predictions "expected"	0	0	0	0	0	0	1	1	1	1	4
Recipe-like procedures	0	0	1	0	0	0	1	1	1	1	5
Only terms in an equatn	0	0	0	0	0	0	1	1	1	1	4
3. Definition: Nominalistic	1	0	0	0	1	0	1	1	0	1	5
Operational	0	0	0	0	0	0	1	1	0	1	3
4. Theories: Fictions	0	0	0	0	0	0	1	1	0	1	3
Rules of thumb	0	0	0	0	1	0	1	1	0	1	4
Convenient, prag	1	1	1	1	1	1	1	1	1	0	9

54 / 110 = 49 %

APPENDIX F

VOLUME 20
Number 2, 1989

INTERCHANGE

A QUARTERLY REVIEW OF EDUCATION

HISTORY, SCIENCE, AND SCIENCE TEACHING

MICHAEL R. MATTHEWS & IAN WINCHESTER
EDITORS

Published by The Ontario Institute for Studies in Education, Toronto, Canada

Interchange, Vol. 20, No. 2 (Summer, 1989), 33–53

Ptolemy Revived? — The Existence of a Mild Instrumentalism in Some Selected British, American, and South African High School Physical Science Textbooks

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Scientific theories are our intellectual constructions about the nature of the physical world. There are at least two ways of relating scientific theories and the world: the first is called *realism*, and the second *instrumentalism.*

A realist believes that theories actually describe what the world is really like. For the realist, the kinetic theory of gases claims that "gases really are made up of molecules in random motion" (Chalmers, 1986, p. 146). On the other hand, an instrumentalist holds that scientific theories do not actually describe the world, but simply relate sets of observations. For the instrumentalist, the kinetic theory of gases is merely a convenient fiction enabling scientists to relate and make predictions about the observable properties of gases, in order to make use of them in a variety of ways. Theories are only useful devices for prediction.

Instrumentalism, then, is an approach to scientific inquiry which shelves questions about the real nature of the universe, and is solely interested in whether its practical purpose of computative predictions work or not. Instrumentalist science stems from tough-minded, common-sense *empiricism*, which regards all knowledge as coming from sensory experience. The inductivist-empiricist assumes that such sensory observation is objective and theory-free. So too does the instrumentalist.

According to Popper, "the *instrumentalist view* . . . has become an accepted dogma" in contemporary physical science, and in fact "has become part of the current teaching of physics" (1956, p. 360). Since physics teaching begins in schools, it is important to see if instrumentalism is present in school science, and if so, its pros and cons.

Instrumentalism from Ptolemy to Dewey

Saving the Appearances

Instrumentalism has its origins in the compartmentalized thinking, the "controlled schizophrenia," as Koestler puts it, which began to emerge with the Greek astronomers around the 2nd century A.D. In order to account for the retrograde loopings of planetary paths, Ptolemy devised a complex system of 40 wheels within wheels or epicycles. He never believed that there really were wheels out there, but they did "save the appearances" and provided a mechanism for accurately predicting the position of the planets. The astronomer "saved the phenomena" by inventing a suitable hypothesis; it was immaterial whether the hypothesis was true or not, that is, whether it was physically possible or not. As Koestler points out,

> astronomy, after Aristotle, becomes an abstract sky-geometry, divorced from physical reality. . . . It serves a practical purpose as a method for computing tables of the motions of the sun, moon and planets; but as to the real nature of the universe, it has nothing to say. (1959, p. 74)

Copernicus, however, put forward a theory which not only predicted but also explained. The Copernican theory provided a more comprehensive conceptual structure with a much greater power for promoting understanding. It revealed a physical link between planetary motion and theory. Copernicus believed that his theory was a true description of external reality, not a mere fictional hypothesis. It did not matter whether you believed in the existence of Ptolemy's epicycles or not; all that mattered was that his theory worked. However, Copernican theory had to be taken seriously for it attempted to describe what is physically really out there. Copernicus' sun-centred system was more than a computational device.

Realism Versus Phenomenalism

Instrumentalist science is interested only in sensory phenomena, and avoids any reference to a reality behind appearance. William of Occam was against the Aristotelian tendency to create unnecessary entities, such as a reality behind the phenomena. Reality, said Occam, is precisely what appears to the senses. All our knowledge about the world comes through our senses. All being is thus reduced to what is perceived. Theologians were quick to realize that Occam's radical empiricism (or nominalism) meant that spiritual beings, and in particular God, were threatened.

Galileo accepted Copernican heliocentric theory as a true description of reality. Cardinal Bellarmino objected to this realist interpretation, but informed Galileo that it was permissable, from the Church's standpoint, to hold the Copernican system as a mathematical device for saving the appearances. In other words, the Church was willing, temporarily, to accept Galileo's theory in a phenomenalist, instrumentalist sense.

Berkeley's Instrumentalism

Similarly, Bishop George Berkeley saw Newton's theory as a serious competitor to religion. What distressed Berkeley was that Newton talked about "forces" as if they were real. For Newton, forces were more than mere terms in an equation. Berkeley regarded forces in mechanics as analogous to Ptolemaic epicycles in astronomy, useful in calculating the motions of bodies, but without real existence. Berkeley's instrumentalism stemmed from his bold empiricism: all our knowledge comes through our senses. Since force is unobservable, we cannot have any knowledge of it. All we can observe is the motion of bodies. Indeed, the notion of force as a causal agent derives from the fact that it is a concept in the mind. Thus Berkeley's instrumentalism derives from his idealistic philosophy.

Mill's Inductivism as a Form of Instrumentalism

The aim of 19th-century positivists like John Stuart Mill was to eliminate metaphysics from science as far as possible. A tough-minded empiricist approach was adopted. Whatever was beyond the reach of experience should be rejected.

Mill was a thorough-going inductivist. He held that scientific inquiry is a process of inductive generalization from the results of observations and experiments. Mill suggested that the world of appearances should be accepted as it is. If the external world is defined as a set of phenomenal objects, the existence of an underlying sub-stratum becomes a pseudo-problem. As Gardner notes (1983, p. 20), Mill saw nothing wrong with belief in a reality behind the phenomenon; he simply found it superfluous, adding nothing to what we already know. Hence, in his view, the object of scientific inquiry should begin and end with the phenomenal world.

In the 1920s, the logical positivism of the Vienna Circle reinforced the inductivist view. It is meaningless to talk about what lies "behind" or "beyond" experience. For positivists, phenomenalism is an adequate approach to science, just as realism is. Both yield successful results. However, the language of phenomenalism is more convenient.

Dewey's Instrumentalism and Pragmatism
An instrumentalist approach to scientific inquiry tends to be pragmatic and utilitarian. Like Mill, John Dewey assumed a phenomenalist standpoint. For a realist, truth is the correspondence between an assertion and reality. For Dewey, truth is that which is confirmed by testing; it is that which works. Truth is created when an assertion is confirmed.

Suppose there is a penny in a box. The realist says, "There is a penny in the box," whether or not the assertion is verified. The pragmatist says, "There is a penny in the box," only when, on opening the box, he sees the penny. Truth is instrumental and expedient. Theories are not "judged in terms of truth or falsity but rather in terms of their usefulness as instruments" (Chalmers, 1986, p. 147). Popper rejects this notion of truth because it is relativistic.

Instrumentalism distinguishes clearly between observation and theory. For the instrumentalist, observation is objective and theory-independent. Scientific theories are mere fictions, nothing but convenient instruments. Theories may, or may not, describe the real world; it does not matter whether they do or not. What matters is the relationships between observations. Thus instrumentalism is a shallow form of realism dealing with appearances only.

Instrumentalism in School Science Textbooks

Cawthron and Rowell (1978, p. 31) suggest that one way of investigating whether instrumentalism is present in school science is to analyze the contents of the most widely used textbooks in school science courses. No matter how objective a science textbook purports to be, it contains explicit or tacit assertions which reflect a particular philosophy of science. Although it is recognized that the contents of textbooks represent the beliefs of their authors, nevertheless they must also reflect the views of the practising school science community who give the texts their popularity in the first place, and who presumably then become influenced by them.

The literature on the subject suggests that "a scrutiny of school science texts almost invariably reveals an implicit epistemological preoccupation with the existence of 'objective' reality" (Cawthron & Rowell, 1978, p. 32). Such textbooks "project an image of science which can be called empiricist-inductivist" (p. 33). Rowell and Cawthron state that "our texts portray science as some inexorable linear pursuit of truth" (1982, p. 93).

In a careful reading of nearly all the introductory first-year, non-major chemistry and physics textbooks in use in the United States during the 1979–1980 academic year, Factor and Kooser point out that

> as with the science and society texts, the narrow inductivism and empiricism of the 19th century, particularly that of John Stuart Mill, plays a formative role in the image of science in skills and drills texts. (1981, p. 28)

The empiricist view is strongly present in textbooks advocating the heuristic method of science education. Discovery by activity, as proposed generally by Dewey, and more specifically in science education by Armstrong, and more recently in *Science — A Process Approach*, emphasizes the role of observation and induction. Driver criticizes inductionism in that it "suggests that there is one unique interpretation of the data" (1983, p. 48). In fact, observation is theory-laden, and children can and do form multiple explanations for events, each of which accounts for the data in a particular way.

Kuhn observed that textbooks "address themselves to an already articulated body of problems, data, and theory" (1970, p. 136). The increasing reliance on textbooks, says Kuhn, accompanies the emergence of a first paradigm in any field of science. Furthermore, reliance on textbooks is becoming increasingly evident, especially in Third World countries, where the teacher often has little, if any, training in science. Thus the textbook is fast becoming the only vehicle for transmitting a correct image of science. As Kuhn says,

> More than any other single aspect of science, that pedagogic form (namely, the textbook) has determined our image of the nature of science. (1970, p. 143)

The aim of this study is to determine the image of science portrayed in a number of selected British, American, and South African high school physical science textbooks in widespread current use in schools. On the basis of the above literature, as well as our acquaintance with school texts, we made the hypothesis that *high school physical science textbooks in current use portray an empiricist-inductivist and, by implication, an instrumentalist image of science.*

Method

We began by listing the essential features of inductivism, empiricism, and instrumentalism and then drawing up a systematic check-list or questionnaire for the different philosophies. The check-list was used to try to ensure a uniform approach to our reading of selected textbooks. By careful reading, a reasonably consistent quantitative and comparative assessment emerged.

The following characteristics were chosen as being characteristic of the inductivist-empiricist view:

1. Science begins with observation.
2. Observation is objective.
3. Inductive generalizations arise from several instances.
4. Experimental data yield a unique conclusion.
5. Observation leads rigorously to laws and theories.
6. Laws are mature theories.
7. Science produces proven knowledge.

The following characteristics were chosen as being characteristic of the instrumentalist view:

1. Observation is objective.
2. Computative predictions relate observations.
3. Predictions are "expected."
4. Calculations are recipe-like.
5. Definitions are nominalistic.
6. Definitions are operational.

7. Theories are mere fictions.
8. Theories are not informative about the physical world.
9. Theories are only convenient instruments.

On the basis of these critiera, the text analysis (see Table 2) was drawn up.

Sixteen high school physical science textbooks were chosen for the study. Seven of these are texts widely used in British schools, as well as in English-speaking schools in Third World countries, such as Lesotho and Swaziland. Six are texts widely used in South African high schools, and are designed to cover the "New" 1985 Standard 8 and 9 Syllabus. (Average pupil age in Standards 8 and 9 is 15 and 16 years old respectively.) The reason for choosing these Standards was to align the textbooks with the corresponding British 0-level and GCSE, and the American *Project Physics*, *CHEM Study*, and *PSSC Physics*.

Eight of the books were read from cover to cover in order to obtain an overall assessment of their philosophy. These were A, B, C, D, E, F, G, and N in the list below.

Textbooks Examined

South African

A. Brink and Jones. (1985). *Physical Science Standard 8*, Juta.

B. Pienaar, Walters, de Jager, Schreuder. (1985). *Senior Physical Science 8*, Maskew Miller Longman.

C. Broster and James. (1987). *Successful Science (Physical Science) 8*, Oxford University Press.

D. Brink and Jones. (1986). *Physical Science Standard 9*, Juta.

E. Pienaar, Walters, Schreuder, de Jager. (1986). *Senior Physical Science 9*, Maskew Miller Longman.

F. Broster and James. (1987). *Successful Science (Physical Science) 9*, Oxford University Press.

British

G. Duncan Tom. (1987). *GCSE Physics*, 2nd Edition, John Murray.

H. Pople and Williams. (1980). *Science to Sixteen*, Oxford University Press.

I. Atherton, Duncan, Mackean. (1983). *Science for Today and Tomorrow*, John Murray.

J. Lewis and Waller. (1986). *Thinking Chemistry (GCSE Version)*, Oxford University Press.

K. Pople. (1986). *Explaining Physics (GCSE Version)*, Oxford University Press.

L. Warren P. (1985). *Physics Alive*, John Murray.

M. Lambert. (1985). *Physics for First Examinations*, Blackie.

American

N. The Project Physics Course (Harvard). (1970). *Concepts of Motion*, Holt, Rinehart and Winston.

O. CHEM Study. (1968). *Chemistry an Experimental Science*, Freeman.

P. PSSC. (1960). *Physics*, Heath.

Using random number tables, 10 pages were selected from *each* of the 16 textbooks. Thus, over the 16 selected textbooks, 160 pages were examined for their image of science.

Three distinct features were sought on each page: (a) level of pupil involvement, both in the text as well as in any practical laboratory work; (b) signs of inductivist-empiricism; and (c) signs of instrumentalism.

(a) *Level of Involvement*

It is suggested here that level of involvement, as discussed by Herron (1971) amd Tamir and Lunetta (1978), provides a way of determining the image of science portrayed in the textbook.

Herron determined the pupil's level of involvement in scientific inquiry by examining whether, in a laboratory inquiry, the problem, the method, and the solution, or any combination of these, were given to the pupil. Table 1 summarizes Herron's levels of involvement:

Table 1/Herron's Levels of Involvement

	Problem	Method	Solution
Level 0	Given	Given	Given
Level 1	Given	Given	Not given
Level 2	Given	Not given	Not given
Level 3	Not given	Not given	Not given

In this study, we interpret Levels 0 and 1 as giving to the pupil an image of science that is cumulative, factual, and proven knowledge. Because Levels 2 and 3, being more open-ended, give the pupil more opportunity for imaginative hypothesis-making, a more correct and up-to-date view of science would be conveyed, namely, that scientific inquiry begins with theory, and not with observation.

Tamir and Lunetta (1978) devised a more refined scheme for analyzing level of involvement. However, whereas they apply their procedure to practical laboratory inquiry textbooks, this has been extended here to include both ordinary expository text as well as any laboratory experiments present in the text. The reason for this is that some of the textbooks examined contain both text and inquiries, and others text only, with separate laboratory manuals. Ideas from Romey (1968) and Lowery and Leonard (1978) were also used, especially as far as the role of questions was concerned.

On a given page, the total number of sentences (excluding captions and headings) was counted, as well as the number of facts, questions, definitions, calculations, and instructions to the pupil-reader. These counts were then totalled for all ten pages of a given textbook, and converted into percentages of the total number of sentences on the ten pages sampled. Data for all ten pages of a given textbook were recorded on a text analysis check-list sheet (Section C on Table 2). At the end of the study, 16 text analysis check-list sheets, one for each textbook, had been completed.

These percentages were then transferred, for comparison purposes, to a summary of the text analysis (Section C on Table 3). Averages of these data were then calculated over the 16 texts in order to obtain a general idea of the overall level of involvement. This is reflected in the bar chart (Figure 1). Also included in this section (C) is a count of the number of practical laboratory inquiries found in each textbook, as well as the level of involvement, following Herron (1971).

(b) *Inductivist-Empiricism*
On a given page, all sentences in which the words "observe" or "observation" occurred were counted, and recorded under C8 of Table 2. These were totalled for a given textbook, and converted into a percentage of the total number of sentences in the ten pages examined in that text. These percentages were then summarized in C8 in Table 3 and the bar chart (Figure 1).

As far as the categories 1 to 9 in section A of Table 2 are concerned, if any of these features was encountered at least once, it was awarded a value of 1. If not encountered, a value of 0 was awarded. Totals for the ten selected pages of a given textbook thus have a maximum of ten points. These totals were then transferred to Table 3 for the sake of comparison. In order to obtain an average over all the textbooks for each category A1 to A9, say A1 on Table 3, all five rows of values in A1 were added. These totals were then added and divided by 16, then by 5, to get (for A1 on Table 3) the average 4.4. Because this is 4.4 out of 10, its percentage was charted as 44 percent on Figure 1.

(c) *Instrumentalism*
Similarly, the categories 1 to 8 under Section B of Table 2 were awarded a value of 1 if such features were encountered at least once. If not encountered, a value of 0 was awarded. Totals for each textbook had a maximum score of 10. These totals were transferred to Table 3, and averaged over the 16 textbooks. Again, because these were out of a maximum of ten, they were recorded as percentages on Figure 1.

Classification of statements according to the criteria in the text analysis often called for perceptive judgments. Therefore, in addition to these results, a detailed set of written notes was kept, justifying these judgments, especially where observation, computative predictions, definitions, induction, and theories and laws were concerned.

Also, the index at the back of the books was examined for any reference to keywords such as "theory," "mode," "law," or "observation." In the absence of an index, the book was skimmed from cover to cover for such references, especially in topics like Atomic Theory, Models of the Atom, and so on.

If any statement could be interpreted in either a realist *or* an instrumentalist sense, the latter was assumed. This was deemed to be a legitimate procedure because (a) positivism accepts both realist theory and instrumentalist theory as successful scientific views and (b) the aim of the study was to read the textbook from an instrumentalist perspective. For example, if the word "observe" was used in the text, it was assumed to refer to *objective* observation. In the same way, any calculation of the rote, plug-in type was interpreted as being a convenient computational device with no necessary connection with the real world, and hence not necessarily informative about the world.

Any references to words like "observe," "look," or "measure" were carefully noted and counted. Similarly, any historical assertion about a scientist "discovering" something was recorded. Any conclusions, or rules, or laws were regarded as inductive generalizations.

The lack of any discussion of the meaning or role of theory, or law, as well as of the theory-ladenness of observation, was also taken to be a sign of instrumentalism.

Preface Analysis
Finally, following Lynch and Strube (1985), the prefaces of all the textbooks were read to see if the author(s) claimed to be presenting a particular view of science, or of theory.

Table 2/Examples of Text Analysis: Textbook B (Pienaar and Walters 8)

Page Number: 188315, 40319285 92147234205306 Total

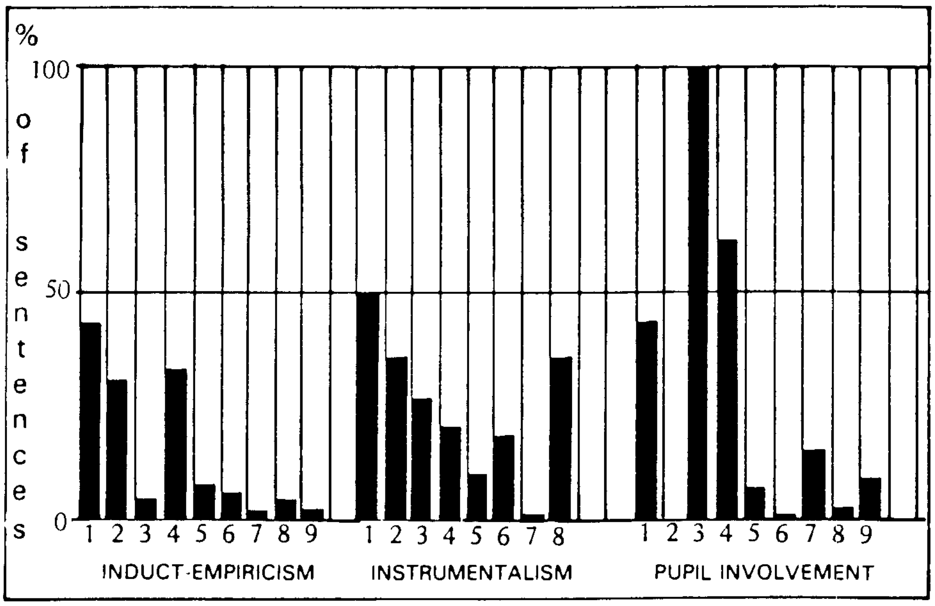
A Inductivist-empiricism											
1 Observation	1	1	1	0	1	0	0	0	1	0	5
Science begins with observation	1	1	1	0	1	0	0	0	1	0	5
Observation objective	1	1	1	0	1	0	0	0	1	0	5
Science "discovers" facts	0	0	1	0	1	0	0	0	1	0	3
Unguided pupil inquiry	0	0	1	0	1	0	0	0	0	0	2
2 Inductive generalisations	0	0	1	0	1	0	0	0	0	0	2
No. of instances few	0	0	1	0	1	0	0	0	0	0	2
Verification	0	0	1	0	1	0	0	0	0	0	2
3 Laws and theories	0	0	0	0	1	0	0	0	1	0	2
Rigorously to laws and theories	0	0	0	0	0	0	0	0	1	0	1
Laws are mature theories	0	0	0	0	0	0	0	0	1	0	1
4 Science proven knowledge	1	1	1	0	1	0	0	1	1	0	6
Unique conclusion	1	0	1	0	1	0	0	0	1	0	4
Facts	1	0	1	0	1	0	0	1	1	1	6
Questions answered immediately	1	0	1	0	0	0	0	0	0	0	2
5. Scientific knowledge is reliable	0	1	0	0	0	0	0	0	1	0	2
6. Science leads to absolute truth	0	0	0	0	0	0	0	1	1	0	2
7. Technological "fix" (solves all)	0	0	0	0	0	0	0	0	0	0	0
8. Linear accretion of knowledge	0	0	0	0	0	0	0	0	1	0	1
9. Science always rational, logical	0	0	0	0	0	0	0	0	1	0	1
B. Instrumentalism											
1. Observation objective	1	1	1	0	1	0	0	0	1	0	5
2. Prediction and control	1	1	1	1	1	0	1	0	0	0	6
Computative predictions	0	1	0	1	0	1	1	0	0	0	4
Predictions "expected"	1	1	1	1	1	0	0	0	0	0	5
3. Convenient instrument	0	1	0	1	1	1	1	0	0	0	5
Recipe-like calculations	0	1	0	1	0	1	1	0	0	0	4
Only terms in equation	0	1	0	1	0	0	0	0	0	0	2
4. Definition: Nominalistic	0	0	1	0	0	0	1	1	0	1	4
Definition: Operational	1	1	0	1	1	0	0	0	1	0	5

5. Theories mere fictions	0	0	0	0	0	0	0	1	0	1	2	
Models convenient devices	1	1	0	1	1	0	0	1	0	1	6	
Mere hypotheses, ad hoc	0	0	0	0	0	0	0	1	0	1	2	
Games	0	0	0	0	1	0	0	0	0	0	1	
Doesn't matter if false	0	1	0	1	0	0	0	1	0	1	4	
Sterile, obscurantist	0	0	0	0	0	0	0	0	0	0	0	
Not informative	0	1	0	0	1	0	0	1	0	1	4	
Mere words	0	0	0	0	0	0	0	1	0	1	2	
6. Passive spectator, uninvolved	0	1	0	1	1	0	0	0	0	0	3	
7. Phenomenal, Superficial, Cosmetic	0	0	0	0	0	0	0	0	0	0	0	
Only observables exist	0	0	0	0	0	0	0	0	0	0	0	
8. Expedient, Pragmatic, Utilitarian	1	1	1	1	1	0	0	0	0	0	5	
C. <u>Level of Involvement</u>											<u>Tot</u>	<u>%</u>
1. No. of lab inquiries	0	0	1	0	0	0	0	0	0	0	1	
2. Practical (level of inquiry)	x	x	0	x	x	x	x	x	x	x	0	
3. Total no. of sentences	16	11	25	13	28	15	26	17	18	16	185	100%
4. No. of facts	14	6	13	3	16	0	0	8	18	15	93	50%
5. No. of questions	0	0	2	0	0	7	4	1	0	1	15	8%
6. No. of definitions	1	0	2	0	1	0	0	1	1	2	8	4%
7. No. of instructions to pupil	2	3	10	0	5	6	5	2	0	1	34	18%
8. No. of references to "observe"	1	2	8	0	5	0	0	0	1	0	17	9%
9. No. of calculations	0	1	0	5	0	2	2	0	0	0	10	

Table 3/Summary of Text Analysis: Totals of each book:

Book (See Table):	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Tot	Av%
A. Inductivist-empiricism																		
1 Observation	4	5	4	2	7	5	2	0	5	1	0	4	5	3	9	6	62	
Science begins with observation	5	5	4	4	7	5	3	6	8	5	9	9	9	3	10	8	100	
Observation objective	5	5	4	2	8	5	3	0	8	1	0	9	7	2	10	8	77	44
Science "discovers" facts	5	3	4	3	6	5	2	7	5	6	9	8	5	1	7	7	83	
Unguided pupil inquiry	3	2	4	2	5	5	2	0	4	0	0	0	2	1	0	0	30	
2 Inductive generalisations	3	2	3	2	5	5	2	4	6	6	0	9	7	4	9	5	72	
No. of instances few	2	2	3	2	5	4	1	0	6	1	0	1	3	1	3	3	37	32
Verification	2	2	2	3	4	4	3	0	5	3	0	7	3	3	4	4	49	
3 Laws and theories	5	2	2	3	1	0	0	2	0	1	0	0	2	0	0	2	20	
Rigorously to laws and theories	4	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	9	6
Laws are mature theories	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
4. Science proven knowledge	6	6	4	5	7	8	4	8	6	9	9	3	4	1	5	4	89	
Unique conclusion	3	4	2	2	5	3	0	0	5	1	0	0	0	1	0	0	26	
Facts	7	6	4	6	8	8	3	8	8	9	9	7	1	0	5	2	91	34
Questions answered immediately	0	2	2	0	2	0	0	0	1	0	0	0	2	0	0	0	9	
5. Scientific knowledge is reliable	1	2	2	2	1	1	2	2	1	0	0	0	0	0	0	0	14	9
6. Science leads to absolute truth	2	2	1	1	2	0	1	1	0	1	0	0	0	0	0	0	11	7
7. Technological "fix" (solves all)	0	0	0	0	3	1	0	1	0	0	0	0	0	0	0	0	5	3
8 Linear accretion of knowledge	2	1	1	1	2	1	1	0	1	0	0	0	0	0	0	0	10	6
9 Science always rational, logical	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	5	3
B. Instrumentalism																		
1 Observation objective	4	5	4	4	8	5	4	0	8	3	8	5	5	1	8	9	81	51
2 Prediction and control	5	6	4	6	7	5	9	9	4	1	6	1	1	1	6	3	72	
Computative predictions	4	4	5	5	4	3	8	2	1	1	1	2	1	4	1	2	48	37
Predictions "expected"	5	5	0	7	5	6	8	4	3	2	1	2	1	3	4	2	57	
3 Convenient instrument	5	5	5	6	3	3	6	7	5	0	5	5	1	3	4	3	66	
Recipe-like calculations	3	4	4	5	2	2	4	3	1	0	1	0	1	3	0	2	35	28
Only terms in equation	2	2	4	5	2	2	4	2	1	0	1	0	1	2	1	2	33	
4 Definition: Nominalistic	3	4	6	3	4	3	1	2	3	1	0	1	4	0	0	0	35	
Definition: Operational	4	5	1	2	2	2	2	3	3	1	4	0	2	2	0	1	34	22

5. Theories mere fictions	5	2	1	6	2	1	4	1	3	3	4	2	1	4	4	2	45	
Models convenient devices	6	6	1	4	4	2	4	7	3	3	4	1	0	0	1	3	49	
Mere hypotheses, ad hoc	1	2	0	2	0	1	4	0	0	0	0	0	0	0	0	0	10	
Games	0	2	0	0	0	0	4	0	0	0	0	1	0	0	0	0	7	
Doesn't matter if false	4	4	0	6	3	2	0	2	2	0	0	0	0	0	0	0	23	12
Sterile, obscurantist	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	
Not informative	1	4	3	3	0	0	0	0	3	1	0	0	0	0	0	1	16	
Mere words	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	
6. Passive spectator, uninvolved	5	3	4	5	2	2	5	1	2	0	4	0	0	0	0	0	33	20
7. Phenomenal, Superficial, Cosmetic	1	0	1	0	1	0	0	0	0	0	0	0	3	0	0	0	6	
Only observables exist	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
8. Expedient, Pragmatic, Utilitarian	5	5	6	5	6	5	4	9	3	2	4	3	0	0	0	2	59	37
C. Level of Involvement																	Tot	
1. No. of lab inquiries	4	1	4	4	7	7	3	0	8	0	0	11	10	5	7	2	73	
2. Practical (level of inquiry)	0	0	0	0	0	0	0	x	0	x	x	1	3	1	1	0	0,4	
3. Total no. of sentences	(						all	100%								)	100%	
4. No. of facts	57	50	42	70	67	57	55	78	80	97	81	52	56	49	60	67	63%	
5. No. of questions	8	8	15	7	7	9	10	13	3	0	17	14	16	5	5	13	9%	
6. No. of definitions	6	4	4	7	4	3	2	4	5	3	2	1	5	2	0	1	3%	
7. No. of instructions to pupil	29	18	23	14	20	20	21	4	12	0	6	33	14	17	33	5	17%	
8. No. of references to "observe"	5	9	9	1	6	2	1	0	4	1	0	4	6	3	7	4	4%	
9. No. of calculations	9	10	22	9	3	19	39	8	5	0	14	1	1	2	0	26	168	



Inductivist-empiricism

1. Science discovers facts
2. Inductive generalisation
3. Laws and theories
4. Proven knowledge
5. Science reliable
6. Absolute truth
7. Science solves all
8. Linear accretion
9. Science rational

Instrumentalism

1. Observation objective
2. Computative predictions
3. Convenient instrument
4. Definitions
5. Theories mere fictions
6. Passive
7. Superficial
8. Pragmatic

Level of involvement

1. No. of lab inquiries
2. Level of inquiry
3. Total no. of sentences
4. No. of facts
5. No. of questions
6. No. of definitions
7. No. of instructions to pupils
8. No. of references to "observe"
9. No. of calculations

Figure 1/Text Analysis Average of All Textbooks

Results of the Textbook Study

With the exception of one textbook, namely, *The Project Physics Course*, all the texts examined reveal a predominance of an inductivist-empiricist approach. This is clearly illustrated in the bar chart (Figure 1). Forty-four percent of the pages sampled reflect a repeated assumption on the part of the author(s) that observation is impersonal and objective, and that it precedes any generalizations. Inductive generalizations, either as laws, but more often as the conclusions of practical experiments in the laboratory, occupy 32 pecent of the sentences sampled. Thirty-four percent of the statements sampled suggest that science is a body of proven facts, that is, achieved knowledge. In our opinion, a serious omission in most of the texts is any discussion of the limitations of scientific method. Very few texts actually make any mention of "observation," "laws," or "theories."

The bar chart also reveals an emphasis on computative predictions (37 percent) and on both nominalistic and operational definitions (22 percent). A mild instrumentalism is implied by this emphasis together with the assumption, noted above, that observation is theory-free. Also implying a mild instrumentalism is the belief, reflected in 28 percent of the pages sampled, that physical science makes great use of mathematical relationships as convenient devices for prediction.

About 45 percent of the sample contained laboratory inquiries. Virtually all of these were at Level 0 (Herron, 1971).

About 63 percent of the sentences sampled were factual. Questions formed large proportions of some texts (e.g., Duncan, GCSE Physics), but on average, only 9 percent of the total comprised questions.

Examples from the Textbooks
Some examples and quotations from the various textbooks are now presented, illustrating their view of (a) observation, (b) computative prediction, (c) definitions, (d) induction, and (e) theories.

(a) *Observation*
Most of the texts assume that observation is objective and completely unaffected by previous theoretical presuppositions. Statements suggesting this are: "Because the scientist cannot directly observe the atoms . . . an atomic model has been devised which explains the different observations" (Book B, p. 229); "You have observed evidence of this" (Book E, p. 96); "Human beings find out things by using their senses" (Book J, p. 3).

The three exceptions, which briefly but clearly discuss the limitations and subjectiveness of observation, are the American textbooks (N, O, and P). The *Project Physics Course* (N) stands out from all the others in that it shows the theory-ladenness of observation by a detailed historical treatment of the Aristotelian versus the Galilean view (e.g., p. 43).

(b) *Computative Prediction*
There are naturally many examples of the use of mathematical equations in most of the texts. These may (or may not) be used by the pupil in a rote, "plug-in," instrumental way, merely "to get the right answer," with little thought of relating it to real life. If this is done, the computations are "expected" predictions (that is, not really informative about the world). There are many worked examples in the texts (for example, on Ohm's Law, Boyle's Law, heat calculations, chemical calculations), as well as large numbers of questions at the end of chapters.

Calculations using equations, like $v = f\lambda$, $R = V/I$, may be interpreted as non-causal. That is, there is no indication that V *causes* I, but only that I always *accompanies* V. The focus of interest implied here is the *relationship* between the variables. This technique side-steps problems of reality.

Inductive prediction is found in several of the texts. This is the notion that on the basis of observing regularities of some past events, we can predict the occurrence of a future one: "We can therefore predict that fluorine will be even more reactive" (Book B, p. 188).

(c) *Definitions*

Among the many types of definition, only two were systematically sought for in the textbooks: nominalist definitions, in which a name is given to a phenomenon or relationship; and operational definitions, which define a concept in terms of the actual operations carried out to obtain it. These are sometimes closely connected. For example, "density" is the name given to "mass per unit volume," and also the operation of dividing mass by volume. Operational definitions are also related to mathematical equations, such as resistance using Ohms' Law.

Here are some nominalist definitions from the textbooks: "Upthrust is the name we give . . ." (Book M, p. 94); ". . . called the critical angle" (Book I, p. 204); and ". . . are called allotropes" (Book E, p. 316).

Examples of operational definitions are as follows: ". . . Resistance R is defined by $R = V/I$" (Book G, p. 172); "(Refractive Index) . . . is defined by the equation . . ." (Book G, p. 18); and ". . . covalent radius, where this radius (r) is half the distance (d) between two nuclei . . ." (Book D, p. 285).

Operational definitions define concepts in terms of the procedures required to measure them. Operational definitions have the instrumentalist property of avoiding difficult questions of a metaphysical nature. But operational definitions have a severe weakness: not all the conditions can be specified.

Usually, a definition should be informative about the real world. It asks the question "What is it?" of the term on the left side of the definition, and answers it by the defining formula on the right. However, according to Popper (1983, p. 92), this is not the way modern science works. Modern science asks: "What shall we call mass per unit volume?" and answers with the name: "Density." It starts with the defining formula, and calls for a name for it. Hence in modern science, definitions are merely shorthand symbols, or succinct phrases, to make language less cumbersome, rather than ways of providing information. Now there is nothing intrinsically wrong with this approach. Indeed, elimination of excess baggage is one of the reasons for the enormous success of science.

However, the cost of using nominalistic definitions is great, because the tendency to give names to complex relationships and phenomena can lead to discussions about the meaning of words, rather than the physical phenomena to which the words refer. Also, the danger of any definition is that it gives the impression that knowledge is a closed book, no longer open to revision. Definitions that seek the essence of things, ultimate truth, are wrong. For, of its very nature, truth is always provisional and tentative.

(d) *Induction*

Induction is the process of generalizing from a relatively few instances. It includes drawing conclusions, formulating laws and rules, verification, and the idea that scientific knowledge is established by many confirmations. Popper endorsed Hume's criticism of induction; namely that by its very nature it goes beyond the facts. It is invalid to assert a universal property on the basis of a comparatively few observations.

An example of an inductive generalization in the text is: "The wave phenomena we observed . . . are characteristic of all types" (Book B, p. 19).

With respect to examples of verification, many of the practical experiments were provided merely so that the pupil could verify a law or principle. That is, they were of the "see-for-yourself" type, for example, Verification of Faraday's Law (Book C, p. 80).

Various references to scientific laws are mentioned (e.g., Ohm's Law, Faraday's Law, Boyle's Law, Snell's Law, Lenz's Law), but none of the texts discussed the notion that laws are inductive generalizations.

Examples of the proven knowledge idea are mainly of the name and date type. Science is seen as leading cumulatively and linearly to our contemporary store of established "unrevisable" knowledge: ". . . experimentation established finally that . . ." (Book A, p. 15); "Soon afterwards Madame Curie discovered radium" (Book I, p. 379).

The only explicit reference to the term "induction" that could be found in any of the texts was in *CHEM Study*. On page 3, induction is described as an elementary logical thought process, and the bounds within which inductive generalizations are valid are given.

(e) *Theories*

Discussion about the role of theory, or the interaction with and priority of theory, in all stages of the scientific inquiry process, is most conspicuous by its absence in most of the textbooks examined. There is also a lack of any explanation about models and their importance. The exceptions are *The Project Physics Course* and, to a lesser degree, *CHEM Study* and *PSSC Physics*.

In reality, scientific theories are arrived at, not by generalizing the sensory data, but by modifying already existing theories. Science begins with theories, not observation. Popper defends this priority of theory. All we know are our theories. The mind is not a *tabula rasa*, as the empiricists maintain:

> All observation involves interpretation in the light of our theoretical knowledge . . . (Popper, 1983, p. 48)

Yet, in spite of this, we read statements like these in our textbooks:

> Initially the existence of electrons was determined by experiment . . . (Book B, p. 219)

Explicit mention of theory is made only in the following texts: Book J, p. 3; *PSSC Physics; CHEM Study;* and Harvard *Project Physics*.

The relationship portrayed in the texts between theory and the real world is an ambiguous one. Most people, as Gardner (1983) states, are naive realists. When we talk about an electron, we believe that there is something out there, existing independently of our thinking, called an electron. And certainly, school pupils, particularly younger ones, are naive realists. No doubt, the authors of these textbooks believe in the independent reality of electrons and photons and other observables. In this sense, they too are realists. So when they talk about "kinetic theory," they surely hold that matter really consists of particles in constant, random motion. Yet it is possible to read their words in a purely instrumental way. Their kinetic theory could refer to reality, but equally it might not. It could be regarded as a convenient fiction only, with no sense of commitment to a common-sense reality.

Finally, it should be mentioned that there are many references in most of the texts to industrial applications of science. For example, on the pages sampled, the uses of transformers and electric motors, as well as the industrial preparation of ammonia and sulphuric acid, are described.

Results of the Preface Analysis

A reading of the prefaces reveals a general unawareness on the part of the authors of the philosophical implications and weaknesses of the instrumentalism present in their texts. Those few who do refer to scientific method have a notion of method which is strongly criticized by contemporary philosophers of science.

Book A. *Brink and Jones 8:* The separation of observation and theory is clearly stated, "It is important in the study of Physical Science that concepts and theories be developed from actual experimental observation and discovery." The authors emphasize understanding phenomena, rather than learning facts.

Book B. *Pienaar, Walters 8:* There is no explicit reference to the nature or method of science, only that the presentation is pupil-oriented, both as regards text and experiments.

Book C. *Broster and James 8:* The authors are convinced that science must be experienced to be understood, and the emphasis is therefore on the experiments. Pupils are also encouraged to keep a list of definitions.

Book D. *Brink and Jones 9:* This preface expresses the same sentiments as in A above.

Book E. *Pienaar, Walters 9:* The authors have made this text pupil-oriented. New concepts appearing for the first time are fully explained. Summaries and questions assist pupils. Practical experiments are integrated into the text.

Book F. *Broster and James 9:* No preface.

Book G. *Duncan:* Hints for pupil revision are given. There is no mention of scientific method or the philosophical aims of the author. However, immediately following the preface is a two-page (mainly photographs) discussion of Physics and Technology. Here we read that physicists "find the *facts* by observation and experiment," and "try to discover the *laws* that summarise (often as mathematical equations) these facts. Sense has then to be made of the laws by thinking up and testing *theories* (thought-models) to explain these laws."

Book H. *Pople and Williams:* The authors state that "science is about asking questions." Answers are found using experiments or looking up a reference book such as this one. "The information that scientists have gained is important."

Book I. *Atherton, Duncan, Mackean:* Each chapter contains essential facts, ideas, details of experiments, everyday applications, and questions for revision. The authors' primary concern has been to provide access to information.

Book J. *Lewis and Waller:* The aim of this book is understanding rather than memorization of facts. The main concepts are developed through analysis of experimental facts. Facts and theory are kept carefully distinct, and presented in a way that reflects the scientific approach, where observation comes first, then inference. This preface clearly reflects the philosophical standpoint of the authors, which is inductivist-empiricist.

Book K. *Pople:* This book deals with physics and its applications. However, the author does not mention his philosophical standpoint. The preface merely discusses the structure of the book.

Book L. *Warren:* Each new idea is investigated by simple experiments. The emphasis is on active involvement and learning from first-hand experience. Summaries identify a "body of knowledge" to be learned.

Book M. *Lambert:* The author states that this book is full of questions, which encourage hard thought. Summaries are given at the end of chapters. No reference at all is made to philosophical standpoint.

Book N. *Harvard Project Physics:* The declared three main aims of this course were: to design a humanistically oriented physics course; to attract more pupils to physics; and to find out more about the factors affecting the learning of science. The focus is on ideas that characterize science as a human activity. Hence it is presented in a historical and cultural way.

Book O. *CHEM Study:* The emphasis is on experimentation. Principles grow out of observations. By understanding principle, memorization of facts falls away. Active engagement permits the student to some extent to become a scientist at school.

Book P. *PSSC Physics:* This text does not present physics as a body of facts but as a continuing process by which we seek to understand the nature of the physical world. Concepts grow through exploration in the laboratory, and analysis in the text. It is humanistically oriented. How we grasp and measure physical quantities, and how instruments are extensions of our senses, is explained. Direct experience is provided, and imagination encouraged. The role and development of theory and models are explored. In kinematics, pupils learn to predict.

Apart from the last three texts listed above, all the others reflect a strong separation between observation and theory. Their implicit approach is empiricist-inductivist. Even *PSSC Physics*, while acknowledging the limitations of scientific procedures and the importance of creativity, follows an inductivist line. It does not mention that observation is theory-laden.

The prefaces generally reveal a strong commitment to traditional Baconian scientific method. Since this inductivist-empiricist approach has serious inherent philosophical weaknesses, we feel strongly that a brief discussion of its educational implications should be included in every preface.

General Discussion and Conclusion

The dominant image of science portrayed in all the British and South African textbooks examined is strongly inductivist-empiricist.

First, in these books, there is a sharp distinction between observation and theory. This is the chief characteristic of a positivistic approach, and the main attribute of inductivism, empiricism, and instrumentalism.

Second, our tests to detect instrumentalism in these textbooks reveal a mild instrumentalism. There is ample evidence that calculations are of the plug-in, recipe-like type, leading deductively to a solution that is isolated from the real world. These are mere computative devices for prediction and control, nothing but "puzzle-solving," in a way, only games.

Third, analysis of definitions in these textbooks reveals the existence of a number of operational and nominalistic definitions, which indicate an instrumental approach.

Our conclusion is that there are clear signs of a mild but widespread instrumentalism in the selected British and South African high school physical science textbooks. The British textbooks contain a stronger emphasis on an instrumentalist attitude than the South African texts. The three American textbooks examined, while not nearly as instrumentalist as the British and South African textbooks, nevertheless do show signs of it.

From the kind of textbook presentation revealed in this study, the pupil could perhaps perceive science as a method for verifying facts already known. He might obtain a view of observation as being completely objective. And he could possibly regard science as a convenient tool for predicting and calculating, in a rote fashion, with little relevance to real life. It is difficult to see how any textbook can be written in any but an inductivist-empiricist way. The very aim of a textbook is to be a condensation of the current state of science. It is a reference book, and so must contain a large proportion of facts. Kuhn (1970, p. 188) believes that one of the primary tasks of textbooks is to introduce the future scientist into the scientific community by means of exemplars (typical problems and solutions of the scientific community). The student needs to *act* on such problems in order to get a feel for science.

Similarly, Ravetz acknowledges that, while a textbook is a caricature of real science, it is necessary for standardization to occur. Ravetz says that

> it is quite necessary, if the fact is to be useful to those who lack the time, skill or inclination to master the elaborate theoretical context. . . . (1971, p. 200)

Something is lost in this process. School science textbooks, in particular, are "standardizations of standardizations," according to Ravetz. Vulgarization of science can easily occur in schools, where many teachers are not science specialists and lack sufficient training in physics and chemistry.

> These inherent limitations of the schoolteaching situation, along with its function of imparting basic craft skills rather than "understanding" must be recognised if there is to be any fundamental improvement in its quality. (Ravetz, 1971, p. 207)

To write a good textbook requires a special skill. Ravetz makes a plea for the inclusion of historical case studies in textbooks. However, cost factors unfortunately impose a severe limitation on this.

In the end it seems that textbooks cannot be otherwise than largely inductivist, empiricist, and instrumentalist. So the responsibility rests squarely on the teacher to counter-act the philosophical disadvantages of these approaches. Hence the teacher must be aware of the dangers involved. For this reason, we believe that all authors should, at the very least, provide some guidance in their preface. This is often especially desirable in Third World countries where teachers lack the required training in science. We recommend that all physical science textbooks should include in their preface a short summary of the following discussion.

The Unsoundness of Instrumentalism

Popper opposes instrumentalism on the grounds that observation is theory-laden. Modern science tends to be phenomenalist, but Popper (1956, p. 383) maintains that it is silly to say that my direct perception of, say, a piano, is valid, whereas my knowledge of its underlying molecular structure is a mere fiction. For surely even my direct observation is steeped in theory, as are my mental constructs of the structure. Both appearance and underlying form are theoretical interpretations. They differ only in the degree of conjecture.

We should consider three reasons why instrumentalism should be avoided in science education. First, it leads to idealism. It makes a clear distinction between appearances and reality, and maintains that we can never have knowledge of things-in-themselves. Such an attitude leads to scepticism. If reality is reduced to action, and action is reduced to what takes place in us, our experience is closed to the transcendental. Berkeley objected to this viewpoint. In order to undercut scepticism, Berkeley rejected one of the most fundamental tenets of the common-sense view of the world, namely, that an external reality exists apart from any consciousness of it. Objects are nothing more than ideas in our minds. All we ever perceive are our ideas. Thus Berkeley adopts idealism in order to escape from scepticism.

Second, positivism is instrumentalist. Logical positivists hold that unless a statement can be verified, it is meaningless. This view, of course, means that any statement made in morality, religion, philosophy, politics, or art is meaningless. The whole notion of God is seriously undermined. Popper regarded this view as nonsense, for truth is much wider than science.

Third, the phenomenalism of instrumentalism commits us to nominalism. For if we do not know things-in-themselves, our concepts of things are only *names*. Knowledge becomes instrumental instead of physically real. Further, because names are arbitrary, instrumentalism tends to become relativist and subjective.

Thus instrumentalism, in its pure form, tends to lead to idealism, agnosticism, and relativism. Our high school physical science textbooks contain a mild form of instrumentalism. We, as science educators, should be aware of its philosophical implications.

But instrumentalism rears its head in other books as well, namely, popular science paperbacks (Capra, 1975; Zukav, 1979) about contemporary particle physics, enjoyed by many pupils. These books portray an idealist-instrumentalist approach. They relate many of the paradoxes of particle physics to Eastern thinking. They make statements, such as "nothing is real unless it is observed" (Gribbin, 1984), and that the Aspect experiments done in Paris in 1982 prove that there is no underlying reality to the world.

The Instrumentalism of Computer Games

Pirsig (1974, p. 24) divides people into two classes: those who are against science and technology; and those who enjoy it. Yet, he says, there is a large third group consisting of technologists, who use science but are not committed to it. They are ***uninvolved.*** They behave like spectators.

A similar phenomenon perhaps occurs in the field of computers and particularly computer games. How easily youngsters become addicted to computer games! They seem to be thoroughly involved. But are they really? Surely those asteroids tumbling across their monitor screens, and laser beams flashing their destructive paths, are mere simulations, flickering images obediently following the programmed co-ordinates? The eye predicts, the hand presses a button, a high-speed digital calculation occurs, and the asteroid is destroyed in a gigantic explosion. But the pieces of shrapnel whizzing past are not real. It is only a game. And it is passive, and the player essentially uninvolved.

We contend that computer games are prime examples of the instrumentalist attitude. This struck us one evening in 1987 when we were using a BASIC program we had written to predict the position of Halley's Comet on any given night. It was only a calculus, like Ptolemy's, for prediction. Data and images could be manipulated in a purely geometric way, with little or no reference to physical reality. The computer was isolated in time and space from everything else in the universe. It had no relationship with the user, or the Cosmos, except in a superficial, instrumental way. It was not interested in the real physical gravitational forces pulling on real masses. It merely computed the mathematical models of Newton's Laws, and came up with the right answer. It was a spectator, and it made the user a passive spectator as well. And therein lay its danger.

Powers (1982) encourages us to take a realist stand in science, for we can easily be deceived by the escapism and superficiality of the instrumentalist approach. Realism

> requires us to take very seriously the question of the consistency of the assumptions our theories make. A recipe-book instrumentalism carries with it no such injunction. Phenomenalism (or submicroscopic phenomenalism) provides a way of brushing problems of intelligibility aside, but if the implication is that we are simply investigating experimental effects we produce in our apparatus and that these can tell us nothing about "what is there," then the whole enterprise may seem like a costly hoax we have played on ourselves; and it will be hard to believe a positivist who claims that this makes no difference. When experimentalists "bombard" protons with electrons they have to "believe" in both their missiles and their targets; though it seems "hard-headed," phenomenalism is a theory for spectators rather than actors. (Powers, 1982, p. 164)

The deliberate lack of commitment to a serious realism suggests that instrumentalists are playing games. For Berne,

> a game is an ongoing series of complementary ulterior transactions progressing to a well-defined, predictable outcome. (1964, p. 44)

Games are substitutes for real living. They are governed by rules, and involve activity and fantasy. Games are directed toward the manipulation of reality, and are evaluated by their effectiveness or pay-off. Games may not be intended to convey information, but merely to follow a predetermined course to an expected conclusion. Games are basically dishonest, for they tend to be cosmetic and superficial, shelving the important issues of life. They can be manoevres to attain pragmatic, utilitarian goals.

The parallel of games with instrumentalism is more than mere coincidence. For, like games, instrumentalism is also basically dishonest, as Koestler (1959, p. 65) says, for this reason: it deliberately ignores whole areas of non-empirical reality. It is a pretence.

Instrumentalism and Pragmatism

Commenting on the recent cut-backs in the American space-research program, Lago (1983) observes that contemporary Western society's emphasis on practicality and financial success has led to utilitarian values. Nothing is worth doing unless it is useful. Since a space-probe to Neptune has no obvious usefulness, the American exploratory space program will probably languish.

> Practicality has created America's greatness, but we have paid a dear price for it — and in the space age, that price is paralysis. (Lago, 1983, p. 28)

There are unquestionably certain human enterprises which are justifiable *in themselves*, without having to be obviously useful. But the instrumentalist attitude tends to blind us to this, and encourages the passivity syndrome which permeates so much of modern society.

Commenting on Dewey's instrumentalism, Bertrand Russell says, "In all this I feel a grave danger, the danger of what might be called cosmic impiety" (1979, p. 782). For Russell, the instrumentalist view of truth about the world lacks the necessary element of humility. It is a step

> on the road towards a certain kind of madness. . . . I am persuaded that this intoxication is the greatest danger of our time, and that any philosophy which, however unintentionally, contributes to it is increasing the danger of vast social disaster. (Russell, 1979, p. 782)

Instrumentalism and Science Education

As science educators, we should not allow our pupils to leave school as passive spectators, able only to turn switches, adjust voltage levels, check instruments. Rather, they must learn to become involved and care about what they do. They should be full-blooded realists, joining in the fruitful, productive quest for knowledge. They must reject sterile, passive, instrumentalist spectatorship and gamesmanship. We believe, with Pirsig, that it is somewhere in this strange separation of realist from instrumentalist, of what man is from what man does, that we may have a clue as to what has gone wrong in this 20th century.

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APPENDIX G

Books and the Sky

Conducted by Mollie D. Boring

QUASARS, REDSHIFTS, AND CONTROVERSIES

Halton Arp. Interstellar Media, 2153 Russell St., Berkeley, Calif. 94705, 1987. 198 pages. ISBN 0-941325-00-8. $19.95.

THIS IS a very unusual book. Halton C. Arp, known worldwide as Chip, is a distinguished observational astronomer. In the first part of his career he worked on various aspects of stellar evolution — his Ph.D. thesis at Mount Wilson on the frequency of novae in the Andromeda galaxy was a fundamental contribution. In his early years at Mount Wilson and Palomar he was considered one of the leading young observers. If we use an equivalent to the ladder system of the Association of Tennis Professionals, Arp would have ranked among the first 20

The Discovery of Quasars

Around 1950 the first accurate positions of radio sources were measured, and identifications with optical objects became possible. The optical counterparts turned out to be supernova remnants in our galaxy, or distant galaxies. However, in 1960 Allan Sandage (Mount Wilson and Palomar Observatories) and Tom Matthews (Caltech) announced the discovery of a faint, starlike object associated with the radio source 3C 48. Sandage described the first optical observations at the December, 1960, meeting of the American Astronomical Society (*S&T:* March, 1961, page 148). The spectrum could not be understood.

Further radio identifications of starlike objects were made by Sandage and others. In 1962 in Australia, Cyril Hazard and colleagues M. B. Mackey and A. J. Shimmins, using the method of lunar occultations, identified the radio source 3C 273 with a much brighter starlike object.

It was early in 1963 — 25 years ago — when Caltech's Maarten Schmidt realized that the emission lines in his optical spectrum of 3C 273 coincided with the Balmer lines of hydrogen shifted toward the red by an astonishing 16 percent of their laboratory wavelengths. Interpreting this unprecedentedly large redshift as due to the Doppler effect, Schmidt deduced that the "radio star" was no star at all, but an extragalactic object perhaps one billion light-years away. For 3C 273 to shine with its observed brightness, it must be 100 times more luminous than any nearby spiral galaxy, making it by far the intrinsically brightest object known at that time.

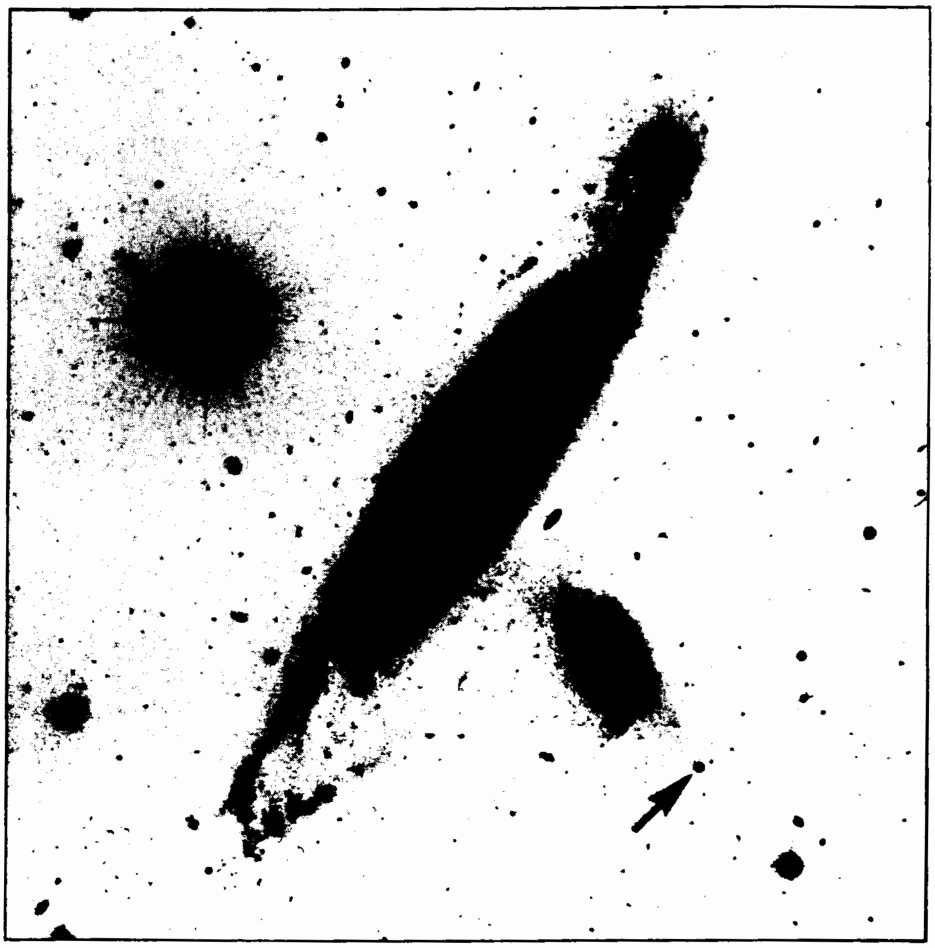
Thus, it is to Hazard, Matthews, and other radio astronomers who determined positions, and to Sandage and Schmidt, that we owe the discovery of quasars. Following these first discoveries, other quasars were identified, and a new subspecialty arose within astrophysics as astronomers scrambled to explain the objects' unusual characteristics. Today, most researchers think of quasars as the extremely luminous nuclei of distant galaxies, systems in many ways like other "active" galaxies but far more extreme in intensity, perhaps due to the action of a supermassive black hole voraciously feeding on stars.

Yet some astronomers have steadfastly refused to accept the fantastic claims being made for quasars. They have presented evidence showing, among other things, that some quasars are physically associated with galaxies having vastly different redshifts, implying that redshift does not correlate with distance for all types of extragalactic objects. Because it would require the abandonment of many cherished notions at the heart of modern cosmology, this suggestion has sparked one of the most acrimonious debates in the history of science.

The central figure in this controversy is Halton C. Arp, who has made the largest contribution to the evidence for galaxy-quasar associations. Arp has just published his retrospective account, so we devote this month's Books and the Sky to the ongoing battle between those defending orthodoxy and those favoring the unconventional approach. Geoffrey Burbidge, a principal in the debate, reviews Arp's book and offers some personal reflections on the evidence for noncosmological redshifts. And, on page 42, Arp himself presents the case that high redshifts do not necessarily mean large distances.

THE EDITORS

A diffuse, faintly luminous connection extends from the galaxy NGC 5296 to the large spiral NGC 5297, as well as in the opposite direction to a high-redshift quasar (arrowed). A compact galaxy just below, and silhouetted against, NGC 5296 must be spatially in front of it. Yet this tiny object's redshift is 23,000 kilometers per second *higher* than the larger galaxy's. That was the first extended object (a galaxy rather than a point-source quasar) Halton Arp and Jack Sulentic found having an excess, or nonvelocity, redshift. Palomar 200-inch telescope photograph.



observational optical astronomers in the world.

In professional tennis your ranking depends on wins and losses, on whom you beat, and on how much money you win. Older players invariably end up losers! In professional astronomy it's very different. There is no unambiguous way to win or lose. Most people are very bright. But advancement depends on judgment by your peers. Thus the important factors for a successful career are your sponsors (where and with whom did you get your Ph.D.); field of research (popular or unpopular); and diplomatic skills (always speak quietly with great conviction, and, when in doubt, agree with the wisest person present, who by definition must come from one of very few institutions). Look upon new ideas with great disapproval and never discover a phenomenon for which no explanation exists, and certainly not one for which an explanation within the framework of known physics does not appear to be possible.

As you get older your ranking will improve. It helps, of course, if you perform creative work, but regular use of a large telescope may suffice instead. All of this to investigate the universe, which is so beautiful and so unimaginable that in 10,000 years we will only have scratched the surface of understanding!

Chip Arp started with impeccable credentials. Educated at Harvard and Caltech, after a short spell at Indiana he was appointed to a staff position at the Mount Wilson and Palomar Observatories, where he remained for 29 years. A little more than 20 years ago Arp began to devote all his time to extragalactic astronomy. At first he compiled the marvelous *Atlas of Peculiar Galaxies*. Then he started to find what he believed were physical associations between some of these galaxies and previously identified powerful radio sources. Soon he found many cases of apparent associations between galaxies and quasi-stellar objects, or quasars.

All of this would have been completely acceptable if the associated objects had the same redshifts, but they did not. Yet Arp believed in the reality of the associations, and, after struggles with referees,

Anatomy of a Controversy

In the last few years there has been a plethora of meetings on cosmology. Throughout all of them the same themes are reiterated again and again. It is taken for granted that we live in an expanding universe that started with a hot Big Bang; that in its first moments the universe swelled enormously in a so-called inflationary phase; that the formation of large-scale structure resulted from "quantum fluctuations"; that galaxies formed from regions of higher-than-average matter density as late as redshifts of 3 to 10; and that most of the mass of the universe is in the form of (currently popular) cold dark matter. In addition, cosmologists argue that counts of quasars and radio sources tell us that there has been complicated evolution in luminosity, number density, or both as a function of redshift — that is, of time.

Is any of this true? Obviously, most astronomers and physicists believe that it is. The hard observational evidence for this scenario rests principally on two measurements: the spectrum of the cosmic microwave background radiation, predicted by George Gamow and his colleagues to have a blackbody form, and the redshift-distance, or Hubble, relation for galaxies. The match between the observed amounts of deuterium, helium, and one of the isotopes of lithium and the amounts predicted by theories of Big-Bang nucleosynthesis often is cited as a third powerful observational argument for this cosmological model.

This evidence taken as a whole is fairly convincing, but it is not as "hard" as is sometimes claimed. The microwave background shows significant departures from the blackbody form, and the underlying assumption of the Hubble relation — that the redshifts are Doppler shifts and therefore indicative of high recession velocities — remains to be proved.

The remainder of this scenario is even more dubious, particularly the belief in inflation and the existence of cold dark matter. There can never be an observational test of inflation, and there is at present no direct evidence for cold dark matter. And, of course, the need for a complex evolutionary history for quasars and radio sources depends completely on the belief that the observed redshifts measure distance (see the discussion by Arp on page 42).

While so much attention is now being paid by observers and theoreticians alike to this current view of cosmology, one of the most fundamental issues — the nature of the redshifts of extragalactic objects — is almost ignored.

If a large part of the redshifts of galaxies and quasars is not due to the expansion of the universe, this will have major repercussions on the popular cosmology just outlined. Moreover, it raises another issue. If some part of the redshifts is not due to expansion, what is it due to?

Both the book by Arp and his article here are concerned with this problem. Evidence for noncosmological redshifts comes from three directions:

• Patterns in the values of the observed redshifts that cannot be understood in terms of the standard cosmologies.

• Physical associations between pairs or small groups of objects with very different redshifts.

• Statistical evidence suggesting that some classes of objects are physically associated with other classes generally having very different redshifts.

What follows is a brief elaboration. In the early 1970's William Tifft found that the differences between the redshifts of pairs of galaxies in clusters were distributed not randomly, but periodically, with a period near 72 kilometers per second. This phenomenon, known as redshift quantization, has now been extended to double galaxies and compact groups (see last January's issue, page 19). Also, since 1967 some astronomers have concluded that there are regularities in the emission-line spectra of quasars. By the late 1970's K. G. Karlsson and others demonstrated that quasar redshifts show periodic peaks on a logarithmic scale, clustering around values of 0.30, 0.60, 0.96, 1.41, and 1.96.

Modern data on physical associations — luminous bridges — between objects with different redshifts comes almost completely from Chip Arp. His pictures of the galaxy NGC 7603 and its companion, and NGC 4319 and the low-redshift quasar Markarian 205 (pictured on the front cover), are well known. While such cases are rare, it has always seemed to me that they are overwhelming.

Statistical evidence for the association of bright galaxies and quasars has also been growing for many years. Again, in my view, it is very strong and shows that there are many quasars and at least some peculiar galaxies with noncosmological redshifts.

The community of astronomers is totally polarized by this argument. Most do not want to hear about it. The strong disbelievers hold that those who propose or believe in this hypothesis are variously naive, mistaken, ignorant of how to do statistics, overly zealous, or worse. They claim that Tifft's results are not reproducible, that we have no theory to explain these phenomena, that we should recant, and that in fact the redshift controversy is over; that is, the status quo has been maintained. This last statement is often made in meetings to which the proponents of unorthodoxy are either not invited, or not allowed to speak.

What does one make of this impasse 20 years after the proposal was first put forward?

Those in the mainstream do have some good scientific arguments. For example, the well-behaved Hubble relation for galaxies in clusters is by itself evidence that for most galaxies the bulk of the redshift is indeed cosmological in origin. But then we have Tifft's data on galaxies, which appears correct, baffles us all, and continues to grow stronger (see the November issue, page 454).

Again, for the orthodox, it appears that many low-redshift quasars are surrounded by "fuzz," perhaps the outer parts of quasi-normal galaxies. This evidence, which is still weak, together with the statistical evidence that in some samples low-redshift quasars have companion galaxies with similar redshifts, also favors the cosmological-redshift hypothesis.

At the same time, these observations do not negate the strong evidence for the existence of noncosmological redshifts. To do so we would have to conclude that *all* of the configurations involving objects with very different redshifts are accidental, and this is too much to expect. In my view both effects must coexist, but how?

Are there theories that can begin to explain what we see? Yes. William C. Saslaw has described a slingshot mechanism that might enable us to understand how discrete objects like quasars can be ejected from the nuclei of galaxies at high speed. Fred Hoyle and Jayant Narlikar have proposed unorthodox cosmologies that might, with some further work, explain noncosmological redshifts. But these theories are still in very rudimentary states.

For some, astronomy faces new and unusual phenomena that call for new ideas. For others, these phenomena are best swept under the rug. I, for one, feel obliged to leave open the possibility that radical revisions in our current views might ultimately be required.

GEOFFREY BURBIDGE

Three quasars (arrowed) apparently sit in the outer arms of the barred spiral galaxy NGC 1073. The chance of finding three high-redshift objects so close to a low-redshift galaxy are about 1 in 50,000, suggesting that the quasars and galaxy are physically associated. Quasars 2 and 3 are separated by about 1.5 arc minutes. Allan Sandage's photograph was taken with the Palomar 200-inch telescope.

his papers were published. Others were finding similar results, and soon the terms "nonvelocity redshifts" (those not associated with the expansion of the universe) and "local" (as distinct from distant, or "cosmological") quasars entered the literature. Arp's ranking in the "Association of Astronomy Professionals" plunged from within the first 20 to below 200. As he continued to claim that not all galaxy redshifts were due to the expansion of the universe, his ranking dropped further.

About four years ago came the final blow: his whole field of research was deemed unacceptable by the telescope-allocation committee in Pasadena. Both directors (of Mount Wilson and Las Campanas, and Palomar, observatories) endorsed the censure. Since Arp refused to work in a more conventional field, he was given no more telescope time. After abortive appeals all the way up to the trustees of the Carnegie Institution, he took early retirement and moved to West Germany. Earlier, Fritz Zwicky had also been frequently criticized by his colleagues in Pasadena (by coincidence?). Zwicky remained a staff member at Mount Wilson and Palomar until he retired, but much of his work continued to be ignored or derided until some years after his death.

Quasars, Redshifts, and Controversies contains Arp's account of his own work and that of others leading, in his mind, to the conclusion that redshifts are not always correlated with distances. It also contains his personal view of the way he has been treated. When he is critical of others, he omits their names. Zwicky was more blunt in his *Morphological Astronomy.* Anyway, for those who have lived through this episode there are no secrets.

Before going on to discuss the subject matter, let me explain my own position. After all, the community sees me as a friend and strong supporter of Arp, and it will be argued that this colors my attitude. In 1966, at about the time that Arp began his fateful observational program, Fred Hoyle and I were trying to make models of quasars that would preserve the general belief that they lay at cosmological distances yet allow us to understand the rapid brightness variability. In the course of this work we considered the possibility that quasars are local, and in our paper we examined the pros and cons of both hypotheses but tried to sit on the fence.

For the next decade I still remained open-minded despite the fact that in the early 1970's a group at the University of California, San Diego, had produced some very strong statistical evidence for local quasars. In addition to this I had concluded that there were peaks and periodicities in the redshift distribution that are very hard to explain in a conventional picture. Moreover, by the end of the decade, despite all of the difficulties, I was convinced that the evidence for local quasars was too great for it all to be wrong. (You can tolerate only so many accidents, and if the noncosmological hypothesis is wrong, *every* juxtaposition of objects with different redshifts must be accidental.) At the same time, evidence that some quasars have cosmological redshifts is compelling. So I am left believing in the radical hypothesis while trying to accommodate some part of the conventional view.

The other part of this learning process has been unpleasant, probably because I have a strong instinct for fair play. It may be argued that this is no substitute for good judgment. But neither are the tactics that have been used by those who want to maintain the status quo. These include interminable refereeing, blackballing of speakers at meetings, distortion and misquotation of the written word, rewriting of history, and, worst of all, the denial of telescope time to those who are investigating what some believe are the wrong things. Thus, for both scientific and sociological reasons, I am sympathetic to Arp.

The book is well worth reading, though I believe that a much stronger case could have been made for the major scientific thesis. But this volume is pure Chip Arp, warts and all. He gives a blow-by-blow description of discovery, data and statistical analysis, refereeing, publication, editorial interference, and more.

In my view the best evidence for the existence of noncosmological redshifts is the following: the three quasars within 2 arc minutes of the center of NGC 1073, each having a redshift at a peak in the distribution found earlier; the low-redshift quasar Markarian 205 joined to NGC 4319; the pair of galaxies NGC 7603 and its companion, which are connected by a

The Crucial Assumption about Redshifts

Almost all of extragalactic astronomy rests on the assumption that large redshifts always measure large distances. Most astronomers believe that the only possible cause of large redshift is the expansion of a universe in which velocity increases with distance.

What is the evidence to support this assumption? Does the apparent brightness decrease with higher redshift in the way one would expect if the distance is increasing? Only for certain extragalactic objects. Many others violate such a Hubble relation. And it is just these latter kinds of objects for which all possible tests yield distances that are much smaller than those derived from their redshifts.

The starlike objects called quasars have the highest redshifts, the most extreme implying recession velocities of 90 percent the speed of light. Strangely, the latter tend to have brighter apparent magnitudes — to exhibit a "backward-running Hubble relation." Truthfully, we must admit there is no actual evidence for these objects having distances that are measured by their redshifts.

For more than 20 years a number of us have been advancing evidence that quasars fall more closely around bright (low-redshift) galaxies than expected by chance. Opponents of this conclusion have tested the association of quasars with fainter, more distant galaxies, and reported lesser degrees of correlation, which they maintain disproves the association. But all the serious tests with bright quasars and bright, nearby galaxies have given proofs of association.

Recently, for example, bright quasars were shown to be 10 times more abundant than normal around the Sculptor group galaxies, our Local Group's nearest neighbors. Even more recently, serendipitously discovered X-ray quasars were tested. It turned out that the redshifts of those around galaxies were significantly different than those in the general field. This last result will lead astronomers to accept higher densities of quasars around low-redshift galaxies, in my opinion not because the evidence is any more overwhelming than it has been for decades, but because theorists can now interpret the excess as due to gravitationally lensed background quasars. (I am willing to argue later whether hypothetical lensing bodies exist out at 2 to 3 diameters from galaxies.)

There have always been examples of high-redshift quasars actually connected to or interacting with low-redshift galaxies. Consider the best-known case. After a decade of resistance, many astronomers now admit that there is a luminous filament, or bridge, extending from the quasar Markarian 205 back toward the nucleus of the galaxy NGC 4319 (front cover of this magazine).

Is Markarian 205 a background object? If so, then why do filaments extend in opposite directions from the nucleus of the galaxy toward it and toward an ultraviolet-bright knot about the same distance on the other side? Why are there radio lobes ejected from the galaxy, an absence of hydrogen gas, ostensibly shock-excited nitrogen emission, and expansion velocities around the ultraviolet knot up to 1,000 kilometers per second? And why are the spiral arms breaking off at the roots in this galaxy?

But the redshift crisis is more serious than just the situation with quasars. There are now many dozens of *galaxies* with widely different redshifts observed to be physically interacting. Therefore the conventional theory that objects with different redshifts must be at different distances is contradicted not in just one case (which, of course, is all it takes) but in many mutually supporting cases ranging from quasars to galaxies.

If galaxies can have nonvelocity redshifts, extragalactic astronomy is in deep trouble. They do. In the Local Group and M81 group together, 21 out of 21 major companions have higher redshifts than the dominant Sb spiral galaxy. Group after group of galaxies shows the more open-armed Sc spirals to have systematically higher redshifts than the Sb's.

The Sc I's, supposedly the most luminous spirals, show the most shocking redshift excesses. In the Virgo cluster the four Sc I's have 900 kilometers per second greater redshift than the average material in the cluster. At their supposed redshift distances some Sc I's have diameters enormously larger than the largest galaxies of which we have any reliable knowledge. They could, for example, swallow the whole Andromeda galaxy, M31, out to M33 in Triangulum. Supernovae would be popping off in such systems about once a month!

Another astonishing result of placing quasars and active galaxies at the distances implied by their redshifts is that some then have internal expansion velocities of up to 30 times the speed of light, making them "superluminal." Accepting the evidence that they are closer makes it unnecessary to hypothesize complicated and implausible mass ejections at 99 percent the speed of light aimed almost exactly at the observer.

Most of the absurd consequences that result from the conventional tenet about redshifts and distances are violently contradicted by observations. When will astronomers reexamine the single, frail assumption on which so much of modern astronomy and cosmology depends?

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luminous bridge but have very different redshifts; and the statistical evidence relating many quasars to bright — not faint — galaxies. Each of these results is fully described, as are the phenomenon of quantized galaxy redshifts found by William G. Tifft and the periodicities of quasar redshifts (see the box on page 40). What is, in my view, some of the weakest evidence — showing that some comparatively nearby galaxies have noncosmological redshifts — is also documented.

One of the most fascinating chapters describes the idea that the alignments of objects with different redshifts are not accidental, but real, implying that galaxies can eject objects, up to and including other galaxies. This is Viktor A. Ambartsumian's old idea, and it might just be correct.

In his next-to-last chapter Arp gives a painfully honest account of the way he was barred from the telescopes. He writes, "The six-person telescope allocation committee . . . sent me an unsigned letter stating that my research was judged to be without value and that they intended to refuse allocation of further observing time."

I remember very well when Arp called and told me this. At the time I was director of Kitt Peak National Observatory. I told him that in my experience telescope-allocation committees were only advisory to directors, and I could not imagine the directors in Pasadena accepting such biased advice. But, as I noted earlier, they did, and Arp's research career in the United States abruptly ended. No responsible scientist I know, including many astronomers who are strongly opposed to Arp's thesis and many scientists outside the field, believes that justice was served.

How will this episode be seen 50 years from now? Everything depends, of course, on how far astronomy has advanced. If, as I suspect, the "Arp effect" is only the tip of the iceberg, then it will look very similar to the case of Alfred Wegener and the theory of continental drift. If not, then all that will be remembered and still used will be the atlases Arp has provided to the community. Those alone are no small legacy.

Quasars, Redshifts, and Controversies recounts a great deal of interesting science. It also gives one side of a very important argument. It is not a textbook and unfortunately contains quite a number of typographical errors. But some of its material could be used for lectures to graduate students.

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Now at the University of California, San Diego, Burbidge is a world-renowned astrophysicist. He has been in the forefront of quasar astronomy for more than two decades.