THE DEVELOPMENT OF OBSERVATIONAL AND ALLIED SKILLS IN THE TEACHING AND LEARNING OF NATURAL SCIENCES

by

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THE DEVELOPMENT OF OBSERVATIONAL AND ALLIED SKILLS IN THE TEACHING AND LEARNING OF NATURAL SCIENCES

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DECLARATION

Student number: 537-056-6

I declare that THE DEVELOPMENT OF OBSERVATIONAL AND ALLIED SKILLS IN THE TEACHING AND LEARNING OF NATURAL SCIENCES is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

(Mr. R. Mhlongo)  
10 April 1997  
DATE
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I am also indebted to my 1995/96 biology student-teachers at Tivumbeni College of Education. The test instrument in Appendix C and the model lessons in Appendix G have been pilot-tested and administered to the then student-teachers.

Lastly, I would like to thank Almighty God who is the source of all knowledge.
DEDICATION

This thesis is dedicated

to

my wife

Audrey

for

her support, encouragement

and

most of all, love,

and

our children

Hlulani, Khetile and Lulekani.
1. ORIENTATION TO THE STUDY

1.1. STATEMENT OF THE PROBLEM

1.1.1. Identification of the Problem

The syllabus of Biology standard 8, 9 and 10 of the Department of Education in South Africa has seven aims. One of these aims is to provide a course which will develop in pupils, the following important attributes: "an ability to make critical, accurate observations of biological material, and to make meaningful records of such observations". The approach to the syllabus embodies the following principles:

* pupils should make their own observations of specimens and experiments;
* pupils should learn how to handle and set up apparatus correctly;
* organisms should be observed in their natural environments;
* constant emphasis should be placed on facts being understood, interpreted, and applied rather than being memorized.

The Secondary Teacher's Diploma (STD) syllabus for biology academic aims to "provide a course which will give the biology teachers in training a deeper insight into subject matter ...and the processes used to generate the subject matter". Some of the more specific aims are:

* to develop intellectual processes used by scientists in generating biological knowledge. These processes include observation, classification, inference, communication, hypothesizing, manipulating variables and experimentation.
* to provide students with the opportunity to develop manipulative/psychomotor skills through the handling and
routine use of materials and equipment.

* to cultivate characteristics such as accuracy in reporting observations and results.

One of the aims of the syllabus in physical science standard 8, 9 and 10 is to train pupils in the necessary skills, techniques and methods of the subject. This includes manipulation of certain apparatus, measuring and observation techniques. One of the aims of general science syllabus for standard 5, 6 and 7 is to develop the ability to observe objectively and to solve problems by applying scientific reasoning skills and scientific procedures.

All the above extracts reveal that scientific observation is one of the most important instructional aims of the natural science syllabi. Indeed, a review of related literature reveals that scientific observation, more than being an important aim, is also a method by which knowledge is gained in the natural sciences (Collette and Chiappetta 1984:13; Corder 1982:77; Hodson 1986a:17-18; Oyeneyin 1985:109; Pestalozzi 1915:109; Popper 1981:72).

Several questions can now be raised concerning the curriculum of natural sciences in the Department of Education in South Africa. Are learners given the opportunity to develop their observational and allied skills? How can observational and allied skills be developed? The researcher is of the opinion that there is a lack of observational and allied skills in the teaching and learning of natural sciences.

1.1.2. Analysis of the Problem

Various studies show that science teaching in secondary schools throughout the world in general is largely expository in character.
In Nigeria, Williams and Buseri (1988:51-59) found that the presentation of factual information (descriptions and explanations) is largely unremitting throughout every lesson. Similar results were obtained by Hacker, Hawkes and Hefferman (1979:51-59) in Britain and Canada.

Beveridge (1979:10) reported that about 90% of the teaching of natural sciences in British schools was directed upon the accumulation of facts. Only 10% of the teaching was directed at the development of observational skills. The problem with this is that the power to recall facts only forms 10% of the knowledge whereas the development of observational skills forms the other 90%.

This sad state of affairs was also echoed by the Biological Sciences Curriculum Study (BSCS) in the United States of America (USA) (Degenaar 1985:33). A survey of 12000 teachers in the USA revealed that over 90% of these teachers use the textbook 90% of the time in their instruction (Marek, Eubanks and Gallaher 1990:822). The instructional activity reported most often by students is reading science textbooks (Jenkins and MacDonald 1989:6). To make matters worse, the assessment of student performance places heavy emphasis on the pupils' ability to recall information.

A perusal of various reports shows that the teaching and learning of natural sciences in South Africa is currently plagued by the same teacher-dominated and textbook bound methods. There is little or no attempt to develop observational and allied skills.

The 1978 report of the South African Association of Teachers of Physical Science (1978:9) expressed the fact that the natural sciences are presented as a detached intellectual activity
principally concerned with learning facts. The teacher is regarded as the possessor of knowledge, and knowledge as a product simply to be transmitted as prepackaged and preprocessed information.

The researcher, like Sanders (1993:13) is convinced that the aims of both biology and physical science teaching are worthwhile. If this is truly so, what, then, could be the cause of the didactic anomaly?

According to Sanders (1993:13) the biology matric exam has a stranglehold on what is taught and how it is taught. The lengthy content-laden syllabus means that there is little time for developing important skills and attitudes. The aims of the syllabi are not achieved. And this is a common phenomenon throughout the world.

Perhaps one does not only have to read the literature to know that the teaching and learning of natural sciences is largely expository in character. One also has to experience it. The researcher in this study, bears witness to this. He has been taught in the same situation in his secondary school years and this does not seem to get any better.

The inadequacy of the teaching methods in natural sciences is attacked from various angles. According to Beveridge (1979:15), the acquainting of pupils with the facts of science which have been observed by others and asking them to be returned on examination is far removed from the procedures and circuitous adventures of scientists. Nielsen (1967:8) asserts that the problem of teaching factual knowledge to a pupil entering the secondary school is that those facts have a good chance of no longer being facts when that learner leaves the secondary school. Falk (1971:5) contends that science is an active mode of
knowledge which cannot be understood solely by contemplation, reasoning or discussion.

1.1.3. Demarcation of the Field of Investigation

The literature study concerns the study of the phenomenon of observation as a science process skill and its influence in the natural sciences curriculum. The study also focuses on the development of observational and allied skills in the natural sciences. Empirical data about observational and allied skills are collected from a selected college of education in the Northern Province. The reader is referred to Chapter 8 for more details about this.

1.1.4. A Move to Solve the Problem

From the statement of the problem above, one is prompted to ask the next question of how this problem could be solved.

Burkinshaw (1987:24), Oyeneyin (1985:109) and Swinehart (1987:429-430) are the few known researchers who have gone beyond the diagnosis of the problem. They all assert that expository teaching should be integrated with science processes.

The researcher in this study, while sharing the same conviction would like to highlight one most important component at the core of the science processes, namely; observation. The quality of observation is of significant importance in determining the validity and strength of all other science processes (Oyeneyin 1985:109).

From the preliminary literature study, the researcher in this study has to concede that the world has seen very little previous research on this subject. One notable example is a
study by Friedler et al (1990:173-191) who investigated the impact of developing the observing and predicting skills on a group of learners.

In Friedler et al's investigation, students did not actually perform the hands-on activities in the laboratory, but they studied experiments as simulated by the computer. This (MBL) computer programme constitutes a new class of technology which allows students to collect, record, and manipulate data.

After a semester's instructional treatment, the posttest has shown that there is a very low correlation (t = 0.01) between the observation and the prediction groups on the scores of the observing skill. The value of t = 3.01 as calculated showed that the test scores on the observing skill on the observation group were significantly higher than those on the prediction group.

Thus the instructional treatment helped the students in the observation group to develop more skills in observing. The observation group was also able to exclude inferences from their observation logs.

The scores on the predicting skill were found to be higher on the prediction group than on the observation group. This group was able to make detailed predictions and to justify them on the basis of their previous experiments.

These findings suggested that the ability of students to observe and to predict depended on the instruction they received.

Friedler et al (1990:189) are emphatic that students should not be expected to learn these skills without being taught.

Another study by Swinehart (1987:429-430) endeavoured to outline how observational skills could be combined with specific
concepts in the teaching of natural sciences in the USA. Burkinshaw (1987:24) had been involved in the development and improvement of observational skills of primary school children in Britain.

De Beer (1996:30) has pointed out that South Africa has also joined the bandwagon on heuristic teaching as advocated by the BSCS of the USA. It should be indicated that Huyser (1992:3) has recently taken a step further by investigating the role of observation in the teaching of biology in South Africa. This includes an investigation into how the observational skills could be developed. However, today, more than thirty years after implementing the BSCS approach in South Africa, the teaching of natural sciences still struggles with the same problems as before.

Notwithstanding the above, the researcher in this study is deeply excited in joining the above authors to further explore this field of study.

1.2. HYPOTHESES

In its simplest sense, a hypothesis suggests a particular relationship between a dependent variable and one or more independent variables (Chadwick, Bahr and Albrecht 1984:44). The following questions can be asked as a prelude to the formulation of a hypothesis:

(a) Are observational and allied skills intuitive or can they be developed?

(b) How should one go about developing observational and allied skills in the teaching of the natural sciences?
(c) Can the teaching and learning of natural sciences contribute to the development of observational and allied skills?

(d) Can observational and allied skills be assessed?

Hypothesis 1. Observational and allied skills can be developed. This hypothesis may also be stated negatively as a null hypothesis ($H^0$) as follows; observational and allied skills cannot be developed. This gives a provisional answer to the first question.

Hypothesis 2. The teaching and learning of natural sciences can contribute to the development of observational and allied skills. This gives a provisional answer to the second and third questions. Since the teaching and learning of natural sciences is a variable that is manipulated, it is known as the controlled, manipulated or independent variable. The observational and allied skills are a dependent variable, they depend upon the way in which teaching and learning takes place.

Hypothesis 3. Observational and allied skills can be assessed.

1.3. SIGNIFICANCE OF THE PROBLEM

The problem as outlined above is significant because it could be linked to the high failure rate and the resulting loss of popularity within the natural sciences. This has proved to be of concern not only to educators, but to politicians and economists alike (Kahn 1991:25).

A solution to this problem will definitely be of great
significance to South Africa. However, the researcher in this study is not under the illusion that his work alone will bring about a magic solution to the problem. A concerted study which is inclusive of all experts in this field would bring about an innovation in the teaching of natural sciences like never before. The high failure rate and the subsequent loss of popularity of natural sciences could be reduced. Pupils could be intrinsically motivated by the subject matter itself, thus learning of natural sciences could be significantly enhanced. This would result in the general improvement in the quality of the teaching and learning of the natural sciences. Ultimately, this could have a positive influence on the country's technology and economy.

1.4. AIMS AND OBJECTIVES OF THIS STUDY

A research aim or objective is a description of the nature of the information that the research is intended to produce. It is here that the researcher specifies the basic descriptive, theoretical or administrative questions that are to be addressed and indicates what information is required to answer them (Chadwick et al 1984:35).

A research aim prescribes a task whereas a research objective describes a task.

1.4.1. Aims

(a) The researcher in this study aims at testing all the hypotheses in section 1.2. above. The study proceeds to investigate a way in which the teaching of natural sciences can contribute to the development of observational and allied skills.
Throughout the literature study the third hypothesis is confirmed, namely; that observational and allied skills can be assessed. This study culminates in a test item inventory to assess observational and allied skills.

1.4.2. Objectives

In order to achieve the aims above, this study:

(a) explores the writings of recognized authorities on:
* observation as a science process
* the development of observational and allied skills
* the theories of learning and the influence of developed observation related skills on learning.

(b) undertakes an empirical research to investigate whether the teaching and learning of natural sciences can contribute to the development of observational and allied skills. Data are collected before and after developing students' observational and allied skills. For more details about the empirical research the reader is referred to the pre-test and post-test experiments in Chapter 8 and 9 in this study.

1.5. DEFINITION OF IMPORTANT TERMS

A given term could have different meaning to different people, it could also have different meaning to the same people depending on the time and the context in which it is used. In this section, the most important terms as used in this study are defined.
1.5.1. Development

Longman Dictionary of Contemporary English (1982) defines the term "develop" as meaning "to study or think out fully, or present fully". In another context it means to bring out the economic possibilities of something. The term also means "to grow, increase, or become larger, or more complete or to promote the growth of something".

The concept "develop" denotes the process of change from a latent elementary or immature state to a state of visibility or completeness. An example is the development of a photographic film; or an embryo.

From the didactic perspective, 'development' is identical to moulding which refers to the educator's action of forming or changing the character and personality of the child. The total impact of all environmental influences on man is described as moulding (Duminy and Steyn 1984:12-14; Engelbrecht, Yssel, Griesel and Verster 1983:14; Piek 1988:9; Stuart 1989:14; Van der Stoep and Louw 1984:34).

Harlen and Jelly (1989:45) define the concept 'development' as meaning a series of changes which take place in children's ideas and skills. These changes are neither wholly spontaneous, taking place as a result only of maturation, nor wholly externally determined, taking place as a result of training. Experience suggests development takes place through the mixture of maturity and experience. This is exactly the context in which it is used in this study.

In science, children's ideas could develop (i.e. pass through various changes) more quickly if children were given more opportunity for appropriate experience.
1.5.2. Observation

Notions like seeing, witnessing, noticing, attending, evidence, data, and facts have to do with observation. Seeing a cat is an example of observation. The word "observe" (and hence also the noun observation) is made to perform both in this task performing way and in this success indicating way. "Observe" sometimes serve in just the ways that "look" and "listen" serve, and it sometimes serve as "see" and "hear". Listening to the songs of birds is another example of observation. We may also refer to a man's observations as his findings, his discoveries. The word "observe" then is sometimes used to indicate what someone is doing, and sometimes to signal the success of what he is doing (Hanson 1969:61-62).

Archinstein's (1968:16) extended meaning of the verb "to observe" includes perceptual activities in which the object in question is hidden or invisible and only the effect of its presence can be seen. In this sense, an electron is observed by the track it leaves in a bubble chamber, and temperature is observed by its effect on the length of a column of mercury. This, the researcher in this study, sees as the legitimate extension of the concept of observation because it accords with the way scientists speak and practice. For purposes of this study, to observe means to make use of the five senses and/or scientific instruments.

Studies (Engelbrecht and Lubbe 1981:18-19, Piek and Mahlangu 1990:30-31) show that sensual observation alone is not enough to make learning possible. Sensory observation of things becomes meaningful only when it is followed by understanding and internal assimilation. It is for this reason that observation is closely linked to perception, i.e. understanding of concrete
observation, or inner experiencing of external observation. Observation of concrete objects, and experience with concrete objects, can only become meaningful and lead towards learning when they are experienced internally. Through the medium of thought man transcends his concrete experience. It follows that without observation, no perception can take place, and without perception, no learning can take place.

The concept 'observation' can be described qualitatively and quantitatively.

1.5.2.1. Qualitative and Descriptive Observation

Qualitative and descriptive observation is defined as "Taking notice of many different aspects of objects or situations, ... Making use of many senses. ... Noticing all kinds of details or changes, .." (Burkinshaw 1987:24). When we observe something, we do so in the light of our experience of observing similar things in the past. We make a selection from the myriad of possible things to observe (Gott 1987:412). Observation involves the description of objects or events, in words or sketches or the identification of similarities and differences (Gott 1987:413).

1.5.2.2. Quantitative Observation

A quantitative observation is a much more precise kind of observation which is closely tied to ideas of measurement (Gott 1987:413). This involves assigning numbers to features of the world, and is therefore, a subclass of observing (Koss 1989:104). According to Gott and Welford (1987:218), the definition of observation which emphasizes the use of measuring instruments, as in 'using linear scales', does so in some cases to the exclusion of qualitative observation. The making of observations in the sense of reading an instrument involves a
theory of instrumentation and may be referred to as indirect observation.

1.5.3. Skill

Longman Dictionary of Contemporary English (1982) defines a skill as "a use of practical knowledge and power". It also means "the ability to do something well". Thus we can speak of a swimming skill or an observing skill.

Brenda et al (1984) as quoted in Wellington (1989:99-100) define a skill as a specific activity which a learner can be trained to do. One characteristic of a skill is visible action which can be assessed. This embraces both broad and specific actions.

The study of science education literature (Carin and Sund 1989:68, and Neuman 1978:5 and 23) shows that the terms 'skill' and process are sometimes used interchangeably with each other. Skills are variously defined as science processes, process skills or simply as skills (Cavendish et al 1990:3). Harlen and Adey (1986:707) define a process skill as any cognitive process involving any interaction with content. Fairbrother takes a totally pragmatic approach by suggesting that skills are "things we want learners to do" and calls these "ings" (Wellington 1989:18). A closer look at the two terms reveals that they are indeed related but do not have the same meaning.

A skill is identified as being separate from a process. A process is seen as a rational activity involving the application of a range of skills (Wellington 1989:99). By implication a process is a much broader concept than a skill. A skill should be seen as a subset of a process. The concept "skill" is sometimes used in the same way as technique. A technique is defined as a manner in which a subject is treated by a person. It is the method of artistic expression used in areas such as writing, art etc. A technique is also defined as a skill in art.
or some other specialist activity (Du Preez and Stroebel 1991:6; Longman Dictionary of Contemporary English 1982).

It is noted that the main emphasis of the concept "skill" is ability, whereas "technique" emphasizes the method or way of doing things.

For purposes of this current study, an "observational skill" is defined as the ability to observe well. The term "allied" in the phrase "observational and allied skills" is an adjective which refers to other skills which are related to observational skills. This is explained fully in section 5.2.

1.5.4. Natural Sciences

The natural sciences entail a systematic body of knowledge of nature. This is an attempt by man to unravel the secrets of creation. The disciplines of natural sciences are depicted in Figure 1.1.

The Physical sciences are concerned with the study of matter and the Biological sciences with living things. The earth sciences are concerned with the study of matter in and around the earth. Mathematics is regarded as the 'language' of natural sciences.

Figure 1.1. The Most Important Disciplines of the Natural Sciences
Figure 1.2. Summary of steps followed in this study
1.6. RESEARCH METHODOLOGY

Two methods are followed in this study, namely; literature study and empirical research (see Figure 1.2.).

1.6.1. Literature Study

The researcher reviews the writings of recognized authorities and of previous research which is related to this topic. This section is divided into several chapters (See Chapters 2 to 7). The main purpose of this literature study is to acquaint the researcher with his field of study and to enable him to undertake an empirical research.

1.6.2. Empirical Research

As indicated in paragraph 1.4.2. (b), an empirical research is undertaken to investigate whether the teaching and learning of natural sciences can contribute to the development of observational and allied skills.

1.6.2.1. Laboratory Achievement Test

Data on the state of observational and allied skills are collected by a laboratory achievement test. A group of learners is pre-tested to find out the state of their observational and allied skills. They are then given an instructional treatment after which they are post-tested using the same testing instrument to try and find out the effect of the instruction. The learners' written responses are analysed.
1.6.2.2. Presentation, Statistical Analysis and Interpretation of Data

Data collected through the laboratory achievement test are presented in the form of tables. This is followed by statistical analysis of data.

1.7. PROGRAM OF STUDY

CHAPTER 1

Chapter 1 is an orientation to the study. It is comprised of the statement of the problem, aims and objectives of the study, definition of important terms and analysis of research methodology.

CHAPTER 2

In this chapter the researcher explores the theory of observation as a science process. The inductivist theory, its assumptions and implications in the teaching and learning of natural sciences is also discussed and appraised.

CHAPTER 3

The theory of observation as a science process is explored further. Special emphasis is placed on the alternative or general theory of scientific observation. This is part of the reappraisal of the role and status of scientific observation in the teaching and learning of natural sciences.
CHAPTER 4

This chapter discusses the different types of observations and their implications to the teaching and learning of natural sciences.

CHAPTER 5

Chapter 5 looks into the categories of observational and allied skills as aspects in the teaching and learning of natural sciences.

CHAPTER 6

Chapter 6 discusses the nature and structure of natural sciences and its implications to the psychology of learning and instructional strategy.

CHAPTER 7

The development of observational and allied skills in the teaching and learning of natural sciences forms part of chapter seven.

CHAPTER 8

Chapter 8 comprises the description of the empirical research methods. The actual empirical research procedures, including the instruments for data collection are all explained in details in this chapter. The laboratory achievement test is constructed to collect information about the learners' observational and allied skills.
CHAPTER 9

Data are presented in the form of tables. Analysis and interpretation then take place.

CHAPTER 10

The last chapter is the summary, principal findings, conclusion and recommendations.
2 THE INDUCTIVIST THEORY OF OBSERVATION AS A SCIENCE PROCESS AND ITS IMPLICATIONS TO THE NATURAL SCIENCES CURRICULUM
2.1. ORIENTATION

It has already been indicated in paragraph 1.1.4. that the theory of observation is a part discipline in which only few science educationists have dared to tread on. Norris (1985:817) has also found that it is difficult to identify in one place a completely elaborated theory of observation. However, the researcher, in this study is persuaded, by sheer enthusiasm, to make an attempt.

The description of a paradigm for the observation process should explain the general laws and theoretical assumptions underlying this field of study. For purposes of this study, it should also be able to give an indication of how observation related skills could be developed and assessed.

A considerable number of science educationists will agree with the researcher in this study that a description of the theory of the observation process will not be complete without reference to the inductivist theory.

In this chapter, a description of the inductivist theory and how it relates to observation is made. The chapter also attempts to answer questions such as how scientific knowledge starts, the status or nature of observation; whether observation is a simple or complex phenomenon, relation of observation to inference, the role of human senses and instruments in observation, the place of theory in observation and the nature of information furnished by observation.

However, the last part of this chapter will show that most assumptions underlying the inductivist theory are in error and cannot lead to the development of adequate observation related skills.
2.2. WHAT IS INDUCTION?

From the educational perspective, induction is a way of reasoning using known facts to produce general laws. It allows us to generalize a number of observations into a general rule; that night follows day and day follows night (Born 1949:7).

For purposes of this research induction progresses from concrete (practical work) to the abstract (principles and laws) (Van Aswegen, Fraser, Nortje, Slabbert and Kaske 1993:98). It involves the inference from particular observations to general or universal statements (Levy 1989:9) The task of the scientist is to induce universal statements from antecedently collected data. For example, a pupil formulates a hypothesis that in green leaves starch can only be formed in the presence of sunlight. He then tests the hypothesis experimentally, interprets the results and formulates a generalization.

The inductivist theory involves the following basic steps: (a) Making observations as accurate and definite as possible (b) Recording these intelligibly (c) Classifying them (d) Extracting from them by induction general statements (laws) which assert regularities (e) Deducing other statements from these (f) Verifying these statements by further observation (g) Propounding theories which connect and account from the largest possible number of laws (Gagné 1970:150; Introductory Readings in the Philosophy of Science 1980:16 and Nuffield Chemistry 1967:2).
2.3. ASSUMPTIONS OF THE INDUCTIVIST THEORY ABOUT THE ROLE AND STATUS OF OBSERVATION OF NATURAL PHENOMENA

From a careful study of the inductivist theory in Chalmers (1990:22) and Norris (1985:821), several assumptions about the role and status of observation in the natural sciences may be implicitly stated. The assumptions are as follows; science starts with observation; observation yields a secure basis from which knowledge can be derived; observation and inference can be sharply distinguished from each other; observation is a simple mental activity and observation is inextricably linked to human sense perception.

These inductivist assumptions are scrutinized in the text that follows. Doubt is cast on the validity and justifiability of each assumption. It is shown that these assumptions are not adequate for developing observational and allied skills.

2.3.1. 'Science Starts with Observation' as an Assumption

The view of the inductivist theory that science begins with simple, unprejudiced observations of selected parts of nature is implicit in, inter alia, the following sources: (Collette 1973:14; Collette and Chiappetta 1984:13; Nuffield Physics 1966; Popper 1981:72). Corder (1982:77) is emphatic that the foundation of science in early childhood years begins with observation.

The researcher maintains that this inductive view seems to bear substance if one considers science at its simplest sense. In Chapter 3 of this research it is argued that science at its complex sense does not necessarily begin with observation. The suggestion that the initial, unprejudiced observations lead infallibly to conceptual explanations is against logical reason.
It is "both philosophically and psychologically absurd" (Hodson 1986a:27).

This seems to plant a misconceived relationship between observation and theory. This may lead one to construct a simple direct relationship between observation and theory. One may be tempted to make a logical conclusion that a change in observational evidence always brings about a change in theory and this seriously underestimates the true complexity. The implication of this is that when the theory is in conflict with observation it is the theory that is rejected. A further complication in the natural sciences curriculum is the danger that the pupils' acceptance of a particular theory prevents them from making observations that might refute it. The reader is referred to section 3.2.2.3. for some black pupils' belief about the cause of lightning.

Hodson (1986a:25) confirmed that this misconceived relationship between observation and theory is promoted in school science courses in most countries.

2.3.2. The Security of Observation as an Assumption.

Pestalozzi (1915:109) believed that sense impressions of nature is the only true foundation of human instruction and knowledge. The belief in the security of the information furnished by observation is also apparent in the frequent representation of science as analogous to detective work. Observation is seen as the sole reliable source of empirical knowledge. Such an approach fosters a view that there is a true and certain explanation awaiting discovery (Hodson 1986a:18; Levy 1989:1).

Indeed, Gallagher and Ingram (1984:23) allege that "science is about asking questions ... you ask scientific questions when
you are reasonably sure that the answers you get can be trusted".

As represented in Figure 2.1, the inductive approach starts with the observation of natural phenomena. This is followed by inductive generalizations. Predictions may then be made from the generalizations. Observation therefore, provides a secure base for generating knowledge (Hodson 1986a:17).

![Figure 2.1: The Traditional View of Scientific Method](Adapted from Hodson (1986a:17))

According to Harris (1979:21) an observer, goes out into the world to observe, collect and record data of facts objectively, and with no a priori ideas about their relative importance to him. He must then analyze what he has observed and recorded with no underlying hypotheses at all except those that relate to the logic of his thinking processes. From this analysis he then draws out relationships and generalizations from among the facts he has collected.

The researcher in this study believes that it is not possible for an observer to be objective in the collection and recording of data. The reader is referred to section 3.2.2. for further details about this.
Gagné (1970:150) maintains that scientific inquiry is a matter of solving problems by "unrestrained inductive thinking". This view of concept formation by induction implies that generalized ideas (concepts) are formed from individual sensory impressions that are similar and contiguous. Gagné further gives an example that a teacher wishing to assist his pupils to the concept of "Mammals have hair", would provide his pupils with many live mammals to observe and record. Another example is that pupils could be given a generalization that sunlight is necessary for photosynthesis. They could then be asked to verify this by experimentation.

The inductivist theory also suffers from its demand that a large number of observations be made under a wide variety of circumstances. How many observations make up a large number? Should a metal bar be heated ten times, a hundred times, or how many times before one can conclude that it always expands when heated? Whatever the answer to such a question, Chalmers (1990:16) contends that it would take a very stubborn inductivist to put his hand in a fire many times before concluding that fire burns. In circumstances like these, the demand for a large number of observations seem inappropriate. In other situations the demand seems more plausible. For example, it would be naive to conclude that "metals expand when heated" simply because a particular metal expanded when it was heated.

Another example is that we cannot be one hundred percent sure that, just because we have observed the sun to set each day on many occasions, the sun will set everyday!

The inductive approach is alternated with the deductive approach where a specific concept, rule or principle is first introduced to learners. The learners have to apply the knowledge they have been given in other new situations. As an example, pupils could be taught a generalization that "Mammals have hair". Later, various animals could be presented to pupils for observation and to deduce whether they are mammals or not.
2.3.2.1. Implications of the Inductivist Theory on the Natural Scientist.

The above assumptions project an image of a natural scientist as an objective, open-minded, unbiased and possessing an all-powerful and infallible method of ascertaining the truth. In over-emphasizing the tactics of a formalized, objective scientific method, the inductivist theory projects a distorted image of a scientist as impersonal and lacking in social responsibility (Cawthron and Rowell 1978:32). By this, it is meant that the resulting knowledge is free from personal values, opinions, preferences and expectations.

Hodson (1986a:18) sees this as partly responsible for the large number of children, especially girls, who opt out of science education at the earliest opportunity. The implicit message of the science curriculum is that to be scientific is to have such attitudes as curiosity, rationality, suspended judgement, open-mindedness, critical awareness, objectivity, honesty, humility and self-accountability. However, there appears to be considerable discrepancy between this curriculum view of scientific attitudes and the characteristics of real scientists (Mahony 1979:13). As Gauld (1982:118) remarks, "teaching that scientists possess these characteristics is bad enough but it is abhorrent that science educators should actually attempt to mould children in the same false image".

2.3.2.2. Implications of the Inductivist Theory on Science Teaching

The shortcomings of the inductive approach as indicated in Van Aswegen et al (1993:98) is that it is time consuming and that not all pupils have the ability to discover for themselves. As a result learning may take place by means of memorising rather than by understanding.
The notion that observation is the only true foundation of human knowledge has several implications in the teaching and learning of natural sciences. According to Hodson (1986a:18), science itself is seen to have the following characteristics:

(i) **It gives access to factual truths about the world.**

(ii) **Its knowledge is derived directly from the observation.**

(iii) **It rationally tests its propositions by means of objective and reliable experimental procedures.**

(iv) **It is a neutral activity untainted by socio-historical and economic factors, producing value-free knowledge.**

The researcher, in this study, sees this method as having led to the expository science teaching in most countries, including South Africa. In South Africa, Levy (1989:18) wrote that science teaching is presented as authoritarian, and the scientist as an expert in observing true facts about the world.

Furthermore, both the teacher and the pupil are confronted with a static body of knowledge, the teacher is viewed as a knowledge transmitter and the pupil as a passive recipient. The knowledge is presented as closed and final facts about nature, not subject to revision (Levy 1989:19 and 56).

The pupils are made to rely on the knowledge which is the result of several 'infallible' observations by scientists. Their own observations, if any, involve a mere carrying out of routine procedures in the laboratory to prove a theory which has been explicitly represented (South African Association of Teachers of Physical Science 1978:9). This is characterized by phrases such as 'To show that ...' or 'To verify that ...'. The theory is announced first, then observational materials are paraded in its
favour. The problem is that even if the observation is not successful, it is a matter of no great importance since all the details of procedure and the correct results are to be found in the textbooks.

In the words of Solomon (1980:15), some of the theories are "notoriously obstinate in the yielding of obeisance". It must be made clear that contrived experiments or demonstrations that are put together to illustrate some "predetermined" concept or fact are not what is meant by observations (Swinehart 1987:429).

2.3.3. An Inference as a Science Process Skill
Allied to Observation

To infer is to draw the meaning from something. For purposes of this research it means to construct a meaning from the observed material.

In this assumption, a sharp, decontextualized distinction can be made between observations and inferences and, as a corollary, there is a scientific language reserved for observation and one reserved for theory (Norris 1985:817). Mossom (1989:70) stated that the ability to observe accurately, without at first making judgments from those observations, is the most basic of all the science processes. The existence of this assumption is demonstrated by, among others, The candle activity (see Appendix A i).

According to the logical empiricist philosophy of science, statements could be classified into material object statements and sense experience statements (Barnes 1967:695).

Using this classification, observation statements are classified as sense experience statements. Observation does not offer categorical statements about objects and events in the external world. It rather offers a report of how things seem to us. They
are reports of the sensations we are having. There could be no doubt about sense experience statements, for example, that the colourless liquid at the top of the burning candle looks like liquid paraffin (Norris 1985:819).

To make categorical statements about the world one must make inferences from observations about how the world seems. The statements are classified as material object statements. These statements are dubitable. For example, a statement that the colourless liquid at the top of a burning candle is liquid paraffin is doubtful (Norris 1985:819).

Thus material object statements and sense experience statements are distinguished from each other by the language used in making them.

It is argued by inductivists that the validity of observation statements are independent of the opinions and expectations of the observer and can be confirmed by direct use of the senses (Hodson 1986a:18). The observer endeavours to keep his mind scrupulously free from prepossessions and favoured views. He seeks only a record of facts uncoloured by preferences or prejudices. To this end he strains himself from theoretical indulgence, and modestly contents himself with being a recorder of nature. He does not presume to be its interpreter and prophet. This is known as the method of colourless observation (Chamberlin 1981:100).

2.3.3.1. Implications of the Inductivist Theory on the Human Mind.

The assumption that human observers have direct access to the properties of the external world implies that the mind is a tabula rasa on which our senses inscribe a true and faithful record of the world (Hodson 1986a:18). But it is now a known
fact that sense experiences are not like that.

This argument prompts one to assume, as Levy (1989:1 and 11) has done, that knowledge of reality involves a mechanical procedure. This means that reality presents itself for observation to the passive mind. As a corollary, one can further assume that nothing enters the mind except by way of the senses.

The researcher, contends that it is simply not possible for one to observe things which one does not expect, know how to look for and is not conceptually prepared for. Theobald (1968) as quoted in Hodson (1986a:21), in emphasizing this point, wrote that "If we confront the world with an empty head, then our experience will be deservedly meaningless". The researcher agrees with Theobald's contention that experience does not give concepts meaning, if anything concepts give experience meaning. This is because a concept is a vehicle through which ideas, thoughts and understanding comes about, not vice versa.

2.3.3.2. Implications of the Inductivist Theory on the Language of Observation.

The inductivist version in which observations are taken to be legitimately reportable only with "seems like, feels like and looks like" language leads to problems. To other scientists, these would not be considered observations at all (Norris 1985:830). In the view of the researcher, this kind of language attempts to avoid interpreting the facts of observation. Yet interpretation is so much an aspect of observation to an extent that observation would almost be impossible without it.

2.3.3.3. Implications of the Inductivist Theory on Observability

Hodson (1986a:20) has rightly pointed out that inductivism offers no guidance on how the innocent, unbiased observer could
restrict his observation to something less than the whole. In The candle activity, one is expected to observe everything, including the chemical composition of a liquid that forms when a candle burns. Norris (1985:819), in challenging inductivism, argues that one cannot observe that the substance is a liquid, or even that it is a substance, because each of these claims is about the composition of what is really observed.

2.3.3.4. Implications of the Inductivist Theory on the Methods of Science

The view in Hodson (1986a:27) that science is projected as a neutral activity propelled only by its own internal logic and independent of socio-historical and economic issues undervalues creativity. It assumes that there is only one way of proceeding in any particular situation, and this makes no allowance for individuality. This overlooks the fact that there is no "scientific method" in the sense of a neat formula.

The curriculum priority afforded to observation seems to set up a chain of false logic which leads one to advocate discovery methods of learning. According to Revised Nuffield Physics (1977:8), the essential aim is for pupils to enjoy their experimentation. For what they need are simple general instructions, where to look but not what to look for. If, for instance, pupils are instructed to look into the microscope and make diagrams of what they observe, they are likely to include air bubbles in their diagrams. Worse of all, they will not have the necessary language with which to label their diagrams because the language is not part of what they observe.

The major impetus in the adoption of discovery learning methods seems, according to Harris and Taylor (1983:43), to have been the fusion of inductivist ideas about scientific method with progressive child-centred views of education. There is growing
awareness that in relying heavily on inductive inferences, discovery learning methods seriously misrepresent both the nature of science and the nature of the learning process (Brandon 1981; Driver 1975; Summers 1982; Wellington 1981). Some other disadvantages of unguided discovery should also be mentioned. The first and indeed one of the most intractable problems has been how such free discovery can be fitted into the curriculum. Being essentially a spontaneous activity, how can it be accommodated within a planned course of study? It seems an insoluble paradox. Unguided discovery exercises are slow and need extension over many teaching periods.

Furthermore, if discovery is to have real meaning, it must be a genuine independent activity—neither following instructions nor manipulated from behind the scenes by a conniving teacher. This raises some questions on the continued existence of the teacher. Unguided discovery learning, therefore, is not the most economical approach to learning. However, the aim of education, namely, the development of observational and allied skills is suitable for purposes of the current study.

2.3.4. The Relation Between Observation and Human Perception and its Implications to the Natural Sciences Curriculum.

In Engelbrecht and Lubbe (1981:18) perception is defined as internal experience of external observation. Both observation and perception are regarded as didactic principles. Humans learn by perceiving and, therefore, the principle of perception is very important in the method of teaching.

The child, by means of his senses, is aware of the concrete world from a very early age. Pick and Mahlangu (1990:30) have rightly pointed out that sensual observation alone is not enough to make learning possible. The concrete observation must be digested (understood) so that meaning can be found in it.
Observation of concrete objects, and experience with concrete objects, can only become meaningful and lead towards learning when they are experienced internally.

Engelbrecht and Lubbe (1981:18) are emphatic that language and thought are the most important components of perception. Without them, no learning can take place; perception without thought is impossible. Through thought man can progress beyond the limitations of concrete observation and concrete experience. Before any thought can take place, man must observe. Before abstract thoughts can occur, there must be some concrete experience. Concrete observation and perception of concrete objects are essential for abstract thought. Perception will be of little use if one cannot use language to explain what he has perceived. Thought requires language to express itself. Language and thought develop from the same basis, i.e. observation and perception.

The researcher sees one notable significance of this assumption to be the use of audio-visual aids not only in the natural sciences curriculum, but in the whole of education. Knowledge which lies beyond the personal experience of the child can be brought into the classroom by means of these aids.

In the education of the child it is important to provide enough perceptual experience, in which the child can find food for thought. The child must be able to integrate what he has experienced in previous observations to absorb new ideas and express them again in language. It is the specific task of the school to provide the opportunities for observation that can lead to control of language and independent thought.

Engelbrecht and Lubbe (1981:19) give a warning that lack of observation may be harmful to the child, just as excessive
observation may disturb his power of abstract thought. We must strive for the right balance.

One very important assumption of the inductivist theory is that scientific observation is inextricably linked to human sense perception, and derivatively to a limited number of information-carrying mechanisms (American Association for the Advancement of Science 1965:13; Cavendish et al 1990:64; Corder 1982:77; Feibleman 1972:27-28; Mossom 1989:70; Saturnelli 1981:1).

The following few paragraphs seem to emphasize the inextricable link between observation and human sense perception.

To observe something, according to Woodburn and Obourn (1965:45), is to direct one's senses and perceptive powers to objects, events or circumstances. Thus nature can be studied only through the senses. Brown (1987:181) asserts that what we observe is the result of a causal process involving our senses. If we observe an object that exists independently of us, what we actually sense is a function of both the properties of the item under observation and the properties of our senses. This, in essence means that what is observed is not an objective material which is independent of our senses. Whatever defects our senses may have, that will influence what we are capable of observing.

Science does not take off from high abstractions, but from sensations. To observe is somehow to read the events recorded in the nervous system as reports of an external world. In the last analysis, the empiricist says: "I will believe what I perceive by means of the senses, and I will let myself to be led to believe nothing else ... " (Feibleman 1972:32). Any beliefs which are to be accorded the adjective, 'scientific', must have to do with events which in some aspects have been hooked up with the nervous system.
Mach (1914), in Feibleman (1972:32) assumed that a material world exists to be known, and has assigned the sense organs a lead in the effort at knowing it. Here the role of the senses in observation goes along with a belief in an observable world.

A further argument by inductivists is that the use of instruments in observation is regarded as an extension of the senses (Feibleman 1972:29; Norris 1985:820). According to Woodburn and Obourn (1965:45), optimum conditions for observing facts require that the subject matter fall within the range of human sense organs, aided, when necessary by instruments. Refer to section 4.4.4. for further details on this.

The assumption that scientific observation and human sense perception are inextricably related, is challenged by Norris (1985:826). He maintains that a study of Observing the Starlight Deflection and Observing the Center of the Sun (see Appendix B (i) and (ii) ) show that this is not always like that.

In the observation of starlight deflection, Norris (1985:826) has noted that there was no direct use of the human senses, observation was imbued with inference from beginning to end.

Norris (1985:827) indicates that the only known way of observing the sun's center is to collect information brought from there by emitted neutrinos. Human senses are not sensitive to this sort of information. Norris (1987:775) maintains that it is, therefore, wrong to link necessarily human sensing to scientific observation. In both these experiments, the scientists themselves speak of having made an observation.

Norris's contention has fueled an acrimonious debate with Willson (1987:280). Willson has noted, in Eddington's (one of the scientist's) diary (see Appendix B (i) ) that Eddington
looked up twice, once to see that the eclipse has begun, and another time halfway through to observe cloud cover. Thus Willson emphasizes the importance of human sense perception in scientific observation.

What the researcher sees in the debate between Norris and Willson is a lack of congruity in their definition of observation. Norris (1985:824) believes that observation is the witnessing of natural phenomena using sensory apparatus. This sensory apparatus can either be human senses or instruments or both. According to Norris, observation is complete even when the information does not reach humans, but resides in the instruments.

The researcher, in this study, has serious reservations to the suggestion that an instrument can observe. The reader is referred to section 1.5.2. for the definition of observation as adopted in this research. A more elaborate argument against this notion appears later in section 4.4.4. of this study.

The researcher agrees with Willson (1987:281) that it is less relevant that the data are collected by an instrument, than that they are interpreted using human senses. Even if data have been collected by an apparatus, the use of human senses in interpretation is inescapable. Brown (1987:183) and Feibleman (1972:34) are emphatic that all observations derived from our instruments must pass through our senses. Scientific formulations must somehow eventually be referable to a world that can be disclosed to human senses. In this way, the researcher adopts a notion that scientific observation is inextricably linked to human sense perception.
2.3.5. Simplicity of Observation and its Implications to the Natural Sciences Curriculum.

Scientific observation is taken to be a simple mental activity. This is suggested most clearly in the "How well do you observe?" activity (see Appendix A (ii)).

The impression given in Norris (1985:821) is that to observe well one must be able to notice details quickly. This creates an impression that observation is a simple mental activity in which many details can be noticed in a short period of time.

In a hierarchy of scientific activities, which includes observing, measuring, classifying, inferring, and controlling variables, observing is ranked as the simplest one requiring the least sophisticated mental activity. The controlling of variables is the most complex science process (Collette 1973:65 and Norris 1985:821).

The inductivist view in Norris (1985:833) that scientific observation is a simple mental activity (Appendix A (iii)), runs a risk that pupils will acquire a distorted image of observation as a science process. As a consequence they may develop science process skills which are inadequate for the role which observation plays in science.

In a point of agreement, Willson (1987:282), says that showing pupils a tray for a short period of time, is not only misrepresentative of scientific observation, but wrong from a psychological perspective. The load on working memory in children is only about five or six pieces of information, without rehearsal. Showing the tray for ten seconds is basically a task for the children's short term memory.
Willson's contention that speed and accuracy have nothing to do with each other in science is not convincing. There are a number of instances where speed and accuracy are essential and have to do with each other in science. Van Aswegen et al (1993:53) argue that pupils should be able to set up an experiment systematically with reasonable speed and accuracy. In applied science such as medicine a student is trained to operate a patient with reasonable speed and accuracy. Pilot training and computer technology are other examples in which speed and accuracy are encouraged. The researcher believes that speed and accuracy should be encouraged in science.

It is now a known fact that science, as opposed to the inductivist assumption in section 2.3.1., does not necessarily start with observation. Suspicions, presumptions and suppositions could also be starting points in the study of natural sciences. Sense impressions of nature, contrary to the inductivist assumption in section 2.3.2. is not the only true foundation of human knowledge and instruction. Thoughts and ideas are also forms of knowledge. Furthermore, observations made by scientists and the resulting knowledge that is produced is not infallible. It is subject to revision. This is what the teaching and learning of natural sciences is all about. It is not possible for an observer to be objective, he interprets the sense impressions according to his theoretical paradigms.

The above arguments all weigh against the use of the inductivist theory to develop observational and allied skills in this study. However, one area of agreement with the inductivist theory has already been identified, and that is the essential link between scientific observation and human sense perception.
2.4. SUMMARY

The following assumptions are implicit in the inductivist theory as described in this chapter:

(a) **Science begins with simple, unprejudiced observations of selected parts of nature.**

(b) **Observations provide a secure base from which inductive generalizations may be drawn.**

(c) **A sharp, decontextualized distinction can be made between observation and inference.**

(d) **Scientific observation is inextricably linked to human sense perception.**

(e) **Scientific observation is taken to be a simple mental activity.**

The researcher has noted that most of the above assumptions are in error because they project an image of a scientist as impersonal and infallible. The teacher is viewed as a knowledge transmitter and the pupil as a passive recipient. Knowledge itself is presented as closed and final facts not subject to revision. The current situation in which the expository teaching strategies are emphasized is seen by the researcher to be a didactical flaw which may have resulted from most assumptions in the inductivist theory.

This theory presents a distorted image of observation as a science process. Its use may lead to the development of science
process skills which are inadequate for the role which observation plays in natural sciences.

The inductivist theory has very little to say about the role played by language in observation. It is silent about the role of theory, thoughts and human expectations. These aspects and many more are discussed in the next chapter.
3 THE GENERAL THEORY OF
OBSERVATION AND ITS
RELATION TO OTHER
SCIENCE PROCESSES IN
THE NATURAL SCIENCES
CURRICULUM
3.1. ORIENTATION

The previous chapter has successfully challenged the time-honoured view that scientific theories can be justified from observations. There is an abundance of evidence that this distorted view on the nature of science is still influential, often with some deleterious results in some contemporary institutions of learning.

This chapter explores a general theory of observation as a science process. The relation of observation to allied science processes of interpretation, inferring and communication is also discussed. The reappraisal of the theory of the observation process should be able to explain the areas which could not be satisfactorily covered by the inductivist theory. These areas are as follows:

* The role of theory, language and intuition in observing scientific phenomena.

* The role of an observation process in the building and testing of theories.

* The role of instruments in the observation of scientific phenomena.

* The significance of inference in observation.

* The psychological state of the observer and the nature of the observed facts.

* Observation process as a continuum of simple to complex interaction.

The implications of each of these areas in the natural sciences curriculum is explored.
3.2. RECONSIDERATION OF THE ROLE AND STATUS OF OBSERVATION
AND ITS RELATION TO OTHER SCIENCE PROCESSES IN
THE NATURAL SCIENCES CURRICULUM

Norris (1985:817), having admitted that there is no elaborate
general theory of scientific observation, ventures into laying
the foundation of such a theory. He postulated (Norris 1985:823)
that a general theory must explicate the sorts of astrophysical
and starlight deflection observations (see Appendix B [i] and
[ii]) which Willson (1987:280) described as theory-confirming
observations. It must also explain the sorts of observations
found in science textbooks, as well as Darwin's observation of
the different shapes of the beaks of finches, which Willson
(1987:280) calls theory-building observation. It must also show
why many deep-seated assumptions about observation, though
misconceived, have seemed so attractive.

Norris (1985:824) and Hodson (1986b:382) claim that
reconsideration of the role and status of observation in the
natural sciences would provide teachers and science curricula
developers with six focuses of attention.

(i) Observations depend on our often inadequate sense
perception and, therefore, are unreliable and fallible.

(ii) Observations are theory-dependent, and theory often,
though not always, precedes observation.

(iii) Indirect observation depends on the additional theory of
instrumentation.

(iv) Concepts and theories are produced by creative acts of
abstraction and are not derivable from direct
observations.

(v) Theories are often justified post hoc by observational
evidence.

(vi) Competing theories may give rise to non-identical
observations when confronting the same phenomena.
Norris (1985:823) proposed that the place to start in exploring the general theory of observation is with the intended role of observation. He suggested that observation is inherently heuristic. It is best conceived in its function as an aid and guide to scientific discovery.

3.2.1. Observation as Interaction and its Implications to the Natural Sciences Curriculum

Shapere (1982), as referred to by Koss (1989:20), describes observation as a subspecies of interaction. An observation of X is any interaction between X and a receptor such that some information about X is transferred to the receptor. The receptor, in Shapere's description, does not necessarily have to be a human being. Any device which can interact in an informative way with the object in question can function as a receptor. The reader is referred to section 4.4.4. for more information about receptors other than humans.

With observation as interaction, the observation process is amenable to description by physical theory, general laws of physical interaction, together with more specific theory of the source, the object to be observed, and theory of the receptor. The physical laws will describe not only the modality of observation, but will also correlate the information of the object with the resulting information of the receptor after the interaction has occurred. The question of observation in this case has become one of epistemological import rather than perceptual. Observability and, therefore, observation no longer hinges on the sensual acuity of the human body, nor on an unambiguous understanding of perception. It hinges instead on an account of the transfer of information from object to receptor, whatever the receptor might be (Koss 1989:21). Thus Shapere's (1982) concept of observation is the same as that of Norris (1985:824), (see section 2.3.4. in this study).
Earlier in this study, the researcher, has expressed his doubts to the suggestion that an instrument can observe. The reader is referred to section 4.4.4. for a critical look at this notion.

The implication of observation as interaction is that learners should be given opportunities to interact directly with their learning material or indirectly through instruments. Learners should develop skills for reading the information from instruments.

3.2.2. The Theory Dependence of Observation and its Implications to the Natural Sciences Curriculum

Hodson (1986b:391) maintains that there is a dynamic relationship between theory and observation. Scientific theories depend on observation to the extent that they are explored, developed and tested by observation, and are accepted, modified or rejected, in part on the strength of observational evidence. Contrary to the inductivist account, much of this observation follows rather than precedes theoretical speculation.

This also applies to critical theory in which Kearney (1991:4-5) asserts that the ultimate meaning of our world cannot be divorced from the historical and political contexts. Observing, therefore, cannot be divorced from the theoretical assumptions of the observer. Meaning and, therefore, observation is only possible by combining the practical and reflective activities or material and intellectual aspects of our existence. This is in stark contrast to Quine's (1973) view in Brent (1983:59-60) that knowledge construction begins at the level of directly observable behaviour.

Hanson (1981:263) maintains that interpretations are instantaneous, in other words, theories and interpretations are
there in the observation. What we choose to observe and the way in which we choose to observe are dependent on our knowledge and our expectations. Making theoretical assumptions is an essential part of observation because they guide the observation process.

We all bring to any situation our own preconceptions which have been formed by our past experience, or lack of it. Our ideas will determine, or even constrain our observations. The implication of this in a didactic situation is that when pupils are asked to observe a bird, for example, they look at it in the light of ideas accumulated through their everyday and scientific experience. Gott and Welford (1987:224) stress that most of these ideas should be purposefully developed by educators.

Scientists have to test their observations for acceptability by using theory. Sense data often have to be rejected on theoretical grounds: For example; the Earth is not flat, a stick partially immersed in water is not bent. Hodson (1986a:23) contends that when theory and observation conflict, nothing in the logic of the situation demands that it be the theory that is rejected. Rejection of observational evidence is a crucial part of scientific research. Knowing what to observe, knowing how to observe it, observing it and describing the observations are all theory dependent and, therefore, fallible and biased.

Observation statements, therefore, do not provide the objective certainty for making generalizations and building laws. They are only as reliable as the theories they presuppose. The validity of theoretical statements cannot be guaranteed by observational evidence. First, because of the unreliability of observations. Second, because of the theory dependence of all concepts involved in observations. Third, because the experimental procedures that produce observational evidence are all theory dependent and often involve elaborate instrumentation, each with its own theoretical underpinnings. For example, designing
apparatus to detect sub-atomic particles requires us to make assumptions about their properties and behaviour. We must speculate in advance of observation about the nature and properties of that which we wish to observe (Hodson 1986a:23).

As indicated in Hodson (1986a:24), the admission that observation is theory dependent does not mean that the world is simply a construct of human mind or that individuals are free to fabricate the world that happens to suite them best. Science does not lose its objectivity because the human mind still has to come to terms with the physical material in the physical world. Furthermore, the truth as published by one scientist should be capable of being confirmed by other scientists.

According to Shapere (1982: 490), it is the close integration of observation and theory that gives science its objectivity. We approach a problem situation with the strongest justified description, and only withdraw to less committal, more neutral ones when specific reasons for doubt arises - and even then, we withdraw only as far as necessary with respect to the available reasonable alternatives.

In emphasizing the close integration of observation and theory, Feibleman (1972:31) warns of the danger that extraneous considerations could creep in. These are things which are not directly related to the particular theory in question. Only those beliefs which are necessary in order to make observation itself possible are allowed. Preconceptions, anticipations and adjacent materials are prime sources of danger which are not completely avoidable in the act of observation. Observation must be largely unaffected by subjective or objective inference.
3.2.2.1. Observational-Theoretical Dichotomy

A drawing of the observational-theoretical dichotomy is a subject of divergent opinions. What seems to be contentious is the ontological criterion of where to draw the line of division.

According to empiricism, observation can be separated from theory by referring to the language that is used. There is an observational language reserved for observable phenomena and a theoretical language for theoretical phenomena (Achinstein 1968:16; Carnap 1936:6; Fodor (1984:38); Levy 1989:12). For example, to say that gas is given off when mercury (II) oxide is heated is an observation statement. But to say that the gas is oxygen is a theoretical statement.

Van Fraassen (1980:17) believed that an entity is observable if it can be observed by unaided human senses. Otherwise it is a theoretical entity. For example, the fact that electrons flowing through a circuit board cannot be seen through the naked eye would be regarded as unobservable and, therefore, theoretical.

The researcher in this study contends that Van Fraassen's criterion is based on the description of observation as a subject of human sense impressions alone. It is now a known fact (see section 4.4.4.) that observation also involves the use of instruments.

The problem as pointed out by Achinstein (1968:16) and Kuhn (1970:14) is that what is theoretical is not necessarily non-observational. Any line drawn in this way between observation and theory is problematically arbitrary.

Hacking's (1983:23) distinction of observation and theory is based on intervention. Something is observable if it can be
manipulated (pushed, reshaped, etc). Otherwise it is theoretical. The problem with Hacking's distinction is that observation is seen to be a function of human acuity.

The researcher in this study aligns himself with Hodson's (1986b:382) contention that a drawing of the observational-theoretical line at any given point is an accident. It is a function of our physiological make up, our current state of knowledge, and the instruments we have available and, therefore, has no ontological significance whatever. A significant change in instrumentation may enable an entity previously categorized as theoretical to be categorized as observable.

A theoretical language brings with it its own observational language. In an introduction of the theory of solubility, for example, we see copper sulphate dissolving, where we previously saw it disappearing. In this case the concept "disappearing" would be regarded as an observational statement whereas "dissolving" would be a theoretical statement. Additional knowledge and experience increases the range and scope of a scientist's observational language and the theoretical assumptions which are 'built in' to observation statements.

3.2.2.2. The Role of Language in Observation

A subject language system originates when an observation is given meaning by the observer. One important sense in which observation is theory-laden rests with the description of an object. Here, the scientists employ descriptive language. These in turn, rely on classification, which presupposes interests.

According to the critical theory, meaning cannot be divorced from its social context. The scientist's language is a subject of his interests (Levy 1989:48) and his historical and political
background (Kearney 1991:4). In a real sense, the language of the scientist circumscribes the nature of observation.

Observation, therefore, is theory dependent. In practice, some view of the world precedes observation. Furthermore, observation statements are expressed in the language of some theory, and such statements are as vague or precise as the theoretical framework against which they are expressed, allows. The quality and usefulness of observations depend crucially on the observational language available to the observer. Without such a language, perception cannot be given meaning. Observations cannot be recorded and criticized. This theory dependence may, on occasions, lead a scientist to make incorrect observations simply because the theoretical position he has adopted is incorrect. Not only do observers frequently miss seemingly obvious things, but what is even more important, they often invent quite false observations (Hodson 1986a:21-22).

The order in which data are collected is not the order in which they belong. Moreover, the very recognition of that which is observed requires the use of an appropriate language. Thus all facts are facts in a system. The phenomenology of a domain is a statement, if possible, mathematically expressed. Data are individuals and there are no sentences which completely describe individuals. Every datum once described is immediately assigned a place in two systems: the system of the descriptive language, and the system referred to by language. The grammar of scientific language is mathematics (Feibleman 1972:54).

From the above, it is quite clear that observation statements cannot be expressed in theory neutral language. This is because most of the concepts used in such statements will have their meaning firmly anchored to that particular theory. The implication of this in a didactic situation is that the learner
must be equipped with the necessary terminology that enables him to observe and communicate his observation. In order to prevent verbalism the development of the appropriate language should be linked to the observable material.

One of the chief difficulties of science at the very outset of simple observation is that all experience is particular. This means that it takes place at a specific time and place. It is about the past and the present but never about the future. Descriptions of experiences, on the other hand, are general, and may also refer to the future.

The language whereby the observer gives an account of his experiences is incurably general. All words except the names of singular objects such as "Pretoria" or "Mandela" are class names, and it is by combining class names into sentences that the observer undertakes to record what he has observed. There is an advantage for science in the fact that in so far as the sentences are general, they refer to other similar situations in the present and future. Thus the description of experience and prediction of the experience of others, in science takes its place as a public undertaking available to continual verification (Feibleman 1972:30-31).

3.2.2 3. Abstraction

By abstraction here is meant the representation of the partial aspect of a material object by means of language. It is a principle of education that a child must first be able to think in concrete (based on observation) terms before he can be able to think in abstract (theoretical) terms (Engelbrecht and Lubbe 1981:13). Abstraction makes possible further observations from a different angle.

Abstractions are made from data disclosed by a person's
experience, not from within the experience itself (Feibleman 1972:60). Observation is the simplest kind of abstraction and this abstraction is worthless unless we can connect it with others under some comprehensive theory (Feibleman 1972:39-40).

The implication of this on education is that a teacher must base his teaching on the concrete world of the child. This can be done by use of charts, models, illustrations and experiments. It goes without saying that pupils, especially at the lower levels of learning should be given more observational material, which will develop their powers of abstraction. As indicated in section 1.5.2., the didactic principle of perception is closely linked to observation. Sensory observation becomes meaningful only when it is followed by perception. Only if observation of concrete objects is experienced internally can it lead towards learning.

3.2.2.4. Conceptualizations

Levy (1989:48) asserts that there are various levels of theory-ladenness. One level involves conceptualizations. Even the simplest observation involves recourse to theory. For instance, a concept "corner" presupposes an understanding of concepts like "wall", "right-angle". A more complex situation would involve the observations of a cloud chamber which presupposes a prior understanding of theoretical concepts like radioactivity.

Hodson (1986a:23) contends that all concepts are anchored to some theory. Particular concepts will even undergo a marked change in meaning when transferred from one theory to another. According to Chalmers (1990:79), the emergence of the concept of electric field provides a particularly striking, and somewhat technical example. When the concept was first introduced by Faraday in the fourth decade of the nineteenth century, it was
very vague, and was articulated with the aid of mechanical analogies and metaphorical use of terms such as "tension", "power" and "force". The field concept became increasingly better defined as the relationships between the electric field and other electromagnetic quantities were more clearly specified.

The meaning of "electrical field" in classical electromagnetic theory reached a high degree of clarity and precision. It was at this stage, too, that the fields were granted an independence of their own. The aether, which was considered necessary for providing a mechanical basis for the fields, was dispensed with.

Hodson (1986a:24) further asserts that when a new theory appears, our notion of what is theoretical statement and what is an observation statement may change. Observation statements are, therefore, not distinguished from theoretical ones by the fact that they contain special observation terms; rather, they are distinguished pragmatically, in that they are statements to which we may assent quickly, relatively reliably and without calculation or inference. The investigative method of science begins with the sheer awareness present in passive observation and ends its first stage at discovery of conceptualized particulars. A conceptualized particular is a description of an individual. It is a generalization from sense observation. Feibleman (1972:55) said that conceptualized particulars have been called concepts.

3.2.2.5. Background Knowledge in Observation

Brown (1987:189) maintains that all epistemically relevant observation requires the application of background knowledge. In familiar cases this often occurs without any explicit inference. This ties up well with Ausubel's (1965) learning theory (see
section 6.3.2.4.) in which learning is based upon the previously learned subject matter. This is the structured body of knowledge or products of learning. Observation and, therefore, learning of new content is based upon this prior knowledge. The more reliable this background knowledge, the greater is the reliability of the observation. Explicit inference is one way in which background knowledge enters into observation.

According to Popper (1981:73-74), background knowledge is so closely related to an observer's expectations to the extent that one may even speak of "inborn knowledge". Thus we have an inborn knowledge which is prior to all observational experience. One of the most important of these expectations is the expectation to find regularities.

Woodburn and Obourn (1965:42-43) wrote that it is the essence of good observation that the eye should not only see a thing itself, but of what parts that thing is composed. If an observer is to become a successful investigator in a particular area of knowledge, he must have an extreme acquaintance with what has already been done in that area. Only then will he be able to seize upon any one of those minute indications which often connects phenomena apparently quite remote from each other. His eyes will be struck with any occurrence, which according to background knowledge, or expectations, ought not to happen. The importance of background knowledge is that what is observed depends not only upon what there is to be observed, but upon the observer, and what he has previously observed. He only sees well who sees the whole in the parts, and the parts in the whole.

The implications of this, according to Hodson (1986a:26-27), is that science educators need to take much more account of children's own views of the world. They acquire a considerable theoretical knowledge before they begin to study science. It is against this theoretical perspective that they interpret the
observations they make in science lessons. This new knowledge has to be firmly anchored to existing knowledge. The duty of the science educator, therefore, is to provide experiences which explore and challenge their intuitive view of the world.

There is now a rapidly growing body of research literature (not least the following: Driver and Erickson 1983, Gilbert, Osborne and Fensham 1982, and Osborne, Bell and Gilbert 1983), attempting to describe the characteristics of this 'children's science'. For instance, some children believe that a stick partially immersed in water is bent. Another example is that if an equal volume of water is emptied into two tumblers, a tall one and a short one, some children tend to think that the tall tumbler contains more water than a short one. This 'science' inevitably differs from 'real science' and these authors suggest ways in which it can be built on closer to 'scientist's science'.

The fact that observations are made and interpreted from a particular theoretical perspective, means that children can be made to learn these. This, in essence means that children's observational and allied skills should be developed.

3.2.2.6. Interpretation as a Science Process Allied to Observation

Everything that reaches consciousness is utterly and completely adjusted, simplified, schematized and interpreted. As Hodson (1986a:19) rightly puts it, our minds are not blank slates; we interpret the sense data that enters our consciousness in terms of prior knowledge, beliefs, expectations and previous experiences. In attaching meaning to the stimuli that we receive Hodson distinguishes between two significant influences, namely; our ability to discriminate and our past experiences and, therefore, our expectations. Discrimination refers to our
capacity to detect differences between stimuli. For example, we can perceive a shape either as a background or as a figure. Our previous experiences profoundly influence our perception. Pre-existing mental constructs cause one to see things in a particular way. One does not see things as they are, he sees things as he is. For example, the microscopic observation of a cross section of a monocotyledonous stem will be meaningless to a person who has never been introduced into this field of knowledge. The cross section of the different cells could be perceived as mere circles.

Hodson (1986a:22) represents observation as follows:

\[
\text{RAW} \rightarrow \text{unconscious} \rightarrow \text{SENSE} \rightarrow \text{conscious} \rightarrow \text{OBSERVATION}
\]

Hodson cautions that the two kinds of interpretations should be clearly distinguished from each other.

What an observer sees depends in part on past experience, knowledge and expectations. When incoming sense data are incompatible with existing mental constructs curious optical illusions are created in such a way that a change in these mental constructs brings about a change in perception. It is not the image falling on the retina that has changed, but the observer! He now has a different perspective, a different view of the world (Hodson 1986a:19-20). In the same way, science learners, have to learn to interpret what they see through a microscope.

Hodson (1986b:382) pointed out that the conditions under which an observation is made is significant. For instance, the colour of an object may depend on the nature of the illuminating light
or on the state of fatigue of the observer. This is not to say that there is no stability or permanence in observations. Dependence on belief and experience is not such as to make observation totally unreliable. Terms in observation statements have their meaning located in the role they play in a theoretical structure. These theories necessarily precede observation. Without theories there are no concepts and without concepts no observations are possible. In other words, there can be no theory independent observation language. Theoretical interpretation is part of the observation process itself, not subsequent to it.

I. The Role of Culture in Interpreting Observations

To borrow Chadwick et al's (1984:12 & 13) phrase, one cannot observe something without misperceiving it. Furthermore one cannot interpret (attribute meaning to) an observation without misrepresenting it. This means that culture and language facilitate (and impede) both observation and interpretation. They may literally affect what is perceived by sensitizing us to certain stimuli and creating a trained incapacity to pay attention to others. We literally do not see many things that our culture, and in particular, our language, have not sensitized us to notice. But the abbreviation and distortion are not over when an object has been perceived. Interpretation, even more than perception, depends upon the experience and expectations of the perceiver. Perception is selective, and stimuli that catch our attention are ones made salient by our experience.

Boulding (1956:18) has written that the growth of knowledge depends in part upon information received and in part upon an active internal organizing principle. Such organizing principles are greatly influenced by our culture. Boulding (1956:7) makes a
distinction between the image (knowledge) and the messages that reach it. His definition of meaning is the change that a message makes in the image. A message, once received (many are not, due to limitations in our sensory equipment) has an impact on the image. The direction and intensity of that impact, depends upon the personal history and immediate situation of the person receiving the message, as well as on his language and culture. If learners are multi-cultural, they will most probably also be multi-experiential. This means that different learners representing different cultural groups may perceive a common object or phenomenon from their different cultural perspectives.

The following incident illustrates that the influence of culture on the interpretation of observation is tremendous. In a school where the researcher taught, lightning struck a tree. The researcher took the opportunity the following day to introduce a lesson on electricity. As an introduction, pupils were asked to give an explanation of the probable cause of lightning. Almost half of the class indicated that lightning is a form of witchcraft. This explanation could not be substantiated from a sound scientific point of view. It must be said that the scientific explanation could hardly convince some of the pupils. It is also possible that even those who appeared convinced could have become what Hodson (1986b:389) refers to as 'conceptually schizophrenic'. That is, pronouncing the official scientific explanation when responding to a teacher's question while privately believing their own views.

II. The Role of Communication in Interpreting Observations

Chadwick et al (1984:13) have stated that one cannot communicate an interpretation of an observation without an additional misrepresentation. Communication, whether in writing, speaking or gesturing, involves a translation from personal to public
discourse. One's communication may include a description of what was observed and at least a rudimentary interpretation of what the observation means. Neither is communicated without loss and bias. Communication in any media depends upon the use of symbols. In observation, there can be no error, the impressions are whatever they are. But errors creep in when observation is described. For description requires at least some rudimentary interpretation.

These symbols have variable meanings and a glossing over of portions of the observation thought to be non-essential or mutually understood. The process of translation into verbal or written language inevitably distorts the observation. There is a corresponding distortion by the receiver of the communication. The reader/hearer does not receive all the messages that are sent. Furthermore, he interprets those that are received according to his own culture, experience, present situation and other factors (Chadwick et al 1984:13).

3.2.2.7. Validation of Observations

Hodson (1986a:27) conceptualizes science as a process with three distinct phases: creation, validation and incorporation into the body of knowledge. This means that scientific knowledge as accumulated or discovered (creation) must stand up to criticism and testing by fellow practitioners (validation). The criteria of truth and acceptability are determined by the community and scientific knowledge is recorded for the community in a style approved by the community (incorporation).

The implication of this in science curricula is that a clear distinction should be drawn between the generation of hypothesis, the testing of observation and the acceptance and recording of scientific knowledge. Hodson (1986a:28) expresses
the sentiments that the distinctions could alleviate many of the problems of mismatch between 'school science' and 'real science' which usually result in children opting out of science.

Science is a social activity and scientific knowledge consists of those observations, concepts and theories which have been validated and accepted by the scientific community. Scientific knowledge is distinctive because it is 'consensible' (expressed in mutually intelligible and unambiguous language) and 'consensual' (confirmed, validated and accepted by other scientists). Ideally the general body of scientific knowledge should consists of facts and principles that are firmly established and accepted without serious doubt, by an overwhelming majority of competent, well informed scientists (Hodson 1986b:391).

In the same way, learners should be given opportunities to verify their observations with one another and with the already established scientific facts. A short discussion of their observations at the end will help them reach a consensus on what conclusion to make. Learners should not be expected to find something new to the community of scientists, rather, they should be expected to find something new to themselves.

3.2.2.8. Theory-Building versus Theory-Confirming Observation

The results of observing starlight deflection (see Appendix B (i)) is usually taken as confirmations of Einstein's general theory of relativity (Norris 1985:821, Willson 1987:280). One important role of observation, therefore, is theory-confirming.

Einstein used the results of many studies in formulating relativity, these studies examined the relationship between variables to establish scientific facts. For example, J.J.Thomson showed that electron beams in a cathode tube could
be deflected and that their mass apparently depended upon their velocity. There was no theory for this fact, but it was part of the corpus of physics that Einstein considered in formulating his theory (Willson 1987:280).

Willson (1987:280) concluded that these studies were exploratory, or theory-building. These examples, in the view of Willson (1987:281) illustrate that the role of observation as a science process is dynamic, it alternates between theory-building and theory-confirming. He criticized philosophers of science such as Norris (1985:824) for exaggerating the role of comprehensive theory in scientific observation.

Norris (1987:774) contends that it is just not the case that individual observations can once and for all be classified as either theory-building or theory-confirming. Referring to Thomson's observation above, Norris argues that they were theory-building for Einstein's theory of relativity. The same observations are also theory-confirming for the theory that cathode rays consisted of negatively charged particles and not electromagnetic waves.

If an observation can at one time and in one context be theory-building and at another time and another context be theory-confirming, then any fallout resulting from a focus on theory-confirming observations would also result from a focus on theory-building observations (Norris 1987:774).

The researcher, in this study would like to point out that focusing solely on theory-confirming observations, as Norris (1985:824) has done, is not to exaggerate the role of theory in observation. A focus on what Willson (1987:280) calls theory-building observations would of necessity lead to the same exaggeration, since the very same observations in other contexts would be theory-confirming observations. The researcher, would like to agree with Norris (1987:774) that it is the role of
observation which is crucial, and that this role changes as the demands of existing theory changes. The state of theory determines which facts are important and how they are important.

In practice, observation is carried out to collect particular data in order to support, refine or test a theory. In Biology, for instance, a pupil could be given a universal statement (theory) that carbon dioxide is necessary for the process of photosynthesis. The pupil could perform an experiment where his observations will confirm the theory. There is, therefore, a clear link between the 'practical investigations' or 'discoveries' conducted at high school level. These investigations are theory-confirming as no new discoveries are really made.

Alternatively, the same experiment could be performed out of the pupil's curiosity to see what will happen to the process of photosynthesis if carbon dioxide is excluded. Thus observation is a highly selective process and only observations considered relevant to the theory under investigation are made. It is our theory which enables us to reject certain observations or to reinterpret them. Additionally, it has to be recognized that observations accepted as correct on the basis of theory X may be rejected as incorrect or even meaningless on theory Y.

Norris (1985:824) contends that observation is the witnessing of some state of affairs using some sensory apparatus, and that this plays a major role in building knowledge in the field in question. In this conception, human senses become just another sort of sensory apparatus, and not necessarily the most reliable and most discriminating type.

Norris (1985:824) maintains that observations are to mark the beginning points of reasoning in the area of knowledge in
question, the basis upon which other knowledge rests. They are also to serve as the basis for testing specific claims to knowledge and for arbitrating between conflicting claims. Thus for a scientist to report something as an observation is to claim that, at least for current purposes and at the current time, this piece of knowledge will not be questioned. That is, the observational knowledge is taken (in the circumstances) to be directly known. This means that, under the circumstances, the inferences which are required to move from the sensory input to the observation report are so taken for granted that there is a sense of passing directly from the sensory input to the report with no intermediate steps.

Norris (1985:825) asserts that scientists are prepared to make such assumptions when they have no reason to doubt and every reason to believe the theories which explain the workings of their sensory apparatus and the transmission of information from the source to the apparatus. Thus, in the Eddington experiment (see Appendix B [i]), the observation of the deflection of starlight was taken as foundational to the field, in the sense that theories of the field would have to concur with it. Specifically, Einstein's General Theory of Relativity was assumed to be testable by this observation. What this amounts to is that physicists had fewer reasons to doubt the theories which explained the workings of Eddington's observational apparatus. This is because they were theories which were a part of physics for a long time and had demonstrated their trustworthiness.

The implications of this in the natural sciences curriculum is that pupils should be given observational material to help them form new concepts, understand principles and generalizations. Some of these materials should be aimed at testing theories that have been taught.
3.2.2.9. Linking Observation and Theory

As science develops, it acquires new knowledge and new ways of acquiring knowledge by the creation of new observational possibilities. Neither observation nor theory has a priority. Sometimes observations may accrue and have to 'wait' while theoreticians attempt to explain them. At other times, quite complex theories may be introduced and have to await observational support for a number of years. On occasions, observation and theory develop together, with theory guiding and shaping the kind of observations that can be made and observations providing opportunities for theoretical refinement (Hodson 1986b:383).

Hodson (1986a:23) further indicates that what is described and explained in science is never 'pure phenomena', but phenomena seen through particular 'theoretical eyes'. Theoretical knowledge opens up possibilities of interpretation that would otherwise not exist. As science develops and acquires new theoretical knowledge, it acquires new abilities to generate knowledge by making 'better' and different observations. Thus we learn about nature and we also learn how to learn about it, by learning what constitutes information, how to collect it and how to interpret it. Competing theories may even give rise to non-identical observations when confronting the same phenomena because observation statements have different meanings in the contexts of different theories.

From the positivist paradigm, Hodson (1986a:25) concludes that 'checking on theories' is done to determine the reliability of the theory, and not to collect 'facts'. However, as indicated earlier, we may reject observations, just as we may reject theories. Thus we have an interesting paradox; our theoretical knowledge can show us that certain observations are unreliable
and in need of revision, and our observation can tell us that our theories are inadequate and in need of revision. When theory and observation conflict, how do we know which is to be rejected? We may reject the theory in the light of falsifying observations, or we may modify those observations in order to retain a well-loved and otherwise useful theory. One complication is the danger that our acceptance of a particular theory prevents us from making observations that might refute it.

Hodson (1986a:25-26) pointed out that a theory's success in explaining the facts is guaranteed because the theory creates its own supporting evidence and excludes the facts which might refute it. Often, a new theory is needed to show up the errors in the old one, it provides an alternative perspective and alternative observational evidence. The new theory may be supported by a test which was not even possible within the context of its predecessor. The earlier theory may be rejected on the basis of an observational test which would have been quite inconceivable within the conceptual framework of the old theory. Thus it may be necessary, on occasions to introduce theories which are inconsistent with existing theories and existing facts - that is, to proceed counterinductively.

It is clear from the above that correspondence with the facts does not necessarily affords any increased truth status about the theory.

The implications of the foregoing paragraphs on the natural sciences curriculum is that educators should emphasize both the product of science (theories and explanations) and the processes by means of which scientific knowledge is generated and validated.
The researcher maintains that for younger pupils in primary school, theory and observation should develop together by pointing at an object and pronounce its name. In higher levels in secondary schools pupils could be expected to start with a hypothesis (theory) and then seek or prepare observational materials to test their hypothesis.

In some instances learners could first be given a sound theoretical frame of reference before they can be expected to make meaningful observation. Huyser's (1992:2) contention against this approach is that learners no longer observe objects and phenomena as they are and as they happen. They observe them according to the way in which they have been taught. The researcher in this study does not see anything wrong with this. After all, it is the theory that guides and shapes the kind of observation. Developing observational skills is all about guiding the pupils on what they should observe! This enables learners to select relevant and appropriate observations and discard irrelevant, inappropriate and incorrect ones. For instance, they will distinguish air bubbles from cells when looking into the microscope.

Perhaps the best way to address the link between observation and theory would be to say that investigations in natural sciences start with inquisitiveness. This inquisitiveness arises from observations of natural objects or phenomena. The claim that science starts with being inquisitive is perfectly compatible with the priority of theories over observation and observation statements. The observations are only problematic in the light of some theory. For instance, how are bats able to fly so dexterously at night, in spite of the fact that they have very small, weak eyes? This poses a problem because it apparently falsifies the plausible theory that bats, like many other animals, see with their eyes.
3.2.3. Natural Sciences rest on the Observation of data
Potentially Observable

In the first place, there is the variable which is the observed object. The attempt to establish an infallible criterion of what constitutes observability has failed. What is observable today may become unobservable tomorrow. Good examples are objects or phenomena beyond an event horizon. Today it is possible to observe the behaviour of the ivory billed woodpecker. But since the bird is nearly extinct it will be impossible to observe it in future.

Conversely, what is unobserved today may become observable tomorrow. Good examples are those things which are unobservable because of the circumstances of the observer. In the past it was not possible to observe neutrinos. But now it is possible (see Appendix B [ii]).

The contention that science rests on the observation of data should be revised. It should read that science rests on the observation of data potentially observable, with the provision that the range of the potentially observable is a shifting one (Feibleman 1972:34).

Norris (1985:825) contends that when investigation leads to new knowledge or to new observations which cannot be reconciled with previously held beliefs, then adjustments must be made somewhere. There is no a priori reason why things formerly held to be observed cannot be discounted as mistakes in observational practice, whether in the observational equipment or in the theories which support interpretations placed on the output of that equipment.

From the above remarks one can conclude, as Norris (1985:825) has done, that observation is limited in the sense that
observations are not immune to revision. There also can be no a priori limits set on what is in principle observable. At one time people might have thought that the far side of the moon was in principle not observable, but now it has been observed. At one time people could not observe molecules; they did not even know that they existed. Today, molecules are regularly observed using electron microscopes. This harks back to Shapere's (1982:492) point that what is observable changes with changes in human knowledge. In fact, one consequence of scientific advance is that it pushes back the bounds of the observable, bringing into the range observable things which were previously unknown, or known but not observed.

Norris (1985:825) argues that observations are not infallible or beyond the possibility of doubt. Every statement in science is in principle open to question. Sometimes it is the observations, the data themselves, which have to be adjusted and not the theories which they were collected to test. Thus observations are bound by time and purpose and this places them squarely in the heuristics of science. Scientific heuristics are chosen, within the contexts of goals being sought and of what is currently taken to be the best scientific knowledge, so as to provide the optimal chance of reaching those ends.

The researcher in this study agrees with Shapere (1982:492) that the specification of what counts as an observation is a function of the current state of physical knowledge. As the knowledge changes, observability also changes.

If a transient phenomenon is being observed, accuracy of observation is unlikely to occur unless the phenomenon can be repeated many times. Good examples are earthquakes and volcanic eruptions. In general, powers of observation can be cultivated (Woodburn and Obourn 1965:45).
Woodburn and Obourn (1965:43) maintain that there are only two kinds of stimulants to secure attention with little or no voluntary effort on the part of the observer. Firstly, there are the smashingly obtrusive, which thrust themselves irresistibly upon our attention by presenting vivid or startling changes to our sense organs. For example, when magnesium ribbon is ignited it produces sparks of flames which cannot escape being noticed.

Secondly, the intrinsically interesting which appeal to our innate wants. A child cannot escape giggling if tickled. In order to be acceptable, a feature of an observation must be: (a) capable of being presented again in similar conditions; (b) if possible, connected with other constants by means of generalizations.

3.2.4. Observed Facts

Feibleman (1972:47) has noted that it is difficult to determine precisely what is observed. A datum is a disclosure of experience, interpreted as some aspects of a material object or event whose existence is held to be irrefutable. An observed fact is the report of a datum, or a proposition in which a datum is asserted. A datum can be either a non-repeatable individual or an empirical theory whose unexceptional nature seems equally well established. In either case the observer is confronted with something which has both a particular and a universal aspect. The particular illustrates the universal. Whenever a universal principle is illustrated, it is a particular material object which illustrates it.

The results of observations which seem inconsistent are often the source of unexpected knowledge. The observed facts point towards laws rather than to other facts. The observed fact is
but an abstraction. There are, roughly speaking, five varieties of observed facts. Simple sense perception guided by contrast discloses the barest fact. The biologist observes under the microscope that this thread is longer than that thread, that this globule is darker than that globule. So the observer interprets when he singles out from the sensory background certain elements and their relations. But he strives to do so no more than is necessary to make observation (Feibleman 1972:48).

At the next level of fact the observer discriminates between substance and properties. For instance, it is not enough to say that an observed substance is water simply because it is a colourless liquid. One must also observe that it is tasteless, odourless, allotropic, polar, etc. Here interpretation is added to the findings of sense experience. The scientific observer comes to his task with special assumptions as part of his equipment (Feibleman 1972:48).

Another level of observed fact contains the reactions which can only be observed indirectly. This is the level of mathematically expressed relations supported by experimentally discoverable data. At such complex levels of analysis what are called data are the interpretations of indirect observation by means of mathematical structures. Often what is observed cannot be explained except on theory that such entities and processes exist. Experimental results may be of this character (Feibleman 1972:49). For instance, the interpretation of Figure 3.1. is that enzyme activity is directly proportional to the temperature. That is, for every increase in temperature up to 40°C there is a corresponding increase in enzyme activity. Enzyme activity drops sharply beyond 40°C. This is because enzymes are denatured at about this optimum temperature. Without mathematical interpretation, such kind of information is not immediately available to the scientist.

The learner should be able to communicate his observations
verbally, in a written language or graphically. Pupils should be trained to plot or interpret graphs.

![Graph showing enzyme activity vs temperature](image)

**Figure 3.1. The Effect of Temperature Increase on Enzyme Activity**

### 3.2.5. The Psychological State of the Observer

Bower and Cohen (1982:331), among others, have shown that persons vary widely in the realms of objects of qualities they are willing to attend to. This quality of observation is, according to Oyeneyin (1985:110), defined largely by the psychological state of the observer. It is the psychology of knowledge that provides the inspiration to the scientist and gives him a sense of certainty in his research. Although the source of data may be the same for any two observers, each is likely to see different aspects of that source at any given time, due to the differences in their level of perception. For instance, an observer whose cognitive-affective state is efficiently directed to the source of data are likely to use his perceptual organs to:
(i) extract more information from a given system;

(ii) make more valid interpretive statements from the extracted information;

(iii) draw more valid and logical inferences from the interpretations;

(iv) possibly generate more workable predictions from his knowledge of (i) to (iii) above.

(v) possibly develop more satisfactory theories than an observer whose cognitive-affective state has not been sufficiently directed to the features of the situation being observed.

Feibleman (1972:34) pointed out that no one sees exactly the same thing on two separate occasions. This is true not only because the object does not remain the same, but also because the observer does not, either. Small errors creep into observation due to many small changes in the condition of the observer.

White (1988:120) wrote that the attributes of the observer affect the selection of events. Among them is the general level of alertness. When this is very low, as in sleep, a stimulus must reach a very high intensity to be noticed. Even in the wakeful state there are variations in alertness. This may be caused by tiredness or illness. This level of alertness is controllable. We can decide to be alert or not within the limits of our physical state. The limits can be expanded by training.

Another attribute that affect selection is the range of cognitive strategies available to the observer. An observer who has developed a strategy of sorting out relevant from irrelevant is likely to make a different selection from the one who treats all stimuli as of equal value (White 1988:121).
3.2.6. An Inference as a Science Process Allied to Observation

From the study of the examples of Observing Starlight Deflection and of Observing the Center of the Sun (see Appendix B [i] and [ii]) the researcher, agrees with Norris (1985:826) that observation and inference cannot be sharply distinguished from each other without regard for the context in which each takes place. In the second example of the observation of the center of the sun there are inferences about the source of detected neutrinos, about how neutrinos travel through matter and empty space, about how they interact with atoms.

Norris (1985:826) points out that these are not just mere low-level inferences, but rely upon the most esoteric theories in physics. These theories are taken to be assumed background knowledge. The result is that the neutrino experiment is taken to be a "direct measurement" of the validity of inferences which previously had depended upon reasoning "from known physical principles rather than from measured facts". From the above it is clear that observation can still be distinguished from inference.

However, Norris (1985:826) contends that such a distinction is based on what scientists working in a particular field are willing to take for granted, and what they take to be open to question. Such scientists have a particular set of background beliefs. When the cutting point between observation and inference is seen in this way, it becomes clear that the boundary will change as scientific knowledge changes.

It should be pointed out that the lessons similar to The Candle Activity (see Appendix A [i]) could still be taught, on condition that the distinction between observation and inference is contextualized. For example, in measuring the temperature
using a thermometer, what is observed or recorded is not the temperature per se, but the length of the column of mercury. The longer the length, the higher the temperature. In this context observation is so closely linked to inference to the extent that one speaks of having observed rather than inferred the temperature.

On the other hand it can be observed that a solution of bromothymol blue changes colour if exhaled air is blown into it. It can only be inferred that the change of colour signifies the presence of carbon dioxide in the exhaled air. In this context, observation is sharply distinguished from an inference.

The researcher, is of the opinion that an inference, in this case, refers to those things which are more open to question. The nature of the liquid at the top of a burning candle is seen by the researcher to be part of the pupils' common knowledge. It does not qualify to be an inference. In order to properly teach the distinction between observation and inference, the researcher, like Norris (1985:829), recommends that activities must be chosen so that the reason for taking inference as less reliable should be obvious to pupils.

3.2.7. Observation as a Selective Process

Observation is a selective process and requires a focus of attention and a purpose; an observer needs an incentive to make one observation, rather than another (Hodson 1986a:21).

Feibleman (1972:30 and 50) wrote that the observer's professional attention is caught by inclinations, by signs of entities and processes, by relations and even by absent objects whose presence were expected. In science, there is always more, phenomenologically speaking, than can be observed, and more,
too, than is pertinent in any observational program. It is important to remember that it is not the entire external world that is placed under observation by a given operation in science, but always some particular segment of it. It would therefore be possible to refer to discriminative or selective observation patterns among learners. Observation, therefore, always involves selection, for each of them happens against a background and within a context of other happenings. The selection of this segment is made in terms of some previously adopted hypothesis, assumed or explicit.

Feibleman (1972:28) asserts that the practice of science involves observation, action and thinking. A scientist observes by means of his senses. By means of the actions, he contrives to determine to some extent what it is that he shall observe; action is also required when he must arrange the objects to be observed. By means of his thoughts, the scientist endeavours to interpret what it is that he is observing.

Observing the starlight deflection and observing the center of the sun illustrate beyond doubt that at least some scientific observations cannot be equated with simple mental processes as suggested in section 2.3.5. According to Norris (1985:828), the making of observations of the types described are among the most complex mental activities in which human beings engage. The reader should consider the degree of planning involved, the amount of expertise required to construct the appropriate observing equipment, the complexity of the phase in which information is actually detected and elaborate interpretations which are required before the result of the observation is known. "As scientific investigation pushes back the bounds of the observable, it is only natural that observation rely less and less on intuitive notions and automatic mental processes" (Norris 1985:829).

In the teaching and learning of natural sciences observational
skills should be developed in such a way that learners are able to act and use their thoughts. This will enable them to select and prepare the observational materials.

3.2.8. The Role of Expertise and Cognitive Psychology in Observation

Willson (1987:282) pointed out that a scientist differs from a student in the amount of knowledge, conceptualization of the problem, solution strategy, number of productions, and time to solution. They also differ in the use of metacognitive or executive skills (Norris 1987:778). Such skills are involved in planning how a task is to be done, monitoring progress towards the end results, and revising when warranted. As a consequence, the way in which scientists make observations is different from that of students.

Observation, therefore, should be presented in accordance with the intellectual development of learners. Inference about the structure of the liquid on a burning candle will certainly be high for an organic chemist, who may think in terms of molecules present and of the processes in progress. But for a beginning high school chemistry learner simple observation is more reflective of the knowledge base and solution strategies available to him. Teaching them that science is highly inferential will have no meaning to them, and is not even necessarily correct.
3.3. SUMMARY

The major concern of chapter three has been to explore a general theory of observation and its implication to the natural sciences curriculum.

The reappraisal has shown that observation involves an interaction between the observer and the object or event. The theory dependence of observation discussed in this chapter certainly undermines the inductivist claim that natural sciences starts with observation. Only the most naive of the inductivists would still want to adhere to that position.

According to the general theory of observation, it is freely admitted that new theories are conceived of in a variety of ways and often by a number of routes. They may occur to the discoverer in a flash of inspiration, as in the mythical story of Newton's discovery of the law of gravitation being triggered by his seeing an apple fall from a tree. Theories may, and usually are, conceived of prior to the making of those observations necessary to test them.

The role of language in observation has become evident. The learner must be equipped with the necessary concepts to enable him to observe and communicate his observations. Observation facilitates abstraction, especially in younger children. Abstraction makes possible further observation.

Science educators should pay much more attention to children's intuitive views of the world which differs from real science. They should provide pupils with experiences which challenge and explore the children's own views of the world.
It has also been shown that the human mind is not like a blank slate on which anything could be impressed. The human mind interprets the data that it receives in terms of prior knowledge. It can use observation to both generate new theories and test existing ones.

The general theory of observation is adopted in this study.
4. CATEGORIES OF OBSERVATIONS AND THEIR IMPLICATIONS TO THE TEACHING AND LEARNING OF NATURAL SCIENCES
4.1. ORIENTATION

Seemingly, the theory of an observation process is not yet a mature body of knowledge which is governed by its own set of paradigms. It is for this reason that one can only speak of a general theory in this study. The discussion of the different categories of observations should, perhaps, be seen as an attempt to further set the standards for legitimate work in this field. The main purpose for exploring this part disciplinary matrix is to eventually identify categories of observational and allied skills. Observation as a science process can be categorized into three basic forms, namely; simple observation, controlled observation and quantitative observation.
4.2. SIMPLE OBSERVATION

Simple observation may be referred to as pre-objective, momentary or naturalistic in character (Feibleman 1972:28, Norris 1987:777). It involves a deliberate exposure to sensory stimuli. Action (psychomotor) and thought (cognitive) play a lesser role than feeling (affective) in simple observation. See also Van der Stoep and Louw (1984:142).

Simple observation requires concentration and, therefore, also training. The treatments are allowed to develop without control or comparison groups. The scientist merely notes and records the phenomena in the ordinary course of nature. This involves the similarities and differences between organisms, samples and populations. As indicated in Van Aswegen et al (1993:15), it normally has to do with measuring and counting. Examples are the observation of the colours of the rainbow, different leaf shapes, etc. The observer goes into the activity in such a way as to be able to see with 'fresh eyes' what there is to observe.

As a rule, what is available to simple observation are the middle sized objects disclosed to ordinary experience. This is what we might normally encounter in our daily lives without recourse to special efforts at observation (Feibleman 1972:41).

According to Feibleman (1972:29), simple observation includes a naive description of an event or an object. The number of material objects existing and available to observation always far exceeds the number observed, this necessitates a kind of sensory scanning in simple observation. Arbitrary observations, though they exist in science, are not scientific. Science is not a matter of mere observation, there is something else connected
with observation in which the scientific distinction rests. This is something in the selection of data to be observed, something in the general principles governing selection of data, or perhaps in the interpretation itself, that renders science unique.

Feibleman (1972:31-32) admits that it often happens that simple observation is a matter of chance. When Galvani in 1786 accidentally touched the leg of the frog with an electric wire he did not know that it would twitch. One can deduce that at the level of ordinary common sense, observation can often happen by chance without any aid from instruments or from mathematical calculations.

Even in simple observation, it is possible to extend the senses by means of instruments. The senses may be extended as with optical telescope, or supplanted as with Geiger counter, but in any case, the observer observes. He observes the object directly or he observes the pointer readings made on the instrument by means of its exposure to the object. Measurement is a form of observation (Feibleman 1972:29).

By means of the similarity of properties of diverse individuals, a bridge is made to the generality of classes. The scientific observer recognizes the general by means of the individual, and it is the uniformity of generals that he is after. In science, a sample of observations is always regarded as a sample of a population, which is indefinitely large and possibly infinite. This infinite population remains hypothetical (Feibleman 1972:30).

For instance, a person X may have observed that a particular starch solution turned blue-black when drops of a particular iodine solution were added to it. This investigation could be
repeated several times by different people with other particular starch solutions and iodine solutions. If this results in the same observation, it could be concluded that an infinite repetition of this investigation will always result in the same observation. It can then be generalized that a starch solution always turns blue-black when drops of iodine are added to it.

4.3. CONTROLLED OBSERVATION

Feibleman (1972:40) describes controlled observation as meaning the procedure of deciding by means of action the condition under which observation is to operate. It differs from simple observation in that it is guided by rudimentary hypothesis, adopted or assumed. Here the hypothesis begins to come more to the fore than it did in simple observation. Good observation requires active speculation for which theory is needed.

The implication is that what is usually observed in controlled observation is not available to ordinary experience. It generally penetrates both below and above the ordinary levels of analysis, to entities and processes of the microcosm and macrocosm respectively. This kind of observation tends to be both prolonged and repeated. Prolonged observation requires practice in concentration and this presupposes a sophisticated kind of training in motor responses and manipulative skills. For example, before a learner can be able to observe an onion cell, he must first be taught the circuitous skills of making wet mounts and focusing the microscope.

Feeling (affective domain) and action (psychomotor domain) are dominant over thought (cognitive domain). The scientist selects what it is that he wishes to observe. Controlling the conditions under which observation is to take place means also to some
extent controlling the observations which are to be made as the result of it (Feibleman 1972:41).

Feibleman (1972:40-41) gives three separate and distinct ways in which observations can be controlled, all of them involve the making of preparations. These are (a) adjusting the object in such a way that it can be brought into focus, (b) getting the ground ready for observation, and, (c) selecting the conditions under which observation is to take place.

4.3.1. Handling of Observational Material

The handling of observational material is the first variety of controlled observation. The proper isolation of the object is a crucial prerequisite to successful observation, and this requires the ability to discriminate between true and false isolates. Extensive labour consisting in operations performed upon the subject matter will often be required before the investigator can begin his observations (Feibleman 1972:41).

Pupils should be trained in motor responses and manipulative skills. The preparation and observation of microscopic slides is perhaps the best example of this variety of controlled observation.

4.3.2. Getting the Ground Ready for Observation

Since human senses alone are hardly sufficient to deal with the recondite areas of nature, instruments have come to play a steadily greater role. The construction of instruments is part of the observational technique. Much skill is called on for both the construction and the use of the scientific instruments (Feibleman 1972:43).

Learners should be encouraged to improvise by constructing
simple scientific instruments to aid their observations when and where necessary. For instance, learners could be provided with a U tube, rubber stoppers and glass tube to construct a simple potometer to measure the transpiration rate. It should be taken into consideration that learners, unlike experienced scientists, will not be able to make complex instruments. At least they should be able to operate these instruments.

4.3.3. Selecting the Conditions Under which Observation is to Occur

A material object or event possesses features not available to any single perspective. Thus varying the perspective is a way of collecting observations on the same object. The systematic variation of perspectives is a way of controlling observations available to the investigator and one of his stock of resources. Chance often operates to pre-empt the scientist's attention, but more often he has planned to devote to it a certain set of manipulations. The unexpected results of manipulations in a laboratory or of planned conditions in the field are equally controlled observations. The greater the degree of preparation, the more likely that the observations will be undertaken at high analytical levels (Feibleman 1972:44).

Consider, for example, the experiment to investigate the effect of temperature on the activity of an enzyme. The temperature variable is under control of the observer. He can decide at what temperature the readings should be taken. Conditions like pH and substrate concentration are held constant during the experiment so as not to affect the results. Similarly the behaviour of a lizard or some chemical could be observed under varying temperatures.
Learners should eventually reach the level of development at which they will be able to select and control the conditions under which observation is to occur.

4.3.4. Indirect Observation

Also included under controlled observation is indirect observation. Indirect observation takes place in a number of ways. Some instruments are used to aid observation directly. Examples are telescope and microscope. But others aid observation indirectly. Examples are centrifuges, spectropolarimeter and the cathode ray oscillograph. The more a science progresses, the more indirect observation takes the place of direct observation.

In indirect observation something observed directly is read as evidence for something else not observed (Feibleman 1972:45). To come to terms with a large variety of biochemical reactions, for example, the influence of different enzyme concentration on reaction rate, the process has to be operationalised and made observable. This may be by placing drops of enzyme of different concentrations on exposed developed photographic film and assessing the results.

Feibleman (1972:45), Shapere (1982:490) and more recently, Norris (1985:824) have always argued that there is observation both by instruments and of the instruments themselves. They point out explicitly, that in some instances where the observational threshold is beyond the realm of human sensitivity, instruments can be used to supplant human senses. The investigator then observes the instrument.

Feibleman (1972:45, and 131-132) said the most common kinds of indirect observation is that involving pointer readings. As
scientific investigations penetrates deeper, it relies more and more upon such indirect means of observation.

Another kind is the direct observation of the effects of phenomena which are indirectly observed. Examples are neutrinos emitted from the sun which can be detected by means of a tank of cleaning fluid buried in the earth (see Appendix B (ii)). The detected neutrinos give information about the center of the sun (Feibleman 1972:133).

The researcher, in this study, finds it hard to believe that an instrument can observe. This is because, the term "observe" is coined by humans to explain their activities. It does not exist outside of humans. It is only humans who can speak of observing and who can observe. Instruments cannot exist unless they are invented by man, let alone observe. When invented, an instrument serves a specific purpose which is determined by the support by a given theory. Such a theory is the product of the mind of man.

It would be correct to argue that instruments are mere aids in the act of observation by humans. For instance, whether or not photosynthesis has taken place on a given leaf can be tested by means of a drop of iodine. It would not be correct to consider iodine as having observed photosynthesis. Rather, the learner, observes the change to a blue-black colour and attributes that as signifying the presence of starch, which is interpreted (by the learner) as evidence that photosynthesis has taken place.

Koss (1989:35) clarifies this point by asserting that the information which goes into the receptor must come out in a form which is accessible to the human scientist. This means that, ultimately, it is a human being that observes.

It is perhaps high time that in as far as the verb "observe" is concerned we should place it between inverted commas, thus
'observe' if the doer is the instrument.

Feibleman (1972:45-46), Brown (1987:182) and Willson 1987:281) are of the opinion that observation by means of instruments increases the likelihood that egregious errors may be made. This harks back to an inductivist’s view that bare sense perception is infallible since it makes no use of tentative theories or learned conceptual structures and skills.

Norris (1987:775), disputes this point, he argues that sometimes human senses can lead to more reliable observation than any known instrument, but sometimes instruments are more reliable. For example, there are instruments far more reliable than human senses for determining altitude, for distinguishing the relative intensity of sound and light, for determining speed, and for measuring pulse rate. In addition, there are instruments which can make observations not even in principle accessible to human senses. The researcher adds that repetition, can reduce the probability of errors in interpretation in some kinds of investigations.

Norris (1985:824) distinguishes between sensing devices which are extensions of the human senses and those that are not. Some instruments such as magnifying glasses, optical microscopes and audio amplifiers can be sensibly thought of as extensions of the human senses. This is because of the central role of human senses in the operation of these instruments. However, instruments such as neutrino detectors (see Appendix B (ii)), while clearly extensions to human sensing capability, involve no central use of the human senses in their operation. In fact, the information being sensed is completely out of the realm of human sensitivity.
4.3.5. Experimental Observation

Experimental observations are dependent upon systematic manipulation of treatments and are said to be preordinate. When an observation methodology is preordained in this sense, the researcher goes into the activity with a particular view of which assumptions to make, which inferences are legitimate, what observations to make, and what the observations will mean (Norris 1987:777).

Experimental observation involves a change in the course of nature by the intervention of our will and muscular powers. This produces unusual combinations and conditions of phenomena. Experiment is thus observation plus alteration of conditions. They are efforts to observe an event or circumstances under conditions where as many extraneous factors as possible are eliminated or their probable influence taken into account. These efforts, if successful, accumulate bit by bit, as evidence for or against a hypothesis (Woodburn and Obourn 1965:44). An example is to investigate the effect of gravity on the growth and development of plants in the laboratory.

Woodburn and Obourn (1965:46-47) argue that there is no sharp transition between observation and experimentation, there is a kind of "natural experiment" that can be termed experimentation or observation with almost equal accuracy. In general, however, experiments are distinguished from observations because they are deliberately undertaken, and features artificially arranged. If a person observes the colours of a rainbow during a rainy season this is termed observation and is not an experimental observation. But if he uses a glass prism to analyse white light this is termed experimental observation.

Norris (1987:778) contends that it is not correct to
characterize, as Willson (1987:283) has done, naturalistic observation as theory-building and some experimental observation as theory-confirming. He maintains that particular observations play a theory building role in one context and a theory-confirming one in another. Willson, however, sees many experimental studies as theory-building in the sense that they are used to establish scientific facts. Few experimental studies are directly concerned with tests of theories. Naturalistic observations are claimed to represent real world conditions better and to allow observations of the evolutionary aspects of an instructional treatment. The loss is in causal explanation and in capability to confirm theoretical expectations.

In experimental observation, learners must be able to identify a problem, formulate a hypothesis, devise a logical work plan, choose appropriate instruments and technique with suitable controls and test the hypothesis. He should be able to choose a suitable method of presenting the results obtained and draw meaningful conclusions. The pupil should be able to set an experiment systematically, with reasonable speed and accuracy.

4.4. QUANTITATIVE OBSERVATIONS

In the social sciences there has been a gradual movement away from quantitative observation towards a more qualitative interpretation of meaning and truth. Conversely from a naturalistic, empiristic and positivistic point of view, qualitative observation rarely produces an accurate description of a phenomenon. In nearly all cases, quantitative observations are required (Woodburn and Obourn 1965:46).
There are at least three procedures underlying quantitative observation. One method assumes that an increase or decrease of the quantity being measured can be equated with a standard unit in some determined ratio. A good example is measurement of temperature in °C. A second method applies some natural conjunction of events that enables the investigator to compare directly the multiples of the quantity with those of the measuring unit. In the third method it is not the quantity itself, but some other quantity connected with it by known mathematical relations that is observed, and these observations provide an indirect measurement of the quantity (Feibleman 1972:137-138, Woodburn & Obourn 1965:46).

Accuracy of measurement depends on the ability to repeat units of exactly equal magnitudes. These units should be such that they can be joined together forming an aggregate that is truly equal to the sum of the parts. Learners should be trained to make accurate measurement using instruments such as thermometers, measuring cylinders, stop watches, etc. Instruments can be used to assist in quantitative observation of an event or circumstance, but they must have no effect on the control of observation (Woodburn and Obourn 1965:46).

As can be seen from the text above, there is an overlap between the three kinds of observations as discussed. Quantitative observation may either be simple or controlled. Furthermore, individual components of simple observation are building units of controlled observation. For this reason, observation may also be regarded as a continuum of simple to complex activities.
4.5. SUMMARY

The different types of observations as discussed above confirm Norris's (1987:778) contention that observation is a continuum of simple to complex interactions. To portray observation at the simple end of the spectrum at all levels of science education risks passing on undesirable lessons about the nature of scientific inquiry (Norris 1985:831-832). However, none of this suggests jumping in at the deep end right from the beginning. There is a continuum of observational complexity through which learners can be led. We would be wrong to assume expertise of learners right from the beginning, but we will be equally wrong to confine them to the simplest forms of observation.

This prompts one to conclude that observational and allied skills could also be categorized along similar lines. Indeed, it is shown in the next chapter that observational and allied skills are divided into basic and integrated skills.
5 THE OBSERVATIONAL AND ALLIED SKILLS IN THE TEACHING AND LEARNING OF NATURAL SCIENCES
5.1. ORIENTATION

The specific purpose of chapter five is to identify the observational and allied skills which determine the teaching and learning of natural sciences. These are the skills which have observation as the common denominator. The use of these process skills can be realized through an act of observing. These are the abilities which have to do with observation and which can be imparted from one person to another. This chapter is, therefore, the basis for the later development of observational and allied skills in chapter 7 and will eventually play a major role in the construction of the research instruments in chapter 8.

The observational and allied skills can be divided into two groups. The first group is composed of the basic science process skills such as observing, inferring, measuring, classifying, predicting and communicating. The second group is known as the integrated skills of hypothesizing, control and manipulating of variables, collecting and interpreting data, experimenting and formulating of models.
5.2. THE ASSOCIATION BETWEEN OBSERVATION AND THE ALLIED SCIENCE PROCESS SKILLS

In section 1.5.3. in this study, a skill has been defined as an ability to do something well. In this section, an attempt to define the phrase "science process skills" is made as a prelude to the description of observational and allied skills.

Several terms have been used to describe science process skills. These are scientific method, scientific thinking, and critical thinking skills (Champagne and Bunce 1991:209). Today, however, "science process skills" is a broad expression commonly used.

The researcher in this study opts for the term observational and allied skills. This option has been taken so as to emphasize the importance of observation in the science process skills. Observational and allied skills are defined as a set of broadly transferrable abilities appropriate to many science disciplines. It is characterized by an action which can be assessed through observation.

5.2.1. Basic Observational and Allied Skills

Various science process skills are discussed in the following sources; Collette 1973:65; Esler and Esler 1981:58-61; and 64; Friedler, Nachmias and Marcia 1990:173; Gagné 1970:150; Jaus 1985:30. It is clear from these sources that the basic science process skills which have to do with observing are; inferring, measuring, classifying, predicting and communicating.

5.2.1.1. Observing as a Skill

The ability to observe accurately is the most basic of all the science process skills. It is essential for the execution and development of other allied skills such as, inferring,

From the study of Cavendish et al (1990:22) it is noted that a good observer sees, hears, feels, smells and tastes with great skill. He also relates to the world around him with greater accuracy. The skill of observing is, therefore, concerned with the use of all the five senses, where it is appropriate and safe to do so. The senses may or may not be aided by instruments (for more details see section 1.5.2. in this study).

Thurber and Collette (1959:61) put it clear that specialized skills such as motor skills which require muscular co-ordination are also included as part of observing. Being able to focus a microscope, lighting a bunsen burner, working with glass tubing and using a hand microtome are examples of motor skills.

It is indicated by Cavendish et al (1990:23) that observing as a skill means being able to notice gross features. This develops into noticing details. The relevance of the detail noticed to the problem in hand is a dimension of development of skill of observation. It is here that the concept dependence of this skill is most easily detected. The information that is gained leads to curiosity, questioning, thought forming interpretations about our environment and further investigation.

In the context of classroom activities, investigations which involve comparing things provide opportunities for children to show the development in observational skills. In the observation of the model of the mammalian heart, for example, the learner should not only notice that the heart has two atria and two ventricles. It should also be noticed that the walls of atria are thinner than those of ventricles and further that the wall of the left ventricle is thicker than that of the right one.
This will sharpen a learner's curiosity to find an explanation for this.

Funk et al (1985: 3 and 7) show that the skill of observing means being able to identify differences between objects or events that are similar. A learner should not only notice that two magnets are similar, he should also observe that when the like poles of the two similar magnets are brought close together, they repel each other, and that the unlike poles attract each other. Even more significant is being able to identify similarities between events or objects which are different from each other. This involves making some links between the things in question, a process which plays a part in widening of concepts, and is thus an important aspect of how observation helps the development of children's understanding.

One could also add that an observer should be able to observe changes in the same thing as a result of taking some action. A description of this kind of observation should include statements of observations made before, during and after the change. The learner should be able to notice that there is a difference in the behaviour of a comb when it is brought closer to small pieces of paper when it is rubbed and when it is not rubbed.

Observing may be summarized as the ability to notice and compare things or events using our five senses, sometimes with the aid of instruments.

All the other science process skills as discussed in the rest of this chapter should be regarded as skills allied to observation. As will be seen, they are the science process skills in which observation plays an indispensable role. The development of observational skills, inevitably, also implies the development of these science process skills.
5.2.1.2. Measuring as a Process Skill Allied to Observation

In section 1.5.2.2 and 4.5, measurement has been referred to as quantitative observation. The study of literature (Cavendish et al 1990:26; Funk et al 1985:5; Van Aswegen et al 1993:16; Zeitler and Barufaldi 1988:97) depict measurement or quantifying as a more precise kind of observation which frequently makes use of instruments.

Feibleman (1972:137) sees measurement as the result of replacing some qualitative aspect of an object or event by a quantitative estimate. This may be duration, extension, motion or force. It usually involves pointer readings on a scale or instrument. The standards adopted in scientific measurement are arbitrary in the sense that they are matters of convenience. For instance, distance can be measured using a ruler, time can be measured using a watch, the instrument to measure volume is a measuring cylinder, temperature is measured using a thermometer, etc. Measurement, therefore, provides us with a basis for comparisons and help us to communicate specifics to others.

A measuring skill is, therefore, determined by the ability to observe with all five senses where it is appropriate and safe to do so. The sense of sight in particular, plays the most important role. A person should be able to see and read a measuring instrument with his eyes. This explains how important it is to observe with all five senses. A blind person's learning of, say, biology can only be possible to a very limited extent. For instance, he can only observe through the sense of touch that a kidney is bean-shaped and that an egg is oval-shaped. In addition to quantifying some attributes, Zeitler and Barufaldi (1988:97), argue that an observer may need to arrange the attributes according to the degree to which some characteristic is displayed. Placing objects and events in ordered sequence is
called seration, examples are seasons and life cycles.

Every kind of measurement, therefore, will always involve observation. A child who has developed skills in using measurement will plan to measure something which is measurable with the equipment and instruments available.

5.2.1.3. Inferring as a Process Skill Allied to Observation

The relationship between an observation and an inference has been discussed in details in section 2.3.3. and 3.2.6. The importance of this relationship warrants a further discussion in this chapter.

While an observation is an experience perceived through the senses, it is clear from Carin and Sund (1989:68), Van Aswegen et al (1993:16) as well as Zeitler and Barufaldi (1988:97-98) that an inference is a conclusion based on past experience and reasoning to explain or interpret an observation. An inference, therefore, goes beyond the evidence in an attempt to interpret or explain a set of observations. For instance, if a circuit board is switched on, it is observed that the bulb glows. An inference can be made from the observation of the glowing bulb that there is an electric current flowing through the circuit. A further example is that it can be observed that an unknown solution turns blue-black if iodine drops are added to it. Similarly, an inference can be made from this observation that the unknown solution is starch. Much that cannot be perceived directly can be inferred from evidence or observations made using scientific instruments.

Piek and Mahlangu (1990:30) have described perception as understanding and internal assimilation of external observation. From this perspective, it can be seen that perception is closely
linked to observation. For example, one can observe through the sense of touch that an electric stove is hot. From this observation it can be perceived that the stove is working and that there is no power failure in the house.

An inference may also consist of making a series of observations, combining and categorizing them, and finally attempting to interpret them (Zeitler and Barufaldi 1988:97). For example, after observing the body coverings of several birds, learners could make a general statement that "Birds have feathers".

Inferring is a skill so closely allied with observing to the extent that the two could be easily confused. At first the idea of a distinction between observation and inference may seem a straightforward and useful one. It links up with things we might like to teach children about respect for evidence, and about the need not to push one's conclusions beyond the available information (Miller 1989:54-55).

5.2.1.4. Classifying as a Process Skill Allied to Observation

In principle every moment, every object we observe, is slightly different from anything else we have encountered. But we recognize familiar objects behaving in familiar ways. For us to comprehend the overwhelming number of objects, events and living things in the world around us, Miller (1989:53) suggests that an imposition of order is necessary. We do this by observing similarities, differences and interrelationships and grouping objects accordingly to suit some purpose. This grouping is known as classification. The basic requirements of any system of classification as indicated in Funk et al (1985:13-14) is that it must be useful.
Human beings have the capacity to classify, routinely, phenomena into groups. In the early stages of science this capacity occurs under conditions of ordinary experience (Feibleman 1972:61-62). Along with observation, the ability to classify is the fundamental cognitive skill on which all knowledge acquisition depends (Law and Lodge 1984:15).

According to Zeitler and Barufaldi (1988:98-99), classifying as a skill incorporates several sub-skills. One is sorting a set of objects into subgroups so that members of each subgroup share a common characteristic unique to that subgroup. For instance, if children are given a set of red, blue, yellow and green paper squares, they could be asked to place the squares in subgroups by colour.

Another sub-skill calls for selecting a characteristic, then creating two subgroups, one with the characteristic, and the other without. This is the classification scheme used frequently in animals and plants. For instance, insects could be classified into winged and unwinged groups.

Occasionally children are asked to construct groups based upon relative terms. Relative terms are characteristics that have little meaning except in relation to some standard. For instance, grouping of objects as large or small. Without some definition to go by, it is not possible to say which objects are large and which are small. Others are hard and soft, hot and cold, more and less, light and heavy, short and long. Relative characteristics can only be stated in comparative terms. For example, the Hydra is larger than an Amoeba, and the virus had always been regarded as the smallest of them all.

Classification using relative terms can only help if at least one of the objects in the classification is known. The known object gives a standard for comparison with the unknown objects.
The researcher believes that using a universal standard unit is a much more valuable technique. The length of microscopic organisms, for instance, could be given in micrometers (µm).

It should be emphasized that classifying, just like inferring and measuring, is not possible without observation.

5.2.1.5. Predicting as a Process Skill Allied to Observation

To predict is to make a forecast of future events or conditions expected to exist (Carin and Sund 1972:69). It is to deduce certain outcomes from a hypothesis and then looking to nature for verification (Collette 1973:13). It is a theoretical anticipation of natural occurrences or of experimental results (Funk et al. 1985:57). Logically speaking, a prediction is a weak deduction (Feibleman 1972:195-196), or a highly developed inferring skill (Esler and Esler 1981:60).

According to the logic of scientific investigation, observation leads to induction and hypothesis. The hypothesis is tested in two ways; by correspondence with the relevant data by means of experiment and by consistency with the existing systems in the science by means of mathematics (Feibleman 1972:195).

In the second of these two tasks, the hypothesis is called a theory. It is next ready for the third and last test, which is by means of prediction and control of phenomena. In this last test it is called a law. In other words a hypothesis is a proposition suspected of being true but for which there is as yet no support beyond observation; and that a theory is a hypothesis which has received a measure of experimental confirmation. One of the great values of laws at this stage in the proceedings is that they point to further observational test. It is from this law that the investigator deduces what
events he can expect to occur or by appropriate methods can bring about. The occurrence of these events constitute one more confirmation of the law (Feibleman 1972:196).

For example, the learner can predict that the blue litmus paper will turn red if dropped in hydrochloric acid solution. Also that a glowing wooden splinter will burst into flames if exposed to oxygen. Prediction, therefore, is not just a wild guess, it cannot be possible to predict the outcome of something if a similar thing has not been observed previously. As indicated in Funk et al (1985:57), prediction is based on careful observation and the inferences made about the relationship between observed events. A skill acquired in prediction is dependent upon the skill acquired in observation. The ability to construct dependable predictions about objects and events allows us to determine appropriate behaviour towards our environment.

5.2.1.6. Communicating as a Process Skill Allied to Observation

To record data is to collect bits of information about objects and events which illustrate a specific situation (Carin and Sund 1989:69).

Even though there is particular value in the permanency of a written account, there is always place for an oral account which can become the basis for a group or whole class discussion. The skill of being able to record and communicate one's work makes it open to the scrutiny of one's self and others, and so is a prerequisite for critical reflection (Cavendish et al 1990:29).

Communication means getting information from one person to another. In some cases people cannot communicate because they lack the right words to describe or explain a certain situation. Other times communication is blocked because people lack the
necessary experience in describing or in explaining a particular object or situation. Vocabulary and experience are basic to good communication. Language development and reading readiness are closely tied to the ability to communicate effectively. It is very important that children should have experiences about which they can speak. Communicating is not limited to verbal forms, drawing is also a form of communication. Facial expressions and acting out are also forms of communication (Neuman 1978:27-28).

Our ability to communicate with others is basic to everything we do. Graphs, charts, maps symbols, diagrams, mathematical equations and visual demonstrations, as well as the written and spoken word are methods of communication frequently used in science (Funk et al 1985:25).

It is clear from the foregoing text that without communication, observation has no value because nobody will know what has been observed. In fact, having adopted a notion that observation is theory laden, the researcher believes that observation will not even be possible without theory. The medium of theory is language which is an aspect of communication. Hodson (1986a:21-22) has rightly pointed out that the quality and usefulness of observations depend crucially on the observational language available to the observer. This observational language is a means of communication. Without it, perception cannot be given meaning and observations cannot be recorded and criticized. The skill of observing, therefore, includes communicating what has been observed. Learners should be given the opportunity to use all forms of communications to express their observations.

5.2.2. The Integrated Science Process Skills Allied to Observation

The basic science process skills as discussed above are considered prerequisites to the integrated science process
skills. The integrated science process skills are processes of the highest order which are recommended for Standard 4 through to Standard 10 (Cavendish et al 1990:101, Funk et al 1985:1, Gagné 1970:101 and 180, Van Aswegen et al 1993:17). The integrated skills include making operational definition, formulating a hypothesis, controlling and manipulating variables, collecting, analyzing and interpreting data, experimenting and formulating models.

5.2.2.1. Making Operational Definition as a Process Skill Allied to Observation

Before commencing with an observing activity such as measurement, the investigator must formulate operational definitions. This means identifying and explaining the necessary conditions for measuring. In Cavendish et al (1990:26) and Funk et al (1985:171), examples of such investigable questions are given as follows; What are we changing, or comparing or looking at? What other things should be kept the same (controlled) so that fair tests or comparisons can be made; what should be measured or compared to find the results; and how can the measurement or observation be made with accuracy?

According to Boehm and Weinberg 1987:37), operational definition should:

* lead the observer to describe the components of an observational situation.

* provide a system that allows more than one observer to collect or interpret the same data.

* force the observer to clearly define the problem or question he wishes to answer through the use of observation techniques.

The reader is referred to section 1.5.3. for a more elaborate explanation of observation techniques. It should be added here that observation techniques refer to the use of technological
instruments as extensions of human senses in making observations. For instance, optical observation through a microscope includes the sensorimotor skill of looking, the cognitive skill of seeing, and the microscope to improve the seeing. The technical manipulation of the instrument, apparatus or machine is added as a cognitive skill to form a technique (Van Aswegen et al 1993:6).

Having adopted a view that observation is selective means that the observer will have to select what is to be observed in advance. In the case of an experiment, for example, the observer must decide what the independent and dependent variables will be, it must be decided in advance what is to be kept constant and what is to be changed. Without operational definition, observation will not be selective and will, therefore, be meaningless. In fact, operational definition will even help the observer to decide in advance whether it is worthy to continue with a particular investigation or observation. Making operational definition, therefore, is a prerequisite to effective observation.

5.2.2.2. Hypothesizing as a Process Skill Allied to Observation

There seems to be as many definitions of a hypothesis as there are authors. Miller (1989:56) sees it as the activity of making an imaginative leap beyond the data to try to account for observed regularities. Collette (1973:6) loosely defines the hypothesis as the untested speculations in science. It is also referred to as a proposed answer to a question or a possible explanation to data. It is a trial idea and should have no scientific standing until it has been tested (Collette 1973:10-11). If a hypothesis is a simple generalization, it can sometimes be tested by looking for more examples (Collette 1973:11-12).
"Hypotheses are the scaffolds which are erected in front of a building and removed when the building is completed. They are indispensable to the worker; but he must not mistake the scaffolding for the building" Wolfgang (1830) as quoted in Collette (1973:81).

For purposes of this study, the most important function of the hypothesis is to determine what should be observed or tested and what is expected as a result, thereby bringing order to an observation.

As indicated in Cavendish et al (1990:25), hypothesizing involves using ideas that one already has, from past experience, to attempt to explain or give a reason for some new event or observation. A hypothesis can be expressed in a number of ways; it is not the form but the intention of a statement which indicates whether or not it is a hypothesis. It must attempt to give an explanation.

For example, if the dissecting lamp fails to light when the switch is turned on, several informal hypotheses come to mind:

a. The plug is not properly connected to the power outlet.
b. The bulb is burnt out.
c. The fuse is burnt out or the circuit breaker tripped.
d. There is power failure.
e. The switch is malfunctioning.
f. There is a bad connection in the circuit., etc.

Each of these speculations/hypotheses can be tested directly by checking the plug connection, substituting the bulb known to be in working condition, inspecting the fuse or circuit breaker, or by noting whether or not lights in the laboratory are on.
The hypothesis is implied in the following statement or proposition. "Seeds grow best in the dark". The implication is that darkness helps seeds to grow.

In order to test the hypothesis in the second example, Observing Activities (1990:25) points out that the first step is to use them to make a prediction. "If we put these seeds in the dark they will grow better than seeds in the light". Sometimes the prediction is made at the same time so the hypothesis is expressed as a prediction. Hypothesis and prediction are separate in function though often coincident in use. Prediction can be made on the basis of data as well as following from hypothesis.

It should be noted in both the examples above that a hypothesis has been preceded by an observation. Popper (1981:73) has rightly pointed out that any kind of hypothesis we choose will have been preceded by observations - the observations, for example, which it is designed to explain. The fact that the light did not go on, and that the seeds grow well in the dark are both observations. In both examples the hypothesis comes in as an attempt to explain what has been observed.

It can be safely concluded that the proper formulation of hypotheses leads to accurate observation. Hypothesizing, therefore, has to do with the skill of observation.

5.2.2.3. Control and Manipulating of Variables as Process Skills Allied to Observation

Various authors (Carin and Sund 1989:68, Learning Science Process Skills 1985:88-89, Zeitler and Barufaldi 1988:99) identify two main types of variables. Independent variables are conditions in an experiment which can be arranged in some way or other by the experimenter. It is independent of the other
conditions. Dependent variables are things or conditions in an experiment which are being influenced or which can change because of other conditions.

Figure 3.1. is the graph of an experiment to investigate the effect of temperature on enzyme activity. The temperature variable is under control of the experimenter since he can decide at what temperature the readings should be taken. The temperature is, therefore, the independent variable. The enzyme activity is a dependent variable since it is dependent on the temperature.

Quite often, there is a third group of variable called controlled (fixed) variables (Dekker et al 1993:41, Van Aswegen et al 1993:18). These are the things or conditions which will ensure that the experiment is fair. Controlled variables are those things which must be kept the same (controlled). In the experiment above, conditions like pH and substrate concentration are, therefore, the controlled variables since they are deliberately held constant.

It should be emphasized that the independent variable (temperature), dependent variable (enzyme activity) and the controlled variables (pH and substrate concentration) are normally observable entities. This is especially true as far as the design of an experiment is concerned. Many other concealed variables which influence the experiment also have to do with observability. The ability to control and manipulate these variables, therefore, is an ability to select what is to be observed. In the final analysis, this is the skill allied to observation.

Learners should eventually reach the level of development at which they will be able to identify, select and control variables in making their observations.
5.2.2.4. Interpreting Data as a Process Skill
Allied to Observation

Carin and Sund (1989:68) define interpreting data to mean analyzing data, determining apparent patterns or relationships in the data. Zeitler and Barufaldi (1988:99) see interpretation as asking the questions such as "What do the data and information mean?"

As indicated in Cavendish et al (1990:27), interpreting includes finding patterns or associations within data, using these to make predictions and what is commonly called "drawing conclusions". Interpreting is concerned with relating one piece of data to another as opposed to leaving them as isolated findings. Interpretation also means to organize information derived from an experiment and eventually to make generalizations supported by experimental findings (Van Aswegen et al 1993:17).

As an example, Figure 3.1. may be interpreted to mean that an increase in temperature up to the most favourable temperature range increases enzyme activity. But an increase in temperature beyond the most favourable temperature range begins to denature the enzyme, thus the enzyme activity falls sharply.

No matter how good an observation may be, Brook, Driver and Johnston (1989:71) argue that it is meaningless unless it is followed by meaningful interpretation. This is as good as not having made an observation at all.
It is pointed out in Cavendish et al. (1990:28) that one of the obstacles to children interpreting data is that they will inevitably have preconceived ideas about the things they are investigating. There is a tendency to use these ideas rather than data in drawing conclusions. A key aspect of interpretation, therefore, is the ability (and willingness) to use the data in making an interpretation. Whether or not this has been done may have to be probed by asking children to explain the basis for their prediction or relationship.

As indicated earlier, and according to the extended definition of observability (using instruments) as adopted in this study, both the temperature and the enzyme activity are observable entities. The observed facts have no meaning unless they are organized into a table. From the table, a graph is constructed. Either the table or the graph may be used to interpret the result. The ability to interpret, therefore, plays a fundamental role in understanding what has been observed.

Feibleman (1972:153-154) is of the perception that observation is for data only, the data per se can never be false. The researcher, in this study is of the opinion that it is not data but an observable entity, phenomenon or event that is permanent and never false. It is the observer's interpretation of an observable entity that offers so many difficulties and can be false!

5.2.2.5. Experimenting as a Process Skill Allied to Observation

Experiments are deliberately undertaken, and features artificially arranged. Feibleman (1972:146-147) asserts that a certain level of sophisticated observations is essential during
the running of experiments. These observations involve the skill of careful reading of automatic recorders, rate meters, counters, scales and timers.

The recording of observations must be done promptly before a lapse of time allows inaccuracies to creep in. Observation at the experimental level is, therefore, no longer naive, and the investigator comes to his observations with deliberate preconceptions. He knows what it is that he should expect to see.

The sources consulted (Best 1981:25 and 57, Chadwick et al 1984:174 and Van Aswegen et al 1993:18) show that the sequence of steps in experimenting include:

* Stating a problem
* Formulating a testable hypothesis
* Identifying and controlling variables
* Measuring and observing
* Interpreting data
* Communicating
* Inferring

Experimenting, as can be deduced, is the most sophisticated kind of observation incorporating most, if not all the science process skills as discussed in this chapter. It is simply not possible to record the results of an experiment without having made an observation.

5.2.2.6. Constructing and Using Models as a Process Skill Allied to Observation

Van Aswegen et al (1993:126) define a model as a recognizable imitation of the real thing with an increase or decrease in size. Creating models means displaying information by means of
graphic illustrations or other multisensory representations (Carin and Sund 1989:68).

Feibleman (1972:143) divides models into concrete and abstract forms. Concrete models are material analogies while abstract models are mathematical. The mechanism in nature is assumed to exist, from the phenomena observed. Then it is compared with a concrete model constructed artificially. The model may be smaller than the original, for example, clay model, or they may be larger, for example, the wooden model of a chemical element.

It is explicit from the everyday teaching and learning of natural sciences that models serve to illustrate or demonstrate an object or phenomenon that is assumed to have been observed. According to Feibleman (1972:143), models for illustration are concrete examples of abstract ideas. The Watson and Crick model of DNA is another good example. Abstract models describe a large mathematical theory concerning the structure of some natural phenomenon. Simulation of reality should be regarded as a kind of an abstract model to emulate a natural phenomenon.

The skill of constructing and using models means, according to Van Aswegen et al (1993:126), that the models should be a reduction or enlargement of the original objects to enable easier observation.

Constructing and using models as a skill means that a model should not be mistaken for a real thing. It is only a partial representation of the real thing even when it is a true one; rarely does a model contains all of the features of the object but only some of them, usually only those that are known. Models are at best only approximations and it is enough if they do suggestively the little that they do. For even in this case there is some unavoidable degree of distortion involved in the mere selection of the known features.
It is evident that both the model and its original counterpart are observable entities, or assumed to be observable entities— to borrow from Feibleman (1972:143). One cannot be able to construct and use a model for which the original thing, or its representative has not been accurately observed. The construction and use of a particular model, therefore, requires an accurate observation of its original entity. This involves observation related skills.

Table 5.1. is a summary of observational and allied skills as outlined in this chapter.
### A. Basic Observational and Allied Skills

1. **Observing**: Using the senses to gather information about an object or event.

2. **Measuring**: Using both standard and non-standard measures or estimates to describe the dimensions of an object or event.

3. **Inferring**: Making an educated guess about an object or event based on previously gathered information.

4. **Classifying**: Grouping or ordering of objects or events into categories based on properties or criteria.

5. **Predicting**: Stating the outcome of a future event based on a pattern of evidence.

6. **Communicating**: Using words or graphic symbols to describe an action, object, event.

### B. The Integrated Science Process Skills

7. **Making operational definition**: Stating how to measure a variable in an experiment.

8. **Formulating a hypothesis**: Stating the expected outcome of an experiment.

9. **Control and manipulating of variables**: Identifying variables that can affect an experimental outcome, keeping most variables constant while manipulating only the independent variable.

10. **Interpreting data**: Organizing data and drawing conclusion from it.

11. **Experimenting**: Conducting an entire experiment, including asking an appropriate question, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing a "fair" experiment, conducting the experiment and interpreting the results of the experiment.

12. **Constructing and using models**: Creating a mental or physical model of a process or event.

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**Table 5.1. Summary of Observational and Allied Skills**
5.3. SUMMARY

Observational and allied skills can be described as attributes of a continuum of science process skills ranging from observing, the most basic skill, through to experimenting, the most complex set of skills.

The common denominator in any one of the science process skills as discussed in this study is observation. Directly or indirectly, the essence or ability to observe lies in the above list of skills. One cannot infer, measure, classify, etc. without involving observation.

The central importance of observation in assessing the use of the above skills becomes clear. How can one determine whether a child can ask questions and suggest ideas of the 'how', 'why', and 'what will happen if' variety unless some form of observation is employed? The skills listed in this chapter, therefore, are observational and allied skills. The next chapter looks at the nature and structure of natural sciences and their implications to the psychology of learning and instruction.
6. THE NATURE AND STRUCTURE OF NATURAL SCIENCES AND ITS IMPLICATIONS TO THE PSYCHOLOGY OF LEARNING AND INSTRUCTION
6.1. ORIENTATION

Any discussion of learning theory will not be complete without reference to the nature and structure of the field in which learning is to take place. The first part of this chapter is an attempt to explore the nature and structure of natural sciences.

The nature and structure of a field of study has to be reflected in its learning and teaching. As indicated by Huyser (1992:5) and Van Aswegen et al (1993:4), it enables the teaching, learning and understanding of the particular field of study.

The psychology of learning and its implications to the natural sciences curriculum is discussed in the last part of this chapter.
6.2. THE NATURE AND STRUCTURE OF NATURAL SCIENCES

According to Degenaar (1985:25), the nature and structure of a discipline refers to the field of knowledge which is revealed in a unique operational manner. The nature of a discipline cannot be entirely separated from its structure, because the one usually suggests the other. Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully.

6.2.1. The Nature of Natural Sciences

It is indicated in Maarschalk and McFarlane (1988:39-40) and Van Aswegen et al (1993:4) that natural sciences entail a systematic and active field of inquiry on nature. The accumulated body of knowledge in this field is ever-changing because new discoveries continue to be made. Advancement in natural sciences is the result of interaction between problem, hypothesis, experiment, observation, data and theory.

6.2.2. The Structure of Natural Sciences

Degenaar (1985:26) refers to a structure as a synthesis of a discipline in accordance with basic concepts and classified systems of knowledge. In the natural sciences, practitioners operate upon their discipline by means of a substantive and a syntactical structure.

6.2.2.1. The Substantive Structure

Studies (Degenaar 1985:26, 27,28; Dekker et al 1993:33; Gardner 1979:32; Huyser 1992:6; Van Aswegen et al 1993:4;) have shown
that the substantive structure is the interrelated collection of powerful ideas that guide research in a discipline. It is the network of related theories, laws and concepts which individual scientists bring to bear when they set out to solve problems in their discipline. It is the coherent, contextual and internal relationship of the various elements of knowledge which constitutes natural sciences. This in essence refers to the body of accumulated knowledge. These are products of knowledge such as facts, concepts and principles.

This kind of knowledge is usually found written in text books in various ways and has mostly been learned by rote memorization. The disadvantage of the substantive structure is that the knowledge is rarely assimilated, as a result it is easily forgotten. Furthermore, the substantive structure always changes as new discoveries are made.

However, this should not suggest that knowledge of the substantive structure is unimportant. It forms the basis upon which further learning can take place and will guide the observation process itself. Knowledge of the substantive structure can be augmented with that of the syntactical structure.

6.2.2.2. The Syntactical Structure

According to the literature (Degenaar 1985:28; Dekker et al 1993:33); Gardner 1979:32; Van Aswegen et al 1993:6), the syntactical structure indicates processes or epistemology of natural sciences. Natural sciences has its own unique manner of unlocking the content of its study field. The syntactical structure is concerned with the way in which new concepts are formed, and the ways in which knowledge is generated and validated. It is concerned with the mode of thinking and
reasoning used in the natural sciences. The nature of natural sciences or its syntactical structure is not only determined by its subject methodology, but also through a specific approach, rationale and underlying philosophy.

Van Aswegen et al (1993:6) describe the syntactical structure in terms of skills to be mastered. The sensorimotor skills entail all the primary reception of impressions from the environment. It involves the five senses and the execution of the most basic spontaneous motor movements. The sensorimotor skills are guided by the cognitive (thinking) skills. A technique is being executed when a scientific apparatus is used.

It is apparent that the essence of the syntactical structure hinges on the observational process skills as described in chapter 4. These observational process skills form the basis upon which the teaching and learning of natural sciences takes place.

As indicated in section 6.1. in this study, the nature and structure of a discipline has to be reflected in its teaching and learning. It enables the teaching, learning and understanding of the particular field of study. What follows is an attempt to describe the implications of the substantive and syntactical structures on the psychology of learning. The implications on the instructional strategy is discussed later in this chapter.

6.3. THE IMPLICATIONS OF THE SUBSTANTIVE AND SYNTACTICAL STRUCTURES ON THE PSYCHOLOGY OF LEARNING

Van Aswegen et al (1993:7) state that the syntactical structure is responsible for the generation and understanding of the substantive structure. The substantive structure directs and sometimes induces the course of the syntactical structure. For
By implication, learning should strike a balance between the products of science and the processes by means of which knowledge is accumulated. The product or substantive perspective of learning involves a change in scientific ideas or concepts. This kind of learning is seen as a specific end in itself. The process or syntactical perspective involves a change in science process skills. It is not an end in itself, but a means to an end (Maarschalk and McFarlane (1988:31). The teaching and learning of natural sciences in most countries is historically based on the substantive perspective (see section 1.1.2.).

There seems to be no general consensus as to the nature of learning. Ideas about children's learning are never certain and are always changed as new evidence emerges. In this spirit the views about learning as discussed in this study are not meant to be a paragon of virtues or a panacea. They (are meant to) reflect what is currently found to be the best available explanation of what learning is.

The approach in this study is not to regard the theory of one psychologist as more correct than another's. Instead, all these thinkers are depicted as trying to describe the same complex reality, namely; learning, from their own personal perspectives.


Jean Piaget is the renowned and most popular psychologist in the field of learning of natural sciences. Studies (Esler and Esler 1981:22-27; Kahle 1979:3-4) show that according to Piaget
(1954), a child goes through about four successive stages until he is capable of abstract or formal thought.

Piaget proposed that a child goes through three types of knowledge; this is physical, logical mathematical and social knowledge. Physical knowledge is the first type to develop. This kind of knowledge develops through observation and interaction with objects. The logical mathematical (reasoning) knowledge evolves out of physical experience. During the development of logical-mathematical knowledge, children are deceived by many of their observations (Carin and Sund 1989:38).

Of special interest to this study is Piaget's (1954) reported (Duke 1990:83, Esler and Esler 1981:3-6) insistence that until children become capable of formal operations, they need two aspects in order to learn. Firstly, in order to progress cognitively, children need environments in which they can experience interaction with a variety of phenomena. They should use all their senses to interact with concrete, manipulative materials. Secondly, children should be able to communicate their concrete experiences. It is perhaps from this notion that a didactic principle "From the concrete and empirical (based on observation) to the abstract and rational (theoretical)" has arisen.

Lawson and Renner (1975:338) are two proponents of Piagetian theory. They also assert that it is experience with the material of the discipline that produces the person who can understand abstract content. It is not studying abstract content that produces students who can interact with the material and invent abstract generalizations. By implication, observation must precede the introduction of theory (abstract generalizations) before learning can take place. The researcher in this study contends that this should be treated as a matter of convenience.
rather than a principle. As argued in section 3.2.2.4. and 3.2.2.5. neither observation nor theory (abstraction) should have a priority. Most often, the theory is there in the process of observation.

It is needless to say that the nature and structure of natural sciences is reflected in Piaget's learning theory. Piaget's physical knowledge which develops through the use of all the senses (observation) is an aspect of syntactical structure. Piaget's logical mathematical knowledge evolves out of physical experience.

6.3.2 Neo-Piagetian Psychologists

The learning theories in section 6.3.2.1. through to 6.3.2.4. below have evolved from Piaget's psychology of learning. The psychologists may also be referred to as the Neo-Piagetian frameworkers (Duit 1991:69).


Gagné's most concrete kind of intellectual skill is indicated (Seifert 1983:195) as discrimination learning, that is distinguishing objects by their observational properties. High school biology pupils learn discrimination skills when, for instance, they learn to distinguish a vein from an artery.

Gagné (1970), as reported in Collette (1973:157) maintains that the aim of education is to produce individuals who are competent in the knowledge getting processes. What this implies is that learning should aim at the development of observational and allied skills.

Collette (1973:158), in an attempt to interpret Gagné's aim of
education, indicates that learning objectives would receive many emphasis than teaching objectives. These would have to be stated in behavioural terms. Learners, for instance, should not only read about or explain how a wet mount is prepared, they should be able to prepare a wet mount of onion cells for observation when given slides, cover slips and an onion bulb.

Gagné (1970) also stressed that what a person has already learnt (pre-knowledge) determines what he will be able to learn (Maarschalk and McFarlane 1988:78). From this perspective, learners should also be taught the products of science. In this way Gagné's (1970) learning theory also emphasized both the substantive and the syntactical structures. The latter has to do with observational learning.

6.3.2.2. Jerome Bruner's (1960) Learning Theory

Gage and Berliner (1988:123) and Seifert (1983:188) have depicted Bruner (1960) as differentiating between three types of learning: the enactive, ikonic and symbolic. Enactive learning means learning by means of and using the body. For example, the psychomotor action of lighting a bunsen burner. It should be clear to the reader that Bruner's enactive learning is based on the syntactical structure which is an aspect of learning through observation. Ikonic learning takes place when the child learns by means of pictures. Symbolic learning takes place by means of symbols. Symbolic learning should, therefore, reflect the substantive structure.

Collette (1973:160) and Seifert (1983:192), in expressing Bruner's position, assert that a body of knowledge is but a product of much prior intellectual activity. Instructing someone is not a matter of getting him to commit the results to mind, rather it is to teach him to participate in the process that
make possible the establishment of knowledge. Knowing is a process, not a product.

In this way Bruner (1960) shares the same view with Gagné (1970) and Piaget (1954) regarding the aim of education. However, Bruner differs from the two psychologists with respect to the means of attaining the aims. Bruner stresses a more free, unguided approach (unguided discovery learning) to education (Esler and Esler 1981:29). The unguided discovery learning has already been reappraised early in section 2.3.2. and was found not suitable for the purposes of this study.

The above assertions further strengthen the researcher's claim in this study that the neo-Piagetian's learning theories reflect both the substantive and syntactical structures. They all explain learning as both a product and a process. Observational learning forms the basic and most important component of the processes of science.

6.3.2.3. Ausubel's (1965) Learning Theory

According to Ausubel (1965), the aim of education should be based upon the previously learned subject matter (Carin and Sund 1989:42). These are the products of learning (Collette 1973:157) or substantive structure. Problem-solving, or discovery learning (an aspect of the syntactical structure) can only occur when children have previously learned basic subject matter in a science area (Carin and Sund 1989:92). He believed that the science curriculum should be concerned with the systematic presentation of a structured body of knowledge (facts, concepts, principles, conceptual schemes, etc.) as a specific end in itself.

Learning is seen as having two dimensions. The reception-
discovery dimension and meaningful-rote dimension. The former is concerned with the amount of content presented, hence it reflects the substantive structure. The latter dimension is primarily concerned with what the student does or does not do during the learning process (Collette 1973:165), this is an aspect of the syntactical structure. In the process of meaningful learning, the learner relates the learning material to his existing cognitive structure (organization of knowledge) in a non-verbatim and non-arbitrary manner. Meaningful learning permits the learning material to be related to the existing ideas as examples, derivatives, special cases, extensions, elaborations, qualifications, etc.

In rote learning the learning material is unstable, easily forgotten and does not lend itself to flexible expression (Collette 1973:166).

Despite the many differences in the Piagetian theories of learning, several major similarities may be identified. The study of literature (Duit 1991:68; Padilla 1991:206; Simmons 1991:248) show that these similarities have evolved into the contemporary psychology of learning - the constructivist view. Thus the constructivist view of learning, as discussed in the next section, is essentially Piagetian in origin.

6.3.2.4. The Constructivist View of Learning

Tobin (1990:404) asserts that constructivism can be traced back to the eighteenth century as a persistant, though not dominant epistemology. However, Duit (1991:68) pointed out that the constructivist view is not a well-elaborated theory like that of Piaget or Ausubel. The term "constructivist" is used as a way of identification. It is more a "view", a framework used to conceptualize pedagogical events in science learning.
According to Duit (1991:68) and Padilla (1991:206), the constructivist view has emerged as a strong central treatise in science education today. It is a very powerful one with much valuable potential. It integrates influential contemporary lines of thought that take counterpositions to traditional empiristic and positivistic ones. It has become so popular and influential within research on students' conceptual frameworks because it fits into the mainstream of alternative (versus traditional) thoughts.

What follows is the discussion of two important assumptions of the constructivist perspective of learning. The implication of the nature and structure of natural sciences on learning through observation is also evident.

I. Learning is an Active Construction of Knowledge Involving the Learner

Human learning is an active knowledge construction process involving the learner. Sensory data are given meaning in terms of prior knowledge. This assumption is explicit in the following sources (Duit 1991:70; Glynn, Yeany, and Britton 1991:10; Harlen 1990:24; Padilla 1991:206; Scott, Dysson and Gater 1987:7; Simmons 1991:248; Tobin 1990:404). This construction of knowledge is through experiences with the physical environment and through social interaction. The learner must discover and construct meaning and understanding of the universe by himself.

For true learning to occur, Harlen (1990:24) argues that "It is absolutely necessary that learners have at their disposal concrete material experiences, and that they form their own active manipulations". Learning is not seen as a process of simply storing pieces of knowledge provided by the teacher. On the contrary, it is seen as a process of active construction of knowledge on the part of the learners themselves (Duit 1991:70). The active involvement of the learner in his own learning is
attributed to the syntactical structure of natural sciences. Learning which involves development of observational and allied skills forms a very important component of the syntactical structure.

One of the most common justifications for learning as an aspect of the syntactical structure is embodied in the Chinese axiom: "I hear...and I forget. I see...and I remember. I do...and I understand" (Padilla 1991:207). The implied wisdom is that the learner will better understand and retain knowledge when given the opportunity to learn through observation.

Learning through observation is further encouraged by activity-centered textbooks and programmes. "Biology in Action" and "Active General Science" are examples. The ground motive behind this move as interpreted in Padilla (1991:206) is the recognition that a child needs to be actively involved in his own learning. This is an aspect of the syntactical structure. Glynn et al (1991:10) state that during a learning process (see Figure 6.1.), the learner carries out cognitive processes and constructs relations in working memory. This has an impact on the questions, observations, and conclusions in the problem-solving environment. When reasoning in working memory about a science phenomenon, the student draws upon relevant facts, principles, and skills stored in long term memory.
It is explicit in Figure 6.1 that learning involves both the substantive and syntactical structures. In the students' long term memory, facts, principles, theories and models all represent the substantive structure. Observation is the basic and most important component of the science process skills in the syntactical structure. The fact that these two structures are closely interconnected and complement each other is stressed in Scott et al (1987:18). The ideas (substantive structure) that are accepted at any time are dependent upon the quality of the processes of testing them (syntactical structure), as well as on the evidence available.
II. Prior Knowledge Influences Learning

In section 3.2.2.5. in this study, it has been categorically stated that observation is influenced by prior knowledge. The literature studies (Duit 1991:70; Scott et al 1987:3 and 7) has shown that in the constructivist view, learning is also influenced by prior knowledge. If $A = B$, and $B = C$, mathematically speaking, $A = C$. Similarly, if observation is related to prior knowledge, and prior knowledge to learning, therefore, observation is related to learning.

6.3.3. The Link Between the Psychology of Learning and Observation

The inextricable link between learning and observation is best illustrated by a model of learning based upon the information-processing approach (see Figure 6.2.). According to this model, the sensory organs receive the sensory signals of looking, hearing, touching, tasting and smelling. This forms an observation image in the short-term memory.

This observation can now be imitated by first making a mental representation thereof in the short-term memory. The represented image is then expressed through motor movement. This movement makes a representation in the form of a symbol (language, graphics, gestures) or a recreation in the form of model (physical model). The learner can make sketches of the organisms.

Carin and Sund (1989:94) assert that learning in the natural sciences begins with environmental contact made through the senses. It is the recognition of a relationship between an idea and an observation, or between two ideas, or between two observations". In section 2.3.4. it has been indicated that
humans learn by perceiving; i.e. having internal experience of external observation. This further depicts the essence of observation in learning.

According to Collette (1973:196) the sensations or observations are more complex than the traditional five senses of smell, taste, sight, hearing touch. They include a sense of equilibrium, a sense of acceleration, a sense of body movement and position, senses of heat, cold, pressure and pain.

![Figure 6.2. A Learning Model based on the Information-Processing Approach](image)

Adapted from Van Aswegen et al (1993:27)
As indicated in Engelbrecht and Lubbe (1981:18), before any thought can take place, man must observe, this should involve some concrete experience. Concrete observation is, therefore, essential for learning. Piek and Mahlangu (1991:245) have rightly pointed out that we remember about 10% of what we hear, 20% of what we see and 65% of what we see and hear. This explains how important it is to observe with all five senses. A blind person's learning of, say, biology can only be possible to a very limited extent.

If learning is seen as an active process of constructing meaning involving an interaction between existing mental schemas and new sensory inputs, Miller (1991:50) argues that it must involve all the science process skills. Observation is a very important and indispensable part at the core of the syntactical structure. This further implies that learning in the natural sciences takes place through observation. Learning, therefore, is inextricably linked to observation. The development of observational skills is, therefore, very important. Children who are faced with new experience try to understand it by using their present ideas. Links are formed between the new experience and ideas from previous experiences by observing similarities and differences.

A pupil who participates, say in an experiment, who sees what happens, and who can taste and feel, will have much better understanding than the pupil to whom the experiment is merely recounted. This further confirms that there is a very strong link between learning and observation.

The observational and allied skills, therefore, should be seen as a continuum of learning activities or a hierarchy of learning (Gagné's 1970:152) from observation through to experimenting. In learning, the learner is not a tabula rasa, or a bench-bound
listener, but an active participant in the construction of knowledge.

The Mannheim School of Selz (one of the German psychology of thought) emphasized the importance of observation. Without observation, abstract thought and, therefore, learning is not possible (Engelbrecht and Lubbe 1981:139). Learning and observation, therefore, should be seen as inseparable entities in the natural sciences.

The reader with a working knowledge of paradigms of learning will realize that the discussion on the psychology of learning in this chapter has not been exhaustive. Many different kinds of learning take place under many different conditions. Furthermore, many different kinds of learning take place under the same condition but involving diverse learners. Learners also tend to learn differently and apply different approaches at different occasions. For this reason it should be argued that some other learning theories which have not been discussed in this study could have some elements of applicability. For instance; the behavioural, the social and the cognitive theories of learning could apply to a single learner during a specific lesson. The respondent conditioning, contiguity learning and operant conditioning are all part of the behavioural psychology of learning which could be linked to learning through observation.

The researcher in this study, has found it interesting to note that a partly rival psychology of learning has developed alongside and parallel to Neo-Piagetian psychology of learning. This is the "alternative frameworkers'" psychology of learning (Duit 1991:69). Unfortunately, there is meager information about this theory. Recently in 1989 some attempts to unite the rival positions have been made. Notwithstanding any anticipated
developments, as may be, in this direction, the researcher is convinced that, at least for the time being, the Neo-Piagetian framework can be taken as the basis to explain learning in the natural sciences. It is likely to foster a more acute awareness, for teachers and pupils, of the nature of their involvement in the teaching-learning processes.

Having adopted the Neo-Piagetian framework, the researcher does not claim that this framework will, at a stroke, solve all the teaching-learning ills in the natural sciences. Scott et al (1987:83) have warned that science teaching and learning will continue to be a difficult task in the future. Many problems are inherent in the "nature" of science knowledge. Secondly, constructivistic science instruction will not help teaching and learning in a simple way. On the contrary, teaching and learning are more demanding if this approach is taken; research is too.

6.4. THE IMPLICATION OF THE PSYCHOLOGY OF LEARNING TO THE INSTRUCTIONAL STRATEGY

The Piagetian psychology of learning and the resulting constructivist view of learning imply that the subject matter should be presented in a sensual way. The instructional strategy should aim at providing enough perceptual experiences in which children can find food for thought. Gage and Berliner (1988:126, 128) have rightly pointed out that children, particularly in the preschool and early primary school years learn well from working with objects, materials and phenomena. Instruction in these early years should begin with hands-on activities that build enactive representations. Audio-visual aids should be used extensively to provide concrete, pictorial, and diagrammatic versions. Pupils should be given a chance to manipulate, act, touch, see, and feel things. This helps them acquire an
understanding of concepts and relationships more effectively than the more abstract forms of learning.

Gage and Berliner (1988:127) give an example that in teaching the concept of number, one could begin by classifying objects on the basis of colour, size, form, weight and coarseness. It is the specific task of the school to provide the opportunities for observation that can lead to learning.

The nature and structure of a discipline has to be reflected not only in its learning, but also in its instruction. Instruction, just like learning, should be based upon the products (substantive structure) of science and the processes by means of which the products are generated (syntactical structure). When this strategy is employed, learners act as a community of novice scholars.

6.4.1. A Generalised Model for a Constructivist Instruction

The adoption of the constructivist view of learning has fundamental implications on the instructional strategy. The major components of this model are orientation, elicitation, restructuring, application, and reviewing of change in ideas. Some of these implications are now explored with reference to the sequence illustrated in Figure 6.3.

6.4.1.1. Orientation

The teaching commences with orientation. This sets the scene for the work to come in introducing the context of the study.
6.4.1.2. Elicitation of Learners' Ideas

The constructivist assumption that prior knowledge influences learning implies, according to Scott et al (1987:10-12) and Simmons (1991:248), that learners' ideas should be elicited at the beginning of a lesson sequence. How does a single teacher elicit the individual views of thirty pupils in 35 to 40 minute slots of time over a week? The best way to do this is to present learners with a circus of observational activities which they are asked to explain in their own terms.

A considerable amount of research (Cavendish et al 1990:28, Hodson 1986a:26, Neuman 1978:31, Scott et al 1987:12; also see section 3.2.2.5. in this study) has been carried out into the kinds of ideas which learners' bring to science lessons. Areas which have been investigated include those of circuit electricity, gravity, dynamics, heat, light, plant nutrition, particulate theory and energy.

Learners' description of observational phenomena in these areas may elicit deep seated and commonly held beliefs. For example; "Plants get their food from the soil". "Energy gets used up when a job is done". "A steady force is needed to produce a steady motion". It would seem unlikely that such ideas can be successfully challenged until their existence is recognized and made explicit by the teacher. An understanding of dynamics would be severely undermined by the existence of the 'steady force - steady motion' idea.

In order to respond to these problems, science teaching schemes which acknowledge and start from learners' existing ideas should be developed. The generalised outline for the teaching sequences is shown in Figure 6.3.
6.4.1.3. Restructuring and Application of Ideas

Within a single class, the range of ideas elicited is likely to be wide. Inevitably, there will be divergence between pupil views and the accepted view of science community. Scott et al (1987:13) indicated that in the restructuring phase, pupils consider the variety of ideas which have emerged. Learners are helped to modify their viewpoints towards that of the currently accepted scientific theory. It should be pointed out that restructuring of ideas is the responsibility of the learner. The teacher can specify appropriate activities designed to promote restructuring but cannot do the learning for the child.

Scott et al (1987:14) pointed out that during the restructuring phase, the teacher may present a surprise demonstration which is designed to promote conceptual conflict. Alternatively, he may wish to introduce a further piece of evidence which would allow
the pupils to extend their ideas. Thus in the Particulate Theory teaching scheme diffusion demonstrations by the teacher would introduce the possibility of particle motion.

In the application phase, pupils are given the opportunity to use their developing ideas in a variety of situations. Thus new concepts may be consolidated and reinforced by extending the contexts within which they are seen to be useful. Application tasks might include further experimental work involving further observation. Inevitably, further restructuring will take place during this phase (Scott et al 1987:14).

6.4.1.4. Review of Change in Ideas

As indicated by the feedback loop in the teaching sequence diagram (Figure 6.3.), the pupils are invited to reflect on how their ideas have changed by drawing comparisons between their thinking now and at the start of the unit.

6.4.1.5. The Changed Role of the Teacher

The notion that useful ideas have to be developed from within the learners themselves means that the teachers' role is no longer that of transmitting ready made products to the pupils. The teachers' role is to help pupils master the processes of learning. This essentially means that instruction should be designed with the aim of developing the syntactical structure.

The teacher is both a coach and a referee. He is a coach in the sense that he sets tasks for the learner which will improve the learner's performance. He is a referee in the sense of helping in the collective development and application of community standards for evidence and argument. The reader is referred to section 7.3.6. for more information about the changed role of the teacher.
6.5. SUMMARY

This chapter has shown that natural sciences consists of the substantive and syntactical structures. The substantive structure is the body of accumulated knowledge while the syntactical structure is the processes by means of which knowledge is obtained. These two structures determine the way in which teaching and learning should take place in the natural sciences.

The Neo-Piagetian psychology of learning advocates that learning should involve both the products of science (substantive structure) and the science process skills (syntactical structure). The learning of natural sciences should, therefore, not only consists of a systematic accumulation of an abstract body of knowledge. It should include the practicing of the processes by means of which knowledge is obtained. Observation, and, therefore, the development of observational skills, forms an indispensable basis for science process skills. Observational skills should be seen as a continuum of learning activities from observation through to experimenting. The foregoing explanations which link learning to observation have made the Neo-Piagetian psychology of learning most suitable for purposes of this study.

The instructional strategy should aim at providing more opportunities for observation. Instruction, especially in younger children, should begin with hands-on activities that build enactive representations. Science teaching schemes which acknowledge and start from learners' existing ideas should be developed.
7. DIDACTIC CRITERIA FOR THE DEVELOPMENT OF OBSERVATIONAL AND ALLIED SKILLS IN THE TEACHING AND LEARNING OF NATURAL SCIENCES
7.1. ORIENTATION

The main purpose of chapter 7 is to discuss the requirements for developing observation related science process skills. Didactic criteria are concerned with the best way in which science process skills may be developed. This chapter, therefore, provides science educators with a sound theoretical foundation from which observational and allied skills may be developed. It is from this sound theoretical frame of reference that an instructional model to deliberately develop and assess observation related skills will emanate. This chapter, therefore, lays the basis for the later development of observational and allied skills in chapter 8.

The first part of chapter seven explores various reasons for developing observational and allied skills. This is followed up by a look at various approaches in which observational and allied skills can be developed. Two main approaches, namely; the process - and the content (product) approach are discussed in detail. The role played by practical activities, evaluation, the computer and the teacher in the development of these science process skills is discussed next.

The researcher then makes a selection of tasks generated to develop observation related science process skills. These involve the description of scientific experiences and the use of science related equipment.
7.2. THE NEED TO DEVELOP OBSERVATIONAL AND ALLIED SKILLS

The term 'develop' as adopted in this study (see section 1.5.1.) means to improve or increase. It is used in the same sense as teaching. This chapter, therefore, deals with the various ways in which observational and allied skills may be taught.

It has been established (Hodson 1986b:386; Mestre and Lockhead 1990:96) that if learners are exposed to an observable phenomenon in the laboratory, not all of them are able to perceive the appropriate observation without instruction. As an example, it cannot be guaranteed that children will be able to perceive features of the magnified onion cells or twig sections before instruction. They may miss the phenomenon under investigation (Hodson 1986b:386) for two reasons, namely; the lower developmental level of their sensing capabilities, and the lack of the necessary theoretical background to the phenomenon under observation. There is, therefore, a need to develop both these aspects.

According to Mestre and Lockhead (1990:94) and Miller (1989:69), pupils who lack the necessary theoretical background may make wide ranging and even conflicting observations. This is because many of them come to school with theories that are quite different from science, and hence cannot perceive observable phenomena as scientists do. For instance, they may misinterpret what they see through the microscope. They may draw obvious, but irrelevant features such as air bubbles. Children's drawings of onion cells viewed under a microscope, or of magnetic field patterns displayed by iron filings become very different once the child has been taught the theoretical background. It has to be ensured that they change their intuitive theories before they
can learn to observe scientific phenomena differently (Hodson 1986b:388; Mestre and Lockhead 1990:95).

Once again classification is cited as an example. Although children are able to classify things from their infancy, Miller (1991:49) contends that, without instruction, they would be quite incapable (as would most adults) of making scientific classification. For instance, they may classify a bat together with birds on the basis that both have wings. There is, therefore, a need to help children learn to appreciate the criteria which scientists use in classifying.

It must surely be acknowledged that the observational information falling on the child's sense organs is influenced by the knowledge he brings to the task. There is more to observing than meets the sense organs. There is always more information available to our senses than we can attend to. Even if we consider only the sense of sight, the visual field is so rich and detailed that we cannot simply observe everything. There is, therefore, a need to teach children the appropriate things to select for observation (Miller 1991:47).

The researcher, in this study, is convinced, from the science education literature (Albers 1988:12, Friedler et al 1990:186; Mossom 1989:204; Naik 1979:91; Solomon 1980:89) that observational and allied skills can (and need to) be developed. This, in essence means that it can be taught and learned.

7.3. APPROACHES IN DEVELOPING OBSERVATIONAL AND ALLIED SKILLS

Having adopted a view that observational and allied skills need to be developed, the next step is to explore ways in which this can be done. There are two main approaches in the development of
observation related skills; these are the process approach and the content or product approach.

7.3.1. The Process Approach

In a broad sense, the term process refers to human intellectual development. Processes, in this sense, are ways of processing information (Van Aswegen et al 1993:15). Human intellectual development, for example, is a cognitive process.

For purposes of this study, a process refers to the fact that the teaching of science should be in line with what scientists do. That is, gaining information by observing, classifying, predicting, etc. The process approach, therefore, utilizes the observational and allied skills as discussed in chapter 5.

The process approach implies that learners require formal instruction in order to develop observation related skills in general cognitive processes like observing and classifying (Esler and Esler 1981:67; Hacking 1983:167).

According to this approach, classroom activities can be designed to improve the observational process skills in general. This means that the knowledge gained in one activity, say observing or classifying, can be transferred to other contexts. A poor observer can be turned into a good observer across all observing tasks (Miller 1989:57). Developing observational and allied skills also means teaching children to be more observant, in the sense that they collect as much data as possible, even that which seems at the time to be irrelevant (Miller 1989:70).

7.3.1.1. Reappraisal of the Process Approach

Miller (1991:51) disagrees that the general cognitive processes can (and need to) be taught. The contention is that these are
the specific pieces of know-how about the selection and use of instruments, including measuring instruments, and about how to carry out standard procedures.

Miller (1991:50) argues that the general observational process skills are available in the child from an early age to the extent that it is difficult to avoid the conclusion that they are, in some sense, 'programmed in'. The task in which the infant must successfully use them are so demanding that it is difficult to argue that they need, in any sense, to be improved or developed.

Every moment and every object one observes, is slightly different from anything else one has encountered. People are extremely adept at classifying as early as their birth. For this reason, Miller (1991:49) argues that no one can sensibly claim that anyone needs to be taught to classify.

The researcher, in this study, cannot imagine how the general observational process skills can be, sort of, 'programmed in' to the extent that no formal instruction is required. The above contention by Miller is, therefore, not tenable. The researcher is convinced that the general observational process skills can (and need to) be taught. Miller (1991:49), himself, asserts that infants can learn to recognize and respond to the shape of the face. At the age of three, children can readily identify cats and dogs as distinct categories. Their facility in classifying is based on learned perceptions of similarity, acquired through socialization but dependent on a given propensity to classify.

The confusion at the heart of the process approach seems to be between means and ends. It is explicit in Harlen and Jelly (1989:40) and Miller (1991:50) that the processes are regarded as just the means of attaining the goals of science, and not the ends. The researcher disagrees with this contention. As
indicated earlier in this study (section 3.2.2.5. I.), the natural sciences curriculum should strike a balance between the products of science and the processes by means of which these products are generated. This means that developing observational process skills is not only a means of teaching and learning natural sciences, but also the end towards which all scientific endeavours should aim.

Pupils in preprimary schools should be taught various shapes, colours, sizes, etc. For instance, a child who is taught to recognize a green colour will always recognize it even if the shape changes. Science experiences for preschool and primary school children emphasize the development of the primary process skills and the children's perceptual skills.

Science educators should have no illusion that the process approach will be easy to implement. As indicated in Van Aswegen et al (1993:19), it requires a great deal of planning, organizing, and hard work.

7.3.2. The Content Approach

The content approach of developing observational and allied skills suggests that observation is influenced by the concepts and theoretical ideas or prior expectations of the observer. These theoretical ideas are a prerequisite for successful observation. The general observational process skills that are isolated from domain-specific knowledge will produce inefficient and probably unsuccessful results. Problem-solving requires knowledge not only of facts, but the way facts are represented and organized or the way the ideas are integrated (Friedler et al 1990:174; Gott and Welford 1987:226). Concepts, theoretical ideas, hypothesis or some kind of prior expectation will enable the development of relevant observation (Miller 1989:52). This approach ties up well with the theory of observation as adopted
earlier in this study (section 3.2.2.), namely that observation is theory-dependent.

The best way to develop observation related skills, therefore, is to equip pupils with the prevailing paradigm held in common by scientists (Hodson 1986b:386). In developing observational skills, reference should be made to the kind and purpose of observation, teachers should provide pupils with the relevant theoretical frame of reference (Miller 1991:48). This is done by emphasizing distinctive and discriminating features and categories, using examples, providing feedback on success, and so on. For instance, in teaching the skills of microscopy it may be sensible to display, in advance, slides of the features to be observed in order to provide a suitable frame of reference (Hodson 1986b:387).

This will equip the observer with certain expectations which will enable him to make relevant and appropriate observations. Such observations will have to be checked against reality. In this way children will be brought to the realization that objectivity does not consist in placing equal weight on all observations (Hodson 1986b:387).

There is an interesting paradox here: unless you know what to look for, you will not see anything, yet if you only look for what you expect you may miss the unexpected and theoretically significant, or may misinterpret it. Children may be taught this point by asking them to consider how we might design apparatus to detect certain entities: unless we speculate about their properties we cannot design instruments to detect them, but our instruments will only detect them if they have these properties (Hodson 1986b:387).

Developing observational and allied skills, therefore, is inseparable from teaching about the models and ideas of science.
It becomes part of the content teaching in science. It motivates and encourages learners to make use of their observational skills as a means of exploring and coming to an understanding of scientific ideas and concepts (Miller 1991:50).

The researcher, in this study, would like to warn that the process approach and the content approach should not be viewed as two independent or opposing approaches. Rather, they are like two sides of the same coin. They supplement and complement each other. One approach is not complete without the other. As indicated in Cavendish et al (1990:64), the natural sciences curriculum should strike a balance between the products of science and the processes by means of which these products are generated.

It is pleasing to note that the new curriculum for student-teachers as proposed by COTEP (1995:9) in South Africa also emphasizes the integration of the process and the product approaches.

7.3.3. The Role of Practical Activities in Developing Observational and Allied Skills

It is explicit in the literature study (Friedler et al 1990:173; Mestre and Lockhead 1990:30; Naik 1979:102; Solomon 1980:130) that the most important aim of practical work is to encourage the development of observation related skills.

Practical work is of paramount importance in teaching, inter alia, the processes of scientific inquiry - also called the experimental paradigm (Mestre and Lockhead 1990:28-30). It helps in the cultivation of such essential skills as observation, drawing conclusion, and controlling variables (Solomon 1980:130). It improves pupils' powers of observation by involving all the senses instead of only looking and seeing (Naik 1979:91). It offers opportunities to teach observation
related skills because learners can be actively engaged in problem solving while applying their content knowledge (Friedler et al 1990:173).

According to Naik (1979:92-93), frequent practical work could improve the ability to interpret observations in a logical way. Experiments can be designed to lend themselves in interpretation at varying levels of difficulty; e.g. from changes of state to changes of chemical structure.

7.3.4. The Role of Evaluation in the Development of Observational and Allied Skills

In section 1.1.1. in this study, it has been established beyond reasonable doubt that the development of skills related to observation is one of the most important instructional aims of the natural sciences syllabi. The most important question that has risen in this regard is whether learners are given the opportunity to develop their observational and allied skills. The literature study (Beveridge 1979:10; Buseri 1988:51-59; Jenkins and MacDonald 1989:6; Marek et al 1990:822; Sanders 1993:13) confirmed the researcher's experience that there is a lack of observation related skills development in the teaching and learning of natural sciences. This does not only apply to the South African education system, but throughout the world as well.

This lack of skills related to observation is caused by the fact that only knowledge related aims are normally addressed by many teachers. Aims which are skills- or attitude-related are largely ignored, especially in the senior standards. Teachers, understandably, feel that as the matriculation examination examines mainly the knowledge of facts, the best teaching methods are those which help pupils to learn the facts. There is little time left over to ensure that they actually understand the work in a meaningful way, or to teach and develop skills and
attitudes (Sanders 1993:14).

One ray of hope is emerging from the evaluation of learners. The Israelis have provided a wonderful illustration of how one barrier to curriculum innovation - the external matriculation examination can be turned into a secret weapon to implement and institutionalize the development of skills of observation (Tamir and Amir 1987:137).

Sanders (1993:13-15) has pointed out that evaluation has a stranglehold on what is taught and how it is taught. For this reason the external matriculation examination should be innovated to assess the learner's performance in science process skills. There should be emphasis of both theory and practical examinations to see whether pupils can use the skills they have been taught. The examination should be used to ensure that teachers DO teach these skills, that they do meaningful practical work, and that they use a pupil-oriented inquiry approach.

In South Africa there is a strong feeling by some science educators (Sanders 1993:15) that examinations should be more skills-oriented and that they should assess what pupils are able to do, not what facts they can remember. On the same vein, COTE (1995:7) states that teacher education should result in the student being able to demonstrate the ability to apply various forms of knowledge. The aims for education should, therefore, be evaluated according to certain prescribed competences.

A Biology User Group (BUG) has been started so that teachers can meet more often to discuss and debate various issues, to plan and develop curriculum materials and to design appropriate test questions. Workshops are being run to assist teachers with the process of teaching skills rather than just facts (Sanders 1993:15).
7.3.5. The Role of the Computer in Developing Observational and Allied Skills

The development of new information technologies in the form of personal computers and their consistent incorporation into the educational system is seen by some authors (Dewhurst, Brown and Meehan 1988:19; Friedler et al 1990:173) as contributing to the development of skills of observation.

Friedler et al (1990:174) maintain that computers can help students reshape their original hypotheses, and display new results. It reduces the workload for students. Word processing and graphing tools relieve students of the need to focus on technical details and permit them to concentrate on the problems at hand.

Using the computer as a tool to collect experimental data might, in the opinion of Friedler et al (1990:175), reduce the burden on students' working memory and enable them to observe more carefully. The feedback provided by the computer limits the students' search space, and thus facilitates their ability to predict more accurately. Since the computer can simulate the collection of data automatically, students can direct their attention to predicting what will happen next, to detailed observation of the experiment, or to other activities.

Dewhurst et al (1988:20) are emphatic that computer simulation programs have the potential of teaching, among others, making accurate measurements and the basics of using equipment.

The arguments as advanced by the two sources above are not convincing. As indicated by Van Aswegen et al (1993:180), computer simulations cannot be regarded as practical alternatives of developing observation related skills. If the description of observation as the ability to use the five senses
is correct, (the researcher believes it is!), most certainly the computer can at best only develop the sense of sight, and probably that of hearing. Such 'observational skills' developed in this way will be theoretical because the learner has not been there in the act. A simulated experiment does not give the same experience as the actual experiment. It remains cognitive. Perhaps the arguments as advanced by Dewhurst et al could be credited if they admit that the resulting skills are a cognitive version of the science process skills, and not a psychomotor version, or observational skills per se.

7.3.6. The Role of the Teacher in Developing Observational and Allied Skills

Teachers are responsible for developing the minds of budding scientists (Cavendish et al 1990:64; Pugh and Dukes-Bevans 1987:19). The teacher could have a particular focus in terms of helping the development of one or two chosen skills, while the children are using several of the other skills in their activities.

In developing observation related skills, Scott et al (1987:16) assert that the role of the teacher is modified. No longer does the teacher play the part of 'purveyor of knowledge'. The teacher's role becomes one of diagnostician, prescriber of appropriate observation related activities and facilitator of learning. As a 'diagnostician' and 'prescriber of activities', the teacher is basically setting up an activity, taking note of how pupils respond to it and then prescribing the next activity in terms of that particular pupil's response. The dynamic nature of the situation is an inevitable consequence of the way pupils learn. Initially, a teacher may feel more exposed in this new role and less 'in control' of events.

7.3.7. General Guidelines on Teaching Strategies for Developing Observational and Allied Skills
Probably no aspect of science has been more difficult to teach than the skills of careful observation. The need to develop observation related skills has, according to Mestre and Lockhead (1990:64), become so important, and, paradoxically, so neglected to the extent that the aims which are set in most syllabii are not realized.

The literature study (Esler and Esler 1981:62-64; Gott and Welford 1987:219-226; Neuman 1978:31-40) has shown that there are a number of tasks that are generated to develop observational and allied skills. These are variously called formal sciencing (Neuman 1978:31) or science experiences (Esler and Esler 1981:62).

7.3.7.1. Activities for Developing Observational Skills per se

Having adopted both the content and process approaches of developing observational and allied skills, observing can be encouraged within the context of normal science activities.

There should be science activities which are aimed at developing the five senses of taste, smell, touch, sight and hearing. Sometimes the emphasis should be placed on all the senses, at other times the focus should be on one sense (Observing Activities 1990:64).

Other science activities should be aimed at asking for similarities and differences, encouraging comparisons and replication. Gott and Welford (1987:219) and Neuman (1978:32) have pointed out that learners should be given the opportunity of learning to compare different types of matter to find their similarities and differences. They should learn to classify things or events and identify variables and/or relationships between variables. A child's idea of what is similar and what is
different can grow in an atmosphere of freedom. Learners should study substances as they undergo change; e.g. mixtures.

If a child believes that two objects are alike in some way and can justify this feeling, Neuman (1978:31) suggests that the child's interpretation must be accepted. It is not the adult's expected answer, but the child's ideas that becomes important. The researcher contends that the adult should not dwell in the child's ideas, rather, he should work from there to develop the more accepted scientific ideas.

As indicated in Gott and Welford (1987:219), the natural sciences curriculum should aim at developing the ability to observe phenomena or events. There should be activities to develop the ability to describe change in scientific phenomena. They must learn to recognize basic characteristics of matter such as common solids, liquids and gases. These are called properties. Some properties of matter include temperature, colour, texture, size, bounciness, viscosity, shininess and smell. Neuman (1978:31) maintains that the ability to examine matter in order to identify its properties is basic to additional learning and discovery.

Developing an observing skill also requires training in muscular co-ordination (motor skills). Motor skills are developed through a combination of observation, imitation, trial-and-error and reflective thinking (Thurber and Collette 1959:62).

Motor skills are developed most easily through project work. The completion of the projects represents the objectives for the pupils. They master the skill in order to attain their objectives. Thus the teacher's general goals are attained (Thurber and Collette 1959:63).

Neuman (1978:37) pointed out that secondary school children
should be given opportunities to perform practical activities involving, among others, the following:

* handling of chemicals, for instance, preparation of chemical solutions
* assembling apparatus such as the potometer
* preparing of microscopic sections
* using dissection instruments
* calibration of thermometer, balance, timer, etc.
* using instruments like microscopes, potometers, etc.

Burkinshaw (1987:24) indicates that all these activities do improve children's performance tremendously over the range of observing tasks set. During these learning activities children develop their observational process skills using their five senses and begin to form concepts of nature and relationships of the world around them.

According to Neuman (1978:37) and Esler and Esler (1981:62), the right kind of class climate is created when children can investigate freely and manipulate the materials in ways that make sense to them. No one should tell them what to do or how to do it. They will have to find out for themselves.

The researcher in this study believes that this will create some problems where there is a syllabus to complete. Some learners may be engaged in activities that are beyond the scope of the syllabus. It may even be difficult or impossible to assess pupils' performance because the teacher will not be aware of what made sense to individual pupils. It is recommended that teachers should guide pupils on what to do with science equipment.
Esler and Esler (1981:62-63) indicated that primary school pupils should be given opportunities to manipulate science related apparatus. Examples are simple materials in basic electricity such as a battery, a socket, a bulb and wires. A child can build a simple circuit and make light go on. Children enjoy testing materials to see if objects are attracted by a magnet. Secondary school pupils could be given hand lenses and microscopes to manipulate. Match boxes connected with a wire produce sound waves that are transmitted by means of the wire.

A large plastic bowl half-filled with water, and a number of smaller containers of various sizes and shapes can provide a group of pre-school children with experiences that will aid in their development in several ways. As the children pour water from container to container, their observations will enhance the growth of Piagetian conservation skills related to volume (Esler and Esler 1981:62). Children can observe that certain objects float in water while others sink (Neuman 1978:39).

Coloured beads and a shoelace provide a pre-school teacher with opportunities for developing several skill areas. Children learn to recognize colours, shapes and sizes of the beads as they place them on a shoe string at the direction of the teacher. They also learn to form sequencing patterns.

Sets of geometric shapes in a variety of colours cut from construction paper permit children a number of experiences that are beneficial to their perceptual and skill development.

By placing unknown objects in large socks and asking children to describe and attempt to identify the objects, teachers help children develop their tactile senses. As they handle the unknown objects children learn words to describe what they feel; such as smooth, rough, hard, soft, etc.
Teachers of pre-school and primary school children collect edible and or aromatic materials, blindfold a child and ask him to identify the substance that he tastes or smells. Such aromatic materials may be placed in different socks for children to identify.

Esler and Esler (1981:23-24) list several crucial activities in the development of children's observation related skills during the preoperations stage (about two to seven years) of child development. These are activities on the conservation of substance, conservation of number, serial ordering and one-to-one correspondence.

As for the activities on the conservation of substance, children should be shown two balls of modeling clay of the same size. They should be asked whether the two balls contain the same amount of clay and whether they contain the same amount of stuff. One ball can then be shaped into, say, a hotdog. The same questions as before may be asked. The child should be requested to give a reason for each answer that is provided.

Activities on the conservation of number may be encouraged by allowing children to play with a pile of beans. Let two children of about five to six years old remove one bean in turns. Let them continue removing beans in this way until the pile is finished. Let one child places his beans in a tall thin jar while the other child places his beans in a short wide jar. Ask the children whether the number of beans in each jar is the same. They should be asked to give reasons of their answers.

The ability to make serial ordering may be developed by giving a child six sticks of different lengths. He could be asked to put the sticks in order from the shortest to the longest. After completion, he should be handed with three additional sticks
that are different in length than any of the original sticks. He should be asked to put the three sticks into the proper positions in the ordered set.

The ability to make a one-to-one correspondence may be developed from a pile of chips. Let two children remove one chip in turns until the chips are finished. Each time a child removes a chip he places it besides the other child's chip in a row in such a way that one row for each child is formed. When both rows contain ten chips the child should be asked if the two rows contain the same number of chips. Spread apart the chips in one row so that the row becomes longer. The same question as before could be asked, children should give reasons for their answer.

Notwithstanding the arguments that have been raised against the How well do you observe activity (See section 2.3.5.), the researcher is of the opinion that the activity should still be used. Jaus (1985:30-31) asserts that observing, the most notable of the observational process skills, is enhanced and amplified in the following activities for learners:

* Have learners orally describe their teacher's appearance without looking at him.

* Having the learners record their observations of a person who runs into their room, take something off their desk, and runs out again.

* Having the students write descriptions of their mother's appearance, etc.

* Changing the classroom around and having the learners note the changes.

Other observational activities as listed by Esler and Esler (1981:23-24) are:

* Structured questions on workcards or multiple choice sheets about practical activities supplemented by teacher interaction with responses sometimes tape recorded.

* Circus of experiments around one theme, children report back to the rest of the class and answer questions.
7.3.7.2. Developing the Inferring Skill

It has been noted from the previous chapters that there are various ways in which an inference is described. In section 2.3.3, it has been described as a construction of meaning from observed material. In section 3.2.6, it has been described as the assumed background knowledge or a conclusion based on past observations and reasoning. An inference, therefore, is inextricably linked to observation.

Developing an inferring skill, therefore, depends essentially on the provision of observations or data for children to interpret. Cavendish et al (1990:64-65) suggests the following:

* Helping primary school children come up with patterns; giving them chance and intervening if they do not.

* Providing material for observation suitable for data gathering with a view to graphic representation.

* For senior primary children, measuring certain features, drawing simple graphs and looking for trends in class-based work; for junior primary children - working in smaller groups with more discussion, more recording.

* Finding their own evidence or using data from a newspaper.

* Teachers should insist that primary school children should differentiate between observation and inferences.

As indicated earlier in section 2.3.3, and 3.2.6, and Appendix A(i) the Candle activity should still be taught to develop an inferring skill.

7.3.7.3. Developing the Measuring Skill

The best way to develop a measuring skill is to plan science activities which require learners to make use of measuring
instruments. According to Solomon (1980:131) measuring is a skill requiring graded exercises. It should start with simple instruments such as the ruler, thermometer, weighing machine, stop watch, etc., and gradually increase to more complex ones. The accuracy of measurement made with these tools continues for many years to be a function of the pupil's growing skill.

A child who has developed skills in using measurement will plan to measure something which is measurable with the equipment and instruments available (Cavendish et al 1990:27).

Recording is a technique that is common in both the measuring and communicating skills. Pupils should be taught to record their observations at the end of the investigatory activity, provided the activity is a simple or short one. But as activities become more extended, and particularly when they involve measurements, recording only at the end and relying only on memory is not adequate. They have to be encouraged to keep records while the work is in progress (Cavendish et al 1990:28).

Activities in which learners are required to follow a work card have a negative influence on the development of recording skill. Learners should be given opportunities to design their own tables, represent their data on graphs, charts, flow diagrams, etc. Following directions to use them is not the same as choosing to use them in appropriate circumstances (Observing Activities 1990:28).

Another aspect of measurement as a skill is deciding the range over which measurement ought to be taken. Measurement involves taking steps to be reasonably sure of each measurement, by checking and repeating it and deciding what to do if it is not the same each time. Pupils do not often do this spontaneously. It is an important experience basic to understanding that
measurements are always uncertain to some degree (Observing Activities 1990:27).

7.3.7.4. Developing the Classifying Skill

In developing the classifying skill, Miller (1989:54) advises that two somewhat different, though, related things should be taught. Primary school children should be taught something of the conventional scientific classification. They should be encouraged to make some aspects of the intuitive process of classifying explicit, by articulating the criteria on which their particular classifications are based. In so doing, it is demonstrated that unlike the propensity to classify, the actual classifications that are used are conventional, and dependent on the purposes in mind.

Scientific classification involves learning the particular classifications which scientists employ and which are established as productive for pursuing scientific ends. An activity in the science classroom involving classifying, or pattern seeking is inextricably linked to a basis of knowledge and commitments (purposes). Whatever we may think, it is these that should be taught (Miller 1989:54).

The skill of classifying can be developed, for example, by displaying a collection of plant parts such as stems, leaves, flowers, fruit and nuts. Primary school children could be instructed to put all of the stems in one place, all of the leaves in another, etc. A primary school pupil could be asked to explain what was done. The idea that one can put things that are alike in some way into a group should be stressed. Using a similar collection of plants, children could be told to put all of the items that are alike in one pile. Then let them sort the remaining items. Primary school children should decide for
themselves how to sort the remaining items. After they have sorted the collection always ask them why they chose to divide them in that way (Pugh and Dukes-Bevans 1987:20).

The above skills in visual discrimination could be repeated using the following insects: flies, butterflies, beatles, wasps, bees, spiders, lice, locust, cockroaches and mosquitoes.

7.3.7.5. Developing the Communicating Skill

Children develop communicative skills when they are asked to describe objects and events in detail. A child's description should be complete enough to enable a second child to identify the object. Communicative skills are also enhanced by having groups of students compile data from an experiment into tables or graphs and report their findings to the rest of class (Esler and Esler 1981:59).

Discussion is a vital part of the developing of skills and ideas further. For such accounts to serve as useful communication they will recount events in a sequence, give the important, not trivial, details and take account of what the audience knows about the work. Communicating observational experiences improves the child's language skills. Children associate visual symbols with things and ideas at an early age. They often find visual symbols the easiest to recognize, so the sense of sight is a logical one to begin with (Albers 1988:12).

Recording is a form of communicating. Flow charts can show changes that take place in plants. These could be stages of growth, etc. Children should be encouraged to chart as many science activities as appropriate. Bar graphs can be used as a follow-up to many of the activities described. When first using graphs, begin with two or three categories. Add up to five categories with primary children. Also begin with real objects
placed on a grid, then use pictures to represent the objects. Other kinds of communications are by means of models, tables, words (written or spoken), drawings, graphs (Pugh and Dukes-Bevans 1987:21).

7.3.7.6. Developing the Skill of Operational Definition

The development of young children's scientific thinking is helped by asking a particular kind of question which can be answered by the child's own inquiry. Development of the skill shows in the ability to express questions in more precise terms such that the information required is clear, and eventually, such that the kind of investigation required to obtain it is also specified. When expressed as "Does sugar dissolve more quickly in tea when it is stirred?", it is investigable. A further step is to express it as, "Does sugar dissolve more quickly in stirred tea than in tea which is not stirred?" Here not only is the variable to be observed (the speed of dissolving) specified, but the variable to be changed (the stirring) is made explicit (Cavendish et al 1990:24).

7.3.7.7. Developing the Hypothesizing Skill

Hypothesizing could be initiated from practical work rather than from teacher questions. This could begin with a very stimulating demonstration in which children should be encouraged to think about reasons for unexpected results. The teacher could also initiate hypothesizing by brainstorming at the beginning of a topic to find what questions the children have about it (Cavendish et al 1990:29).
Chapter seven has revealed that a pupil, without instruction, is not capable of making scientific observation. This necessitates the development of his sensing capabilities and the inculcation of the relevant theoretical paradigm.

The process approach of developing observational and allied skills involves a formal instruction to develop cognitive processes like observing and classifying.

The contention that the general observational process skills are sort of 'programmed in' to the extent that no instruction is necessary has been found to be untenable. On the contrary, the researcher, in this study, asserts that the general observational process skills can be taught.

Developing skills related to observation is not only a means of teaching and learning, but it is also the end towards which all scientific endeavours should aim.

As for the content approach, an assimilated body of knowledge is a prerequisite for successful observation. In this method the best way to develop observational and allied skills is to equip learners with the prevailing paradigm held in common by scientists.

In order to effectively develop observational and allied skills, the process approach should be used in conjunction with the content approach.

Observation related skills are enhanced by practical activities,
evaluating them in examinations, the use of the computer and the availability of the teacher to give guidance. They are also improved when describing science experiences and using scientific equipment frequently. Generally, all skills allied to observation can be encouraged within the context of normal scientific activities.
8. TEST DESIGN AND STRATEGIES
FOR ASSESSING OBSERVATIONAL
AND ALLIED SKILLS
8.1. ORIENTATION

The problem that is being investigated in this study is the conceived lack of observational and allied skills in the teaching and learning of natural sciences. This problem has been stated and described in the first part of chapter one and is briefly restated in the first part of chapter eight.

This chapter examines some fundamental ideas about methods of classroom assessment. Two most important classroom assessment methods; observation and testing are discussed and reappraised. The twelve observational and allied skills as discussed in chapter five are now used as criteria for constructing a test instrument. There is also a discussion of each item that is constructed.

Although the actual data resulting from the test instrument are analysed in chapter nine, the strategies which are applied are discussed in chapter eight. The reliability, validity and usability of the test instrument is also discussed here.
8.2. REVIEW OF THE PROBLEM

The problem that has triggered this study is the conceived lack of observational and allied skills in the teaching and learning of natural sciences. The following questions have been raised in the last paragraph of section 1.1.1 and section 1.2 to precede the statement of the hypotheses:

i. Are observational and allied skills intuitive or can they be developed?

ii. How should one go about developing observational and allied skills in the teaching of natural sciences?

iii. Can the teaching and learning of natural sciences in secondary schools contribute to the development of observational and allied skills?

vi. Can observational and allied skills be assessed?

The hypotheses as stated in chapter 1 are restated below:

Hypothesis 1: Observational and allied skills can be developed.

Hypothesis 2: The teaching and learning of natural sciences can contribute to the development of observational and allied skills.

Hypothesis 3: Observational and allied skills can be assessed.

As argued throughout the literature study, the teaching and learning of natural sciences can contribute to the development of observational and allied skills. It has also been established that observational and allied skills can be assessed.

The main concern of chapter eight, therefore, is to search for the method which is applicable in the empirical testing of hypotheses 1 and 2. These two hypotheses are now condensed into
a single hypothesis. In order to provide what is regarded in Best (1981:271) as a stronger test of logic this hypothesis is restated negatively as a null hypotheses ($H^*$). It is stated thus:

"There is no significant difference between the mean scores of students before and after developing the twelve observational and allied skills as listed in Table 5.1."

Any apparent difference that may be observed is simply the result of sampling error or chance. This hypothesis implies that teaching has no contribution to the development of observational and allied skills. An alternative hypothesis ($H_1$) may be posse against the null hypothesis thus:

"The mean scores of students after developing the twelve observational and allied skills in Table 5.1. are significantly higher than those before".

This means that the difference that is observed is too large to attribute to sampling error or chance. The implication is that the teaching and learning of natural sciences does contribute to the development of observational and allied skills.

The empirical research explores the methods of collecting data about observational and allied skills in a group of learners. Data are collected before and after instruction in science process skills. Certain applicable statistical techniques are used to put the researcher in a position to reject the null hypothesis and, by implication to accept the alternative hypothesis.
8.3. METHODS OF ASSESSING OBSERVATIONAL AND ALLIED SKILLS AMONG LEARNERS

There are three different techniques for assessing the classroom teaching-learning objectives. These are (i) laboratory reports, (ii) observation and (iii) testing. Observational and allied skills may also be assessed using these techniques.

For purposes of this current study, laboratory reports will not be suitable. This is because if available, the reports have information which is very difficult to quantify. This leaves us with two important assessment methods which may be applied in this current study. These are observation and testing, both of which are discussed in the sections that follow.

8.3.1. Observational Methods

An observational technique is a method of assessing classroom learning goals as they occur naturally (Seifert 1983:363). For instance, the correct lighting of a bunsen burner, setting and focusing of a microscope. To gather appropriate evidence about such skills and performances, Airasian (1991:252) asserts that one should observe and judge each pupil's actual performance or some product thereof. Observational technique underlies all the methods used by scientists in their gathering of data (Chadwick et al 1984:73). This method requires that pupils be put in a situation where they can show how well they can perform a given science process skill.

Observation, (or performance assessment, to borrow Airasian's 1991:252 terminology), is clearly the most basic method for obtaining information about the world around us. Most certainly, it is the best method for assessing observational and allied skills in this study because it offers some clear advantage over other methods.
In the traditional classroom, a pupils' ability to write down a list of steps to conduct an experiment was always regarded by a number of teachers as the best way to assess the pupil. Unfortunately, knowing how to do something and actually being able to do it are two different issues. Rather than asking pupils how they would focus a microscope, it is best to observe them actually focusing a microscope. The distinction between being able to describe how a skill should be performed and actually being able to perform it is an important one in assessment. Just because they can write down a list of the steps they would follow to conduct an experiment does not mean that, given appropriate apparatus and materials they could actually conduct it or prepare it.

According to Airasian (1991:255, 264 & 265), observation, as a means of assessment should be seen as having the following distinguishing characteristics. It should:

* ask pupils to demonstrate a given skill.
* specify the actual skill to be demonstrated in advance.
* be rated according to an identified standard of adequacy.
* have a clear purpose which identifies the decision to be made from the performance assessment.
* identify observable aspects of the performance that will be observed and judged.
* provide an exercise or setting for eliciting the performance. For instance, in a performance assessment to determine pupils' skill in setting and focusing a microscope, one would have to create a situation in which there were microscopes, slides, and a plan that allowed the pupils to be observed while performing the behaviour.
* have a pre-determined scoring or rating procedures. Scores are based on the performance criteria, these are specific behaviours a pupil should perform to carry out an activity properly. They are important in the performance because that is what the observer looks for, and consequently, what the scores should describe.
The teacher can either observe targeted behaviours as they naturally occur in the classroom or arrange a specific exercise or situation under more controlled conditions (Airasian 1991:275). However, the following section highlights several disadvantages of the observational methods.

8.3.1.1. Disadvantages of Observational Methods

In a research like this current one, the following disadvantages as listed in Airasian (1991:260, 262) are almost prohibitive in using this method:

(a) One most important disadvantage of observational method is that it is a time-consuming process. It takes so much time to carry out an observation of each student doing some task or performing some activity. Also see Seifert (1983:364).

(b) Other difficulties in conducting good performance assessments is the need to identify the characteristics of a good and bad performance before assessing.

(c) Also, a variety of problems can result from the observation and rating process itself, including subjectivity of rating, shifting performance criteria, and obtaining an inadequate sample of pupil performance.

Other disadvantages are listed in Chadwick et al (1984:76-77) as follows:

(d) Notwithstanding mechanical devices such as video cameras and recorders, the basic tools for data collection in observation are the fallible and often inadequate sense organs. For one thing, what we see and what we hear are influenced by our mental and physical states. Observer fatigue and boredom are critical factors in an observational
method. After observing something for a time, people may begin to miss fine details, count inaccurately, or overlooking important changes in the nature of the interaction. More serious, however, is that because of the limits of the sense organs, observers may literally not see or hear what goes on, or may misinterpret what is observed. Only part of the situation may be visible or audible to the observer at a given time. Often, the behaviour that the performance assessment tries to capture is fleeting and difficult to discern and observe.

(e) Selective perception is often a problem. Even the best trained researcher may produce biased data because of selective perception. People tend to sense certain phenomena more than others. This has a risk that something else that is also happening may be missed. People tend to perceive those phenomena that carry meaning from their own point of reference. A dramatic event may distract attention from something that actually has more theoretical relevance to the research objective. Also see Walklin (1991:153).

(f) Our senses are poor instruments for making comparisons because they adjust to conditions. A characteristic that initially seems very important may fail to retain our attention as it becomes commonplace. If the observer is emotional, he loses objectivity and may react in anger instead of recording. He seeks prestige or ego satisfaction within the group, rather than observing this behaviour in others. He sympathizes with tragedy and may not record its impact upon his fellow members. Moreover, as he learns the correct modes of behaviour, he takes them so much for granted that they seem perfectly natural. As a consequence, he frequently will fail to note these details.

(g) Our senses do not operate independent of our past
experiences. Consequently, both what we observe and interpret are influenced by what we have previously seen, heard, felt and done. A person sensitized by past experience to certain types of exchanges will see those things to which he may be sensitized, while the same events may be completely missed by someone from a different background having a different set of sensitivities.

(h) The very process of observation may influence the phenomenon that is being observed because human subjects often behave differently when they are under observation.

(i) Finally, Frith and Macintosh (1984:100) maintain that the setting of practical exercises as written questions which require practical rather than written responses has a major disadvantage of artificiality.

Because of these problems, the discussion of observational procedures and observational instruments do not warrant any further attention in this study.

8.3.2. Testing Methods

According to Airasian (1991:12), testing techniques refer to assessment methods in which pupils write down their responses to questions or problems. It does not matter whether students use pencil, pen, crayon, or markers to record their answers. Drawing a picture also belongs to this technique.

Gage and Berliner (1988:569-570) describe a test as a systematic procedure for measuring a sample of a person's behaviour in order to evaluate that behaviour against standard norms. It is a method of obtaining trustworthy estimates of achievement. A Test should be seen as complementing rather than substituting observation (Also see Hargreaves 1990:87-88). They are the
primary methods for gathering classroom assessment data (Airasian 1991:14). Tests are themselves observations of behaviour that are more efficient, more refined, and less biased than other ways of observing.

Tests can be classified into two types according to their use. When tests are used to compare one student with another, they are called norm-referenced tests. But when they are used to compare each student according to an absolute standard, they are called criterion-referenced tests (Airasian 1991:321; Gage and Berliner 1988:572 574; Seifert 1983:368). The criterion-referenced tests are much more suitable for purposes of this current study.

Tests can further be classified into standardized and unstandardized according to the assessment procedure. Standardized refers to the extent to which an assessment procedure is administered, scored and interpreted in the same way for different test takers at different times and different places (Airasian 1991:15). Most standardized tests are constructed by organizations outside the local educational institutions in consultation with test specialists, curriculum experts and teachers.

The unstandardized or teacher-made tests are constructed for personal use and reflect the particular instruction provided in a given classroom. Essentially, teacher-made assessment instruments are intended for one-time use with a single group of learners at a single point in time (Airasian 1991:16).

Due to the complexity of assessment procedures in a standardized test, the researcher in this study opts for the unstandardized, criterion-referenced test.

One single disadvantage of written tests alone as indicated in
Seifert (1983:363) is that they are unable to assess learning goals as they occur naturally. For instance, they are unable to assess a learner's ability to correctly light a bunsen burner. Written tests alone are unable to assess the psychomotor skills of setting up and focusing a microscope. Thus written tests alone are appropriate only for certain aspects of attainment.

In this study, the researcher has counterbalanced this disadvantage by setting up a test instrument (see Appendix C) which requires learners to respond in practical terms by doing something. As indicated in Frith and Macintosh (1984:98), a response ought to be made to depend upon the correct completion of relevant practical work. Thus testing in this study does not precludes practical activity. If a response, given in writing is correct, the researcher agrees with Seifert's (1983:363) assumption that the learner must have followed the correct processes to get it.

The contention in Airasian (1991:253) that one has little direct evidence for this is challenged by the fact that at least the answer, if correct, is part of the evidence. For instance, if a learner has given a correct written identification of a specimen under a microscope, it can be assumed that he can set up and focus the microscope. In this case the possibility of cribbling will have to be minimised.

For a number of reasons, tests remain the most popular form of classroom evaluation. From a study of literature (Airasian 1991:17; Gage and Berliner 1988:569-570; Hargreaves 1990:87; Seifert 1983:357 and 368), a synopsis of these reasons may be listed as follows:

(a) Reliability is illustrated more with formal tests than with informal methods of evaluation. In this study the coefficient of reliability of the test instrument in
Appendix C after development of observational and allied skills was 0.83, a relatively high reliability (see section 9.2.3.2.).

(b) Tests are also easier to summarize and interpret than most other kinds of observations. One reason for the popularity of tests is that they give us a quantitative estimate of ability or achievement; they tell us how much.

(c) Tests are more efficient to administer than observations. In the same amount of time it takes to gather information from one student in observations, tests gather information about the whole class. For many objectives, tests yield comparatively small amounts of effort by the teacher.

(d) A distinct advantage of tests is that they provide standard experiences to which all students, individually, must respond. Tests permit many pupils to work simultaneously on a task. This is a relatively fair way to judge student learning.

All the advantages above serve to overshadow the single disadvantage as discussed.

The researcher in this study agrees with Hargreaves (1990:87) and Seifert (1983:363) that in an ideal situation, observational and testing methods would have to complement each other in assessing learning objectives. Since such a thorough investigation is impractical in a study like this current one, the researcher is obliged to compromise this ideal by giving written tests alone. This compromise probably reduces the reliability and validity of assessment in the interest of a big advantage in practicality. After all, learners must be evaluated with the resources actually at the disposal of the evaluator at a given moment in time. However, the fact that the test
instrument in Appendix C requires learners to respond in practical terms by doing something is an added advantage that counterbalances the lack of an observational method.

8.3.2.1. Construction of a Test Instrument

A test instrument is no better than its constituent items. What follows is the description of test items as constructed by the researcher. See Appendix C for the complete test instrument.

I. The Observing skill:

Observing as defined previously in section 5.2.1.1. means using the senses to gather information about an object or event. Before a student can actually use the senses, he must understand the concept of observation. Test items 1 and 2 are aimed at testing the student's understanding of the concept of observation. With these two items, it is assumed that if a student understands the concept of observation, he will be able to observe using the appropriate senses. A student who has no understanding of this concept is likely to use his eyes only.

Observing also means the ability to aid the senses by means of instruments. The ability to observe using a microscope is being assessed in items 3 and 4. This involves the psychomotor skills of preparing a wet mount and of focusing the microscope. The skills of comparing and selecting also come into play. Scoring on the actual performance is difficult. It is assumed that if the learner can identify the microscopic organism, he has been able to prepare a wet mount and focus it under a microscope.

The following materials are provided for item 3: glass slide, cover slip, dissecting needle, filter paper, medicine dropper, paper towel, petri dish with hibiscus pollen grains in distilled water. The same materials are provided for item 4, however,
hibiscus pollen grains are replaced by maize pollen grains. This station is manned by the teacher or researcher.

Item 5 assesses the students' ability to observe through the ears (auditory observation), thus the bursting of the grain which is followed by a popping sound.

Item 6 assesses the students' ability to observe through the tongue (taste) and nose (smell). In this case the visual observation as well as the ability to use the tactile senses are taken for granted.

Items 7 and 8 assess the students' ability to observe simple test tube reactions involving single stimulus. In test tube A is a dilute hydrochloric acid solution whereas in B there is sodium hydroxide solution. Each student is expected to observe:

* **haptic change** - change in the temperature of a solution (this can be observed through touch).

* **visual changes** - effervescence of gas from a solution (to have balls of gas forming inside), precipitation of a solid from solution, redissolution of a precipitate and dissolution of a solid in a solvent.

The reader will have noticed that there are eight items for assessing the observing skill per se. There are only two items for assessing each of the other related (allied) skills (8.3.2.1. II to XII). This is because the ability to observe has been described in section 5.2.1.1. as the most basic of all the science process skills. It is essential for the execution and development of the other science process skills.
II. The Measuring skill:

Measuring, as described in section 5.2.1.2, is a precise kind of observation. This involves the use of both standard and non-standard measures or estimates to describe the dimensions of an object or event. Test items 9 and 10 are designed to assess the skill of using a triple beam balance and measuring cylinder to determine the mass and volume of substances respectively.

III. The Inferring skill:

To infer is to make an educated guess about an object or event based on previously gathered information. Item 11 is aimed at testing the students' ability to give an inference based on observed facts. If drops of iodine solution are added to an unknown substance (in this case, starch solution), a blue-black colour will be observed. From this observation a student should be able to make an inference that the unknown substance in the test tube is starch. This test item also assesses the students' ability to distinguish an observation (blue-black colour) from an inference (starch).

Test item 12 is also intended to test the students' ability to make an inference based on observed facts. In this case the observed facts consist of two drawings; an adult kangaroo and its skull showing the side view. From these observed facts a student is expected to make an inference that the kangaroo is a herbivore. The structure of the skull and the teeth are supposed to provide enough information that will enable the student to make a correct inference.

IV. The Classifying skill:

Classifying is the ability to group or order objects or events into categories based on certain properties or criteria. This
ability is assessed through items 13 and 14. The items also test the students' knowledge of the structure of insects. Without this knowledge of insect features, a student will not be able to make a scientific classification of the insects.

V. The Predicting skill:

To predict is to state the outcome of a future event based on a pattern of evidence. In this case this pattern of evidence is observation. Items 15 and 16 assess the skill of making a prediction on the movement of water molecules across a selectively permeable membrane. If a student does not understand the phenomenon of osmosis he will not be able to make the correct prediction from the experimental set-up.

VI. The Communicating skill:

Communicating has to do with the use of words or graphic symbols to describe an action, object or event. Items 17 and 18 are intended to test the students' ability to communicate by means of graphs. A student has to study the raw scores that are provided. Using these raw scores he should be able to make a graphical representation of the data on a piece of paper or even in his mind. If a student makes the correct choice, this means that he had been able to make the correct pictures of all the graphs.

VII. The skill of Making Operational Definition:

To make an operational definition means stating how to measure a variable in an experiment. In items 19 and 20 an apparatus set-up to investigate the effect of light stimulus on the direction of growth of stem tips is provided. In this case light is the variable which is under the control of the experimenter. A
student should be able to indicate how this light stimulus can be controlled.

VIII. The skill of Formulating a Hypothesis:

Formulating a hypothesis has to do with the stating of the expected outcome of an experiment. Items 21 and 22 have been adopted from Tamir and Glassman (1971), see Doran (1980:83). In item 21 a student has to observe the experimental set-up in which there are three sets of Elodea plants each of which receives a different light intensity. A student who is able to formulate the problem under investigation is the one who can give the hypothesis of the experiment. This is because the formulated problem contains a hypothesis that light is necessary for photosynthesis.

In test item 22 an apparatus set-up to investigate alcoholic fermentation (anaerobic respiration) is provided. By observing the air bubbles that are released occasionally, a student should be able to formulate the aim of the experiment. The aim, if formulated correctly contains a hypothesis that the mixing of sugar solution and yeast cells always results in alcoholic fermentation. Another possible question in this experimental set-up could require a student to give an explanation why liquid paraffin was added. Any response which indicates that liquid paraffin prevents evaporation contains a hypothesis that water can be lost through the process of evaporation.

IX. The skill of Controlling and Manipulating of Variables:

The identification and controlling of variables that can affect an experimental outcome is the most important aspect in scientific investigations.
In order to assess the above skills, students are first given instruction to study a passage which is describing an experiment. From the passage, students are expected to give answers to items 23, 24, 25 and 26. As such these items are not based on a hands-on activity, but rather on what De Beer (1996:35) refers to as the mind experiment. Items 23 and 24 require a student to identify a dependent and independent variable respectively.

X. The Experimenting skill:

As indicated in section 5.2.2.5, experimenting is the most sophisticated kind of skill incorporating all the other science process skills as discussed in this study (also see the summary of all the observational and allied skills in Table 5.1.). Experimenting has to do with the following: asking appropriate questions, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing a "fair" experiment, conducting the experiment and interpreting the results of the experiment.

Any student who performs well in items 25 and 26 is deemed to have mastered all the science process skills.

XI. The Interpreting skill:

Students are instructed to examine a dissected model of the heart that is provided before answering questions. Item 27 require students to give the significance of the difference in thickness between the ventricular and atrial walls. Item 28 require the student to give the significance of the difference in thickness between the right and left ventricular walls.

Students who perform well in these two items have the ability to interprete the significance of form to function.
XII. The skill of Constructing and using Models:

To construct a model is to create a mental or physical structure of an object, process or event. In item 29 students are instructed to construct a double helix model to represent the structure of a DNA model. A student who constructs a correct structure means that he has the correct concept of the structure of a DNA model.

However, a student who produces a correct structure of the methane model as is asked in item 30 does not necessarily understands the concept of three dimensionality. The concept of three dimensionality is best assessed by asking the student to demonstrate it using the model that he has constructed.

8.3.2.2. Test Design and Strategies for Data Analysis

According to Chadwick et al (1984:177), design refers to the overall strategy concerning the setting up of an empirical investigation. Among the variety of test designs that are discussed in Borg (1987:229-259, 286) as well as Wallen and Fraenkel (1991:191-211), the one group pretest-posttest design is most suitable for purposes of this study. Only one group is involved in this design. This group is pretested, exposed to the experimental treatment and then tested again. The test instrument that is used in the pretest is the same as that in the posttest. The pretest and posttest scores are then compared to determine if a significant change has taken place. The effects of the treatment are judged by the difference between the pretest and the posttest scores. No comparison with a control group is provided.

The data are analysed using the Student's Distribution (t) test for correlated means. For purposes of this current study, the t-test is applied to compare the mean scores of testees before and
after developing their observational and allied skills. Using the coefficient of correlation (τ), Best (1981:281) points out that the appropriate t-test would be based upon the formula:

$$t = \frac{M_1 - M_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2} - 2\tau \left( \frac{S_1}{\sqrt{N_1}} \right) \left( \frac{S_2}{\sqrt{N_2}} \right)}}$$

Where

- $M_1$ = mean of testees after instruction
- $M_2$ = mean of testees before instruction
- $N_1$ = number of testees after instruction
- $N_2$ = number of testees before instruction
- $S_1^2$ = variance of testees after instruction
- $S_2^2$ = variance of testees before instruction
- $\tau$ = Pearson's product moment correlation coefficient

The number of degrees of freedom (df) would be $N-1$, where $N$ is the number of pairs (sample). It is asserted in Mulder (1989:145) that if the calculated t value is smaller than the t critical value (see t distribution table in Appendix E) for $N-1$ df, the null hypothesis cannot be rejected. It can, therefore, be concluded that for a one tailed test based either on 5% or 1% level of significance, there is no significant difference between the arithmetic mean before and after developing observational and allied skills. The implication is that the teaching did not contribute to the development of observational and allied skills.

Borg (1987:230) points out that this design is a very weak one because of lack of a control group. Furthermore, Chadwick et al (1984:181-182) point out that the design is susceptible to error from all of the extraneous variables which threaten the internal validity of the test. These are history, maturation, effects of
testing and instrumentation.

History refers to events other than the instructional treatment itself which can happen before each test. This might cause an observable difference in achievement between the pretest and posttest scores (Best 1981:64).

Maturation refers to processes other than the instructional intervention itself which change subjects over time. These processes may be biological, psychological, or emotional. These changes may be confused with the effects of the instructional treatment (Chadwick et al 1984:182).

According to Best (1981:64 and 81) the effects of pretesting have a sensitizing effect which make students aware of issues that they had not thought of before. It may enable students to be more proficient in the posttest performance. Chadwick et al (1984:182) adds that the test effect threatens the internal validity even if different versions of the pretest and the posttest are given.

Notwithstanding the disadvantages above, this kind of design is occasionally used. According to Borg (1987:231) and Chadwick et al (1984:181) this is the best design which is especially helpful for studies a teacher wants to carry in a single class. This ties up well with the researcher's decision to make a non-probability sample (see section 8.3.2.4.I.). This kind of sample effectively means testing a single class.

In this study the researcher has deliberately avoided test designs which involve the setting up of a control group. This is because the test items were selected from the work which covers the Biology STD II syllabus. The posttest scores were planned to form part of the students' year mark. The central problem with the setting up of a control group is that it would be ethically
unjustified. The researcher would deliberately put this group at a disadvantage by not developing their observational and allied skills.

Chadwick et al (1984:15) assert that one cannot justify a course of research that will have serious harmful effects for the subjects of that research, even in the interest of advancing scientific knowledge. The researcher, while appreciating the freedom of inquiry, is committed to protecting the best interest of his subjects. It is for the above reasons that a one group pretest posttest design is applied in this study.

8.3.2.3. Model Lessons on Observational and Allied Skills

It has been indicated in chapter seven that the best way to develop observational and allied skills is to integrate the process and the content approaches. This, in essence means that the observational and allied skills are integrated in the content when the lesson is presented. When the model lessons were first presented in the pilot study, learners were left for themselves to follow instructions on worksheets. Demonstrations were performed only on selected aspects. The results were not so impressive. It was, therefore, decided to improve the lesson presentation during the next administration of the test. This appears in Chapter 9.

Lesson 1 in Appendix G is aimed at developing two kinds of skills. These are the skills of observing using a compound microscope and communicating the observed facts through labelled diagrams. The development of both these skills is integrated to the study of a cell. The skills of observing through the microscope includes the ability to make wet mount preparation of microscope slides.

Observational and allied skills may be developed by special type
The best option, therefore, is either to reduce the population to a workable size, or use a nonprobability sample. The researcher opts for the latter.

According to Best (1981:13), the nonprobability sampling procedures do not necessarily produce samples that accurately reflect the characteristics of the population of interest. As a result they may lead to unwarranted generalizations. These kinds of sampling procedures use available classes as samples.

Using the nonprobability sampling procedures, a group of thirty second year biology student-teachers at Tivumbeni College of Education was chosen as a sample (N). Their age ranged from 21 through to 38 years. All of them had biology in standard ten. Only twenty five subjects actually passed biology first year course. The other five were those who were allowed to carry it into the second year of study. The subjects were not expected to have had training in the science process skills. This is because of the nature of teaching in the schools from which they came and the fact that the practical component only starts in the second year college level.

The original test instrument with twenty six questions was tried out upon these students.

The researcher acknowledges the fact that the sample in this study is not just a collection of objects, but is a group of fellow subjects. As indicated in section 8.3.2.2., it is unethical to divide the sample into an experimental and a control group. Rather, the same test is given twice to the same group, before and after developing their observational and allied skills.
of lessons which are not necessarily linked to the content. For instance, Lesson 2 in Appendix G is aimed at developing the **measuring** skill in general. The skills involved in the measurement of volume, length, time, temperature, diameter and mass can be applied in various situations for a variety of learning content. The **communicating** skill is developed when learners write down their **observation** using the correct units of measurement.

Lesson 3 has been extracted from an inductivist theory of observation (see Appendix A (i)). It is designed to teach the distinction between an **observation** and an **inference**.

The first paragraph in Lesson 4 is an attempt to set up several questions which can be answered by performing the experiment. This is the observation related skill of **operational definition**. Other skills allied to observation as developed through this lesson are **predicting**, hypothesizing, and control of **variables**. Learners also have a feel of developing the highest science process skill, namely; **experimentation**.

Lesson 5 is aimed at teaching about the skills of controlling experimental variables. The glucose concentration is under the control of the experimenter and is, therefore, a **manipulated** or **independent** variable. The percentage germination is the **responding** or **dependent** variable.

Learners are also taught how to interpret the results of the experiment. The interpretation of Table 5 is that the germination of pollen grains is directly proportional to the concentration of glucose. That is, for every increase in glucose concentration up to 60 g/litre there is a corresponding increase in the germination of pollen grains. Germination of pollen grains drops gradually beyond 60g/litre.
The skill of constructing and using a dichotomous key is developed through lesson 6.

8.3.2.4. Pilot Study

The pilot study is intended to make a trial run of the test instrument on a group of students as similar as possible to the students who will be tested. In this research, the pilot study is comprised of the sampling procedure, administration of the pretest and posttest, giving of model lessons and statistical evaluation of the test instrument itself. The exact details of the procedures followed in each of these aspects of the pilot study is discussed in section I through to III below.

I. The Sampling Procedure

The usual strategy to obtain a representative sample is, as indicated by Chadwick et al (1984:53), to draw a probability sample. The process of doing this is random sampling. This refers to the selection of units from a universe or population so that every unit has exactly the same chance or probability of being included in the sample. In this study, the population would be all second year biology and physical science student-teachers in the Department of Education in South Africa.

This kind of sampling is not practical in a study such as this current one. This is firstly because it is simply not possible to obtain a representative sample of such a population. Secondly, majority of the test items are of a practical nature requiring certain laboratory equipment which can conveniently be set in one venue, getting a representative sample to such a venue would be a mammoth task indeed! Thirdly, testing, due to its practical nature, is unlikely to be completed in a single session, more than one day may be required for this.
II. Administration of the Pilot Test.

The administration of the pretest took place during the first week of September 1995. It lasted for four periods of forty minutes each which were spread over two days.

The model lessons in Appendix G were then presented as experimental treatment. After the instructional treatment, students were tested again (posttest) to see if there is any significant change in their performance. The same testing instrument was used in both the pretest and posttest administrations.

III. Statistical Evaluation of the Test Instrument

Studies (Doran 1980:101; Mulder 1989:209; Seifert 1983:357-362) has shown that the test instrument is often evaluated using four constructs. These are item analysis, determination of the test reliability, validity and usability. What follows is a discussion of each of these four constructs.

(a) Item Analysis

Item analysis as defined by Gage and Berliner (1988:632) is a process whereby the responses of students are analysed until a pool of good items is created. In a criterion-referenced test such as in this study the responses of the students before and after instructional treatment are analysed.

The commonly employed parameters for item performance are the difficulty index, discrimination index, an index of sensitivity to instruction and the effectiveness of distractors in multiple-choice items (Doran 1980:96). The difficulty index, an index of sensitivity to instruction and the effectiveness of distractors in multiple-choice items are more suitable for a criterion-
reached test as applicable in this study. For this reason, they are discussed in details below.

(i) The Item Difficulty Index

The item difficulty index \( p \) is defined as the proportion or percentage of respondents who correctly answer an item (Gage and Berliner 1988:632). The calculation required to obtain an item difficulty value involves a division of the number of students who responded correctly \( R \) by the total number of students in the sample \( N \). The formula for difficulty index is often expressed as \( P = \frac{R}{N} \).

Using the above formula, the difficulty index of all items before and after instruction was computed. Before instruction, the range was 9% (most difficult) through to 39% (least difficult) with an arithmetic mean of 21%. After instruction the range changed to 17% (most difficult) through to 68% (least difficult) with an arithmetic mean of 38%. This means that the instruction helped to reduce the difficulty of the items by an average of 17%.

According to Doran (1980:197) the normal range would be 30% (for the most difficult) through to 90% (for the very easy). In this pilot study, most of the items proved very difficult for students, hence a certain amount of adjustment was necessary. It was also apparent that the instruction needed a great deal of improvement if students were to perform well in the next skills assessment.

The effectiveness of instruction was also determined by the use of an Index of Sensitivity to Instruction which is discussed in the section that follows.
(ii) An Index of Sensitivity to Instruction.

A simple formula for determining an item's sensitivity to instruction $S$, is given in Gage and Berliner (1988:632) as follows:

$$S = \frac{(NCA - NCB)}{NT}$$

$NCA =$ is the number of students answering correctly after instruction.

$NCB =$ the number of students answering correctly before instruction.

$NT =$ total number of students.

Using this formula, the sensitivity to instruction for all items was computed. The indices of sensitivity to instruction ranged from 0.10 through to 0.30 with an arithmetic mean of 0.20. According to Gage and Berliner (1988:632), items with values closer to 1.00 are more sensitive to instruction. The implication in this study is that the instruction was not very effective and would have to be improved when the test is administered next.

(iii) The Effectiveness of Distractors in Multiple-choice Items.

As a general rule for evaluating distractors, Mulder (1989:200) points out that the minimum testees that must mark the distractor is determined by the following formula:

$$\text{Boundary} = \frac{N - \text{number of correct answers}}{2 \times \text{number of distractors}}$$

Using the above formula, the boundaries for the responses after
instruction for multiple choice items were computed. The boundaries ranged from 0.50 through to 1.20. In some questions the number of testees that have marked each distractor were found to be below the calculated boundaries (i.e. 0.50 to 1.20).

It was, therefore, necessary to rephrase these items. After the necessary adjustments were made, the final test had thirty items (see Appendix C).

(b) Reliability

Reliability, as indicated in Doran (1980:103-104) and Seifert (1983:358) is how consistently a test measures what is measured. This consistency can be across time (stability), in terms of form (equivalency) or within one administration of one test (internal consistency). Reliability across time is usually computed from a test-retest administration of a given instrument, (e.g. two weeks or less interval). This has to be the same test (or a parallel form of the same test).

One of the major problems connected to this method is indicated by Mulder (1989:209) as the time span that elapses between the two administrations of the test. If the test is repeated too soon, then memory will play an important role, since some testees will still remember the answers to certain items. Alternatively, if the time lapsed is too long, then some testees may either have gained new knowledge which could boost their performance, or they may have their knowledge receded with the result that their performance may have consequently become weaker. Most readers will agree with Mulder (1989:211) that compiling two completely equivalent tests may prove to be a hassle for researchers.

It is for this reason that in this study reliability is tested within one administration (internal consistency). This is
accomplished by administering two parallel forms of a given measure. Since reliability refers to the degree of correspondence between two independent sets of score measurements for the same testees, Mulder (1989:209) asserts that it can be expressed as the correlation between the two sets of scores. This is the Pearson's product moment correlation coefficient (τ). The formula for τ is as follows:

\[ r = \frac{N \sum XY - (\sum X)(\sum Y)}{\sqrt{N \sum X^2 - (\sum X)^2} \sqrt{N \sum Y^2 - (\sum Y)^2}} \]

Where

- \( N \) = Number of testees
- \( X \) = Scores in the first test
- \( Y \) = Scores in the second test

The most frequently used type of reliability is known as split-half reliability method for internal consistency. It is the method used to test the coefficient of reliability in this study. The group takes the test only once, but for scoring purposes the test itself is split into two equivalent subtests. Scores in the odd numbered questions are correlated with those in the even-numbered ones, just as if they were complete tests in their own right.

Using the formula for the Pearson's Product Moment correlation coefficient \( r \), the coefficient of reliability is computed as 0.20. This method is more convenient, however, one disadvantage as highlighted in Seifert (1983:358) is that the two subtests are, by definition, somewhat shorter. This fact allows for random variation to be more of an issue in half-tests than in the whole test, this explains why a negligible coefficient of reliability of 0.20. is obtained.
When reliability is computed statistically, the above disadvantage can be counterbalanced either by the application of the Spearman-Brown formula (Best 1984:199, 254; Mulder 1989:213; Wallen and Fraenkel 1991:98) or Spearman rank order coefficient of correlation (Best 1984:246; Mulder 1989:77). Both these formulæ indicate how the reliability of the test is increased when it is expanded by identical items.

Spearman-Brown formula ($\tau_{e+}$):

$$\tau_{e+} = \frac{2\tau}{1+\tau}$$

Where $\tau$ = coefficient of correlation

Spearman rank order coefficient of correlation ($\rho$)

$$\rho = 1 - \frac{6\Sigma D^2}{N(N^2-1)}$$

Where $D$ = the difference between the paired ranks

$\Sigma D^2$ = the sum of the squared difference between ranks

$N$ = number of paired ranks

As indicated by Mulder (1989:80), it takes much less time to calculate Pearson's $\tau$ and then Spearman-Brown $\tau_{e+}$ than it does to first determine the rank orders and then calculate the Spearman rank order coefficient of correlation ($\rho$). For this reason, the Spearman-Brown formula ($\tau_{e+}$) is applied in this study. The coefficient of reliability ($\tau_{e+}$) is then increased to 0.33.

It can be deduced from Best (1981:255) that any coefficient of correlation, whether it is a Pearson's product moment correlation coefficient ($\tau$), a Spearman-Brown formula ($\tau_{e+}$) or
Spearman rank order coefficient of correlation (\(\rho\)) is a value between 0.00 and 1.00. If the value of a coefficient of correlation is closer to 1.00 this indicates a high degree of reliability, a value closer to 0.00 indicates a very low degree of reliability. The increased value of 0.33 is closer to 0.00. This signifies a very low coefficient of reliability.

This, however, is a crude criterion for the evaluation of a coefficient of correlation and may somewhat be misleading. As indicated in Best (1981:255), the significance of the coefficient of correlation depends upon the nature of the variables, the number of observations, the range of scores and the purpose of the application. A test of the statistical significance of any coefficient of correlation is based upon the concept of sampling error.

In order to determine whether or not a coefficient of correlation is statistically significant, Best (1981:285) provides the following formula:

\[
L = \frac{r \sqrt{N - 2}}{\sqrt{1 - r^2}}
\]

Where \(r\) = observed coefficient of correlation (\(r_{+e}\))
N = size of the sample

Using the above formula, the value of \(L\) is computed as 1.86. With \(N-2\) degrees of freedom (df), on a one-tailed test, at 5% level of significance, this value is statistically significant because it is higher than the \(t\) critical value in the \(t\) distribution table (see Appendix E). However, it is not statistically significant on a two-tailed test at both 5% and 1% levels of significance. This is because here it is lower than the \(t\) critical value in the \(t\) distribution table. By implication, the test items need improvement before they can be
administered next.

Best (1981:274-277) describes the df as the number of observations that are independent of each other, and which cannot be deduced from each other. For instance, when computing the mean, 1 df is used up or lost. Subsequent calculations of the variance and the standard deviation will be based on N-1 independent observations or df. The df is the correction for the number of independent observations. This is particularly important when the sample (N) is small.

Because of sampling error, the mean of the sample is unlikely to be identical to the population mean. The use of the number of df rather than N in the denominator tends to correct for this underestimation of the population variance or standard deviation. However, when the sample is large the correction is negligible.

In this study the number of df is N-2 because there are two observations, the pretest and the posttest.

(c) Validity

The validity of the test is defined as the degree to which a test measures what it is designed to measure within a given population (Gage and Berliner 1988:583). There are several kinds of validity namely; face validity, criterion-related validity, content validity, statistical validity and construct validity. According to Borg (1987:118) each of these different kinds of test validity is relevant to a different type of measure and different testing situation. The most appropriate kind of validity in this current study is content validity. What follows is a discussion of this kind of validity with respect to the test instrument in Appendix C.
(i) Content Validity

Content validity means that a test is based on a more thorough analysis and sampling of an area or skill or knowledge (Gage and Berliner 1988:583, Seifert 1983:360). As stated in Borg (1987:118) it is particularly important in selecting tests to use in experiments involving the effect of different instructional methods. It is, therefore, important primarily in assessing the effect of developing observational and allied skills. This kind of validity is important in studies of school achievement testing. This is because of the degree of relationship between the achievement test used in the study and the curriculum taught.

According to Best (1981:197), content validity is specifically related to the traits for which it was designed. It shows how adequately the test samples the universe of knowledge and skills that a student is expected to master. The test instrument in Appendix C has a high content validity because all the twelve observational and allied skills have been tested. This is because it covers all the observational and allied skills that are so much important in the teaching and learning of natural sciences. However, biology is the area of knowledge that is covered by most items.

By examining the test instrument in Appendix C, it is noticed that it satisfies the criterion of relevance. The test items are directly related to the natural sciences objectives and actual instruction. When used in conjunction with educational measurement, Doran (1980:101) contends that relevance must be considered as the major contributor to content validity.

(d) Usability

The concept usability has little to do with psychological
theories of measurement, but much to do with practical matters. According to Seifert (1983:362) and Best (1984:200), a test instrument is usable to the extent that it can be administered, scored and interpreted easily and that its results are clearly understandable.

The test instrument in Appendix C provides a setting for eliciting student performance. It has predetermined scoring procedures. Scores are based on the product which is related to performance criteria. The test instrument requires learners to respond in practical terms by doing something. The response is made to depend upon the correct completion of the relevant practical work. This kind of test, therefore, does not preclude practical activity, and hence is usable for purposes of this study.

In this study the average coefficient of reliability of the test instrument in the posttest administration as computed in section 9.2.2.2 is 0.52. This moderate coefficient of reliability confirms Seifert (1983:357) assertion that reliability is illustrated more with formal tests than with informal methods of evaluation. Tests are also easier to summarize and interpret than most other kinds of observations. A test instrument gives a quantitative estimate of ability or achievement.

Tests yield comparatively small amounts of effort by the researcher. They are more efficient to administer than observations. In the same amount of time it takes to gather information from one student in observations, tests gather information about the whole class (Airasian 1991:17.

Tests are usable because they provide standard experiences to which individual students must respond. Tests provide a relatively fair way to judge learning because students work simultaneously on a task (Gage and Berliner 1988:569-570).
8.3. SUMMARY

This chapter has shown that an **observational** technique underlies all the other methods in the gathering of data in classrooms. It is, therefore, the best method for assessing observational and allied skills in this study.

A test is seen as complementing rather than substituting observation. Tests are themselves observations of behaviour that are more efficient, refined, and less biased than other ways of observing.

In an ideal situation, therefore, observational and testing methods would have to complement each other in assessing learning objectives. But, since such a thorough investigation is impractical in a study like this current one, the researcher has compromised this ideal by giving tests alone. This compromise probably reduces the reliability and validity in the interest of a big advantage in practicality.

Several problems have proved prohibitive in using the observation method. These are; identifying the characteristics of a good and a bad performance, problems of rating the observation process itself, i.e. subjectivity of rating, shifting performance criteria and obtaining an inadequate sample of pupil performance. The organs of observing are fallible and often inadequate.

For a number of reasons, tests remain the most popular form of classroom evaluation. A synopsis of these reasons may be listed as follows:
Tests are more reliable. They are easier to summarize and interpret than most other kinds of observations. Tests are more efficient to administer than observations. The test items as constructed proved very difficult to students. It was, therefore, decided to improve the lesson presentation during the next administration of the test.

This chapter has also shown that the Student's Distribution (t) test for correlated means is the main statistical strategy which is relevant for this study. The t-test is applied to determine if there is a significant difference between the mean scores of students before and after developing their observational and allied skills in chapter nine.
9. RESULTS OF THE MAIN FINDINGS OF THE EMPIRICAL RESEARCH IN OBSERVATIONAL AND ALLIED SKILLS
9.1. ORIENTATION

The main concern of chapter nine is to test the null hypothesis ($H_0$) that: "There is no significant difference between the mean scores of students before and after developing the twelve observational and allied skills in Table 5.1".

Any apparent difference that may be observed is, therefore, simply the result of sampling error or chance. An alternative hypothesis ($H_1$) is posed against the null hypothesis thus: "The mean scores of students after developing the twelve observational and allied skills in Table 5.1. are significantly higher than that before".

This chapter, therefore, provides science educators with an empirical foundation for assessing and developing observational and allied skills.
9.2. COLLECTION, PRESENTATION AND ANALYSIS OF DATA ON OBSERVATIONAL AND ALLIED SKILLS

The empirical research aims at assessing learners' observational and allied skills in a group of learners before and after instruction in science process skills. It explains the sampling procedure, test administration and data presentation and analysis.

9.2.1. Sampling, Test Administration and Presentation of Data

The sampling procedure as used in this test administration is the same as that which was used in the pilot study (see section 8.3.2.4.1). Thirty second year biology student-teachers at Tivumbeni College of Education were used as a nonprobability sample. These subjects shared similar characteristics with those in the pilot study (see section 8.3.2.4. I. Three subjects carried biology first year course to their second year of study.

The test administration took place at the beginning of the 1996 academic year. The pre-testing took place during the first week of February when students were oriented into biology second year course. This was aimed at testing the students' pre-knowledge on observational and allied skills. It lasted for six hours which were spread over three days, with approximately two hours each day. After the administration of the pretest, the items were marked, the students' scores for each item are presented in Tables 9.29 (a) through to 9.39 (a) (See Appendix H).

The model lessons as discussed in section 8.3.2.3. and written down in Appendix G were then presented as experimental treatment before the post-test. This lasted for approximately sixty minutes each day for five days which were spread over three weeks. Each lesson was presented in such a way that learners
were not left to follow instructions on the worksheet by themselves. The researcher actually demonstrated the procedure in each paragraph separately. Special emphasis was laid upon what Airasian (1991:190) refers to as "teaching to the test". The instruction was based upon the subject matter which was similar to the subject matter from which the test is constructed.

After the lessons were presented, the test in Appendix C was administered to student-teachers as a posttest. The items were then marked, the students' scores for each item are presented in Tables 9.29 (b) through to 9.39 (b) (See Appendix H).

9.2.2. Evaluation of the Test Instrument

The revised test instrument in this chapter is evaluated using the four constructs as discussed in section 8.3.2.4. III. These are item analysis, test reliability, validity and usability.

9.2.2.1. Item Analysis

The pilot test in Chapter 8 was followed by item analysis as an attempt to create a pool of good items. After this second administration of the test in Chapter 9, item analysis is intended to verify if the item revision and improved lesson presentation were worthwhile. Item analysis in this chapter follows the same procedure as in the previous chapter.

I. The Item Difficulty Index

As indicated in Chapter 8, the calculation required to obtain an item difficulty value (P) involves a division of the number of students who responded correctly (R) by the total number of students in the sample (N). Using this formula in conjunction with Table 9.1. and 9.2., the difficulty index of all items
before and after instruction has been computed and tabulated in Table 9.3.

<table>
<thead>
<tr>
<th>Test Items</th>
<th>Difficulty Index before Instruction</th>
<th>Difficulty Index after Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37</td>
<td>87</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>77</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
<td>73</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>40</td>
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<tr>
<td>8</td>
<td>10</td>
<td>33</td>
</tr>
<tr>
<td>9</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>13</td>
<td>50</td>
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<tr>
<td>11</td>
<td>27</td>
<td>53</td>
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<tr>
<td>12</td>
<td>20</td>
<td>47</td>
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<tr>
<td>13</td>
<td>23</td>
<td>50</td>
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<tr>
<td>14</td>
<td>17</td>
<td>43</td>
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<tr>
<td>15</td>
<td>20</td>
<td>47</td>
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<tr>
<td>16</td>
<td>13</td>
<td>43</td>
</tr>
<tr>
<td>17</td>
<td>37</td>
<td>80</td>
</tr>
<tr>
<td>18</td>
<td>27</td>
<td>73</td>
</tr>
<tr>
<td>19</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>43</td>
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<tr>
<td>21</td>
<td>23</td>
<td>47</td>
</tr>
<tr>
<td>22</td>
<td>17</td>
<td>43</td>
</tr>
<tr>
<td>23</td>
<td>13</td>
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<tr>
<td>24</td>
<td>10</td>
<td>43</td>
</tr>
<tr>
<td>25</td>
<td>7</td>
<td>53</td>
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<tr>
<td>26</td>
<td>10</td>
<td>47</td>
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<td>27</td>
<td>10</td>
<td>43</td>
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<td>28</td>
<td>13</td>
<td>50</td>
</tr>
<tr>
<td>29</td>
<td>13</td>
<td>43</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>47</td>
</tr>
</tbody>
</table>

Table 9.1. A Comparison of Difficulty Index before and after developing Observational and allied skills

The criterion for the evaluation of item difficulty is provided in Table 9.2.
The criterion is such that the distribution of values combines items of moderate difficulty with items of extreme difficulty and ease.

Using Table 9.2 as a criterion in conjunction with Table 9.1., the percentage of item difficulty indices before and after instruction is calculated in Table 9.3. As can be seen, 93% of the items were very difficult before instruction. This figure was reduced to only 03% after instruction. Majority (77%) of the test items after instruction were moderately difficult. It is clear from this table that the instruction has been successful in developing the students' observational and allied skills. All items were satisfactorily answered by a reasonable number of students.

<table>
<thead>
<tr>
<th>Difficulty</th>
<th>Percentage of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very easy</td>
<td>0.85 - 1.00</td>
</tr>
<tr>
<td>Moderately easy</td>
<td>0.60 - 0.85</td>
</tr>
<tr>
<td>Moderately difficult</td>
<td>0.35 - 0.60</td>
</tr>
<tr>
<td>Very difficult</td>
<td>0.00 - 0.35</td>
</tr>
<tr>
<td>15%</td>
<td>35%</td>
</tr>
<tr>
<td>35%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 9.2. The Criterion for the evaluation of Item Difficulty. Adapted from Doran (1980:97).

<table>
<thead>
<tr>
<th>Difficulty</th>
<th>Before instruction</th>
<th>After instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very easy</td>
<td>0.85-1.00</td>
<td>00%</td>
</tr>
<tr>
<td>Moderately easy</td>
<td>0.60-0.85</td>
<td>00%</td>
</tr>
<tr>
<td>Moderately difficult</td>
<td>0.35-0.60</td>
<td>07%</td>
</tr>
<tr>
<td>Very difficult</td>
<td>0.00-0.35</td>
<td>93%</td>
</tr>
</tbody>
</table>

Table 9.3. The Item Difficulty before and after instruction
Notwithstanding the above, Gage and Berliner (1988:632) point out that the Item Difficulty Indices are not very accurate in determining the effectiveness of instruction. The most accurate formula is an Index of Sensitivity to Instruction which is discussed in the section that follows.

<table>
<thead>
<tr>
<th>Test items</th>
<th>Number of students answering correctly before instruction (NCB)</th>
<th>number of students answering correctly after instruction (NCA)</th>
<th>Index of sensitivity to instruction (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>26</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>24</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>23</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>22</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>16</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>14</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>12</td>
<td>0.3</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td>9</td>
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<td>14</td>
<td>0.3</td>
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<td>13</td>
<td>0.3</td>
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<td>16</td>
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<td>14</td>
<td>0.4</td>
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<td>0.3</td>
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<tr>
<td>30</td>
<td>3</td>
<td>14</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**ARITHMETIC MEAN** → 0.4

Table 9.4. An Index of Sensitivity to instruction
II. An Index of Sensitivity to Instruction.

Using the formula $S = \frac{(NCA - NCB)}{NT}$ as previously described in section 8.3.2.4.III (ii), the sensitivity to instruction for all items is computed and presented in Table 9.4.

The above table shows that the indices of sensitivity to instruction range from 0.2 through to 0.5, with an arithmetic mean of 0.40. Table 9.5 provides the criterion for the evaluation of item sensitivity to instruction.

<table>
<thead>
<tr>
<th>Range of values</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 through to 0.20</td>
<td>negligible sensitivity</td>
</tr>
<tr>
<td>0.20 through to 0.40</td>
<td>low sensitivity</td>
</tr>
<tr>
<td>0.40 through to 0.60</td>
<td>moderately sensitive</td>
</tr>
<tr>
<td>0.60 through to 0.80</td>
<td>substantially sensitive</td>
</tr>
<tr>
<td>0.80 through to 1.00</td>
<td>highly sensitive</td>
</tr>
</tbody>
</table>

Table 9.5 The criterion for the evaluation of Item Sensitivity to instruction. (Gage and Berliner 1988:632).

It is explicit from Table 9.5 that the average value of $S = 0.4$ signifies a low sensitivity to instruction. According to the Index of Sensitivity to Instruction, therefore, the instruction was not effective enough and would have to be improved further, if the students were to be tested again.

III. The Effectiveness of Distractors in Multiple-choice items.

As indicated in section 8.3.2.4.III. (iii), the minimum testees that must mark the distractor is determined by the formula:

$$\text{Boundary} = \frac{N - \text{number of correct answers}}{2 \times \text{number of distractors}}$$
Where \( N \) = total number of testees.

Since out of the five possible answers, there is only one correct answer, this means that there are four distractors.

Before determining the minimum boundaries for student responses to items 1 through to 6, the results of the student responses are first put into their proper perspectives in Tables 9.6. through to 9.11.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>No response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Posttest</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>26</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9.6. Results of Student Responses to Question 1

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>No response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Posttest</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 9.7. Results of Student Responses to Question 2

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>No response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Posttest</td>
<td>2</td>
<td>23</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9.8. Results of Student Responses to Question 3

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>No response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Posttest</td>
<td>22</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9.9. Results of Student Responses to Question 4
Table 9.10. Results of Student Responses to Question 17

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>No response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>4</td>
<td>11</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Posttest</td>
<td>2</td>
<td>24</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 9.11. Results of Student Responses to Question 18

The minimum boundaries for the responses after instruction for item 1 through to 6 are computed and presented in Table 9.12.

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest Boundary</td>
<td>2.40</td>
<td>2.60</td>
<td>2.60</td>
<td>2.90</td>
<td>2.40</td>
<td>2.80</td>
</tr>
<tr>
<td>Posttest Boundary</td>
<td>0.50</td>
<td>0.75</td>
<td>0.88</td>
<td>1.00</td>
<td>0.75</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 9.12. Boundaries for Student Responses for items 1 through to 6

A critical study of Tables 9.6 through to 9.11 show that, with the exception of distractor C in item 5, the number of testees that have marked each distractor for each item respectively is not below the calculated minimum boundaries in Table 9.12. According to Mulder (1989:200), these kinds of distractors serve a purpose and must be retained.
However, the number of respondents in distractor C (item 5) in the pretest administration equals to 2. This is less than the calculated minimum boundary of 2.4.

Again the number of students who responded to this very same distractor in the posttest administration is zero. This is far below the calculated minimum boundary of 0.75.

Distractor C in item 5, therefore, serves no purpose and must be replaced by another suitable distractor if the students were to be tested again.

9.2.2.2. Reliability

It has been pointed out in section 8.3.2.4. III (b) that reliability in this study is tested within one administration by using the split-half reliability method. The group takes the test only once, but for scoring purposes the test itself is split into two equivalent subtests. Odd numbered questions are correlated with even-numbered ones, just as if they were complete tests in their own right.

As indicated in section 8.3.2.4. III (b), reliability is expressed as the correlation between the scores of the odd numbered questions and those for the even numbered ones. This coefficient of correlation is determined by means of the Pearson's product moment correlation coefficient ($r$) with the formula:

$$r = \frac{N \sum XY - (\Sigma X)(\Sigma Y)}{\sqrt{N \sum X^2 - (\Sigma X)^2} \sqrt{N \sum Y^2 - (\Sigma Y)^2}}$$

Where $N$ = Number of testees
$X$ = Scores in the odd numbered questions
$Y$ = Scores in the even numbered questions
The determination of the coefficient of correlation in this section should not be confused with that in section 9.2.3 below.

In this current section, the coefficient of correlation is intended to determine the internal consistency of the pretest as well as that for the posttest. This is the split-half reliability method for internal consistency. It compares scores of the odd numbered items with those for the even numbered ones.

In section 9.2.3 the coefficient of correlation is aimed at finding out if the instructional treatment was effective. This is by determining the relationship between the posttest and the pretest scores.

In both cases, the Pearson's product moment correlation coefficient ($\tau$) has been used.

The coefficient of reliability is now computed using the Pearson's product moment correlation coefficient ($\tau$) formula in conjunction with Tables 9.29 through to 9.39 (see Appendix H). Values of coefficients of reliability are calculated before (pretest) and after (posttest) developing each of the twelve observational and allied skills. The results are presented in Table 9.13.

The values of $\tau$ in the first column of Table 9.13 make the test seem less reliable. According to Best (1981:254), this is because the two subtests are by definition, somewhat shorter. This allows for random variation to be more of an issue in the half-tests than in the whole test. This disadvantage is counterbalanced by the application of the Spearman-Brown formula ($\tau_{tt} = 2\tau / 1 + \tau$). The results are presented in the second column of Table 9.13. As can be seen, the $\tau_{tt}$ has the effect of increasing the values of the coefficient of reliability. This is because the test is expanded by identical items.
Table 9.13. Summary of data on the Coefficient of reliability

<table>
<thead>
<tr>
<th>Observational and Allied skills</th>
<th>Pretest</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \tau )</td>
<td>( \tau_{tt} )</td>
<td>( \tau_{rr} )</td>
<td>( \tau )</td>
<td>( \tau_{tt} )</td>
<td>( \tau_{rr} )</td>
<td>( \tau )</td>
<td>( \tau_{tt} )</td>
<td>( \tau_{rr} )</td>
<td>( \tau )</td>
<td>( \tau_{tt} )</td>
<td>( \tau_{rr} )</td>
<td>( \tau )</td>
<td>( \tau_{tt} )</td>
<td>( \tau_{rr} )</td>
<td>( \tau )</td>
</tr>
<tr>
<td>1. Observing</td>
<td>0.24</td>
<td>0.39</td>
<td>2.42</td>
<td>0.33</td>
<td>0.50</td>
<td>3.05</td>
<td>0.33</td>
<td>0.50</td>
<td>3.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Measuring</td>
<td>0.35</td>
<td>0.52</td>
<td>3.24</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Inferring</td>
<td>0.15</td>
<td>0.26</td>
<td>1.44</td>
<td>0.47</td>
<td>0.64</td>
<td>4.40</td>
<td>0.47</td>
<td>0.64</td>
<td>4.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Classifying</td>
<td>0.04</td>
<td>0.08</td>
<td>0.42</td>
<td>0.20</td>
<td>0.33</td>
<td>1.86</td>
<td>0.20</td>
<td>0.33</td>
<td>1.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Predicting</td>
<td>0.20</td>
<td>0.33</td>
<td>1.86</td>
<td>0.53</td>
<td>0.68</td>
<td>4.87</td>
<td>0.53</td>
<td>0.68</td>
<td>4.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6. Communicating</td>
<td>0.15</td>
<td>0.26</td>
<td>1.44</td>
<td>0.26</td>
<td>0.41</td>
<td>2.39</td>
<td>0.26</td>
<td>0.41</td>
<td>2.39</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Making of Operational definition</td>
<td>0.15</td>
<td>0.26</td>
<td>1.44</td>
<td>0.40</td>
<td>0.57</td>
<td>3.47</td>
<td>0.40</td>
<td>0.57</td>
<td>3.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Formulating the Hypothesis</td>
<td>0.60</td>
<td>0.75</td>
<td>6.02</td>
<td>0.40</td>
<td>0.57</td>
<td>3.68</td>
<td>0.40</td>
<td>0.57</td>
<td>3.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Control of Variables</td>
<td>0.13</td>
<td>0.23</td>
<td>1.25</td>
<td>0.41</td>
<td>0.58</td>
<td>3.79</td>
<td>0.41</td>
<td>0.58</td>
<td>3.79</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Interpreting</td>
<td>0.17</td>
<td>0.29</td>
<td>1.59</td>
<td>0.34</td>
<td>0.51</td>
<td>3.14</td>
<td>0.34</td>
<td>0.51</td>
<td>3.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Experimenting</td>
<td>0.36</td>
<td>0.53</td>
<td>3.29</td>
<td>0.61</td>
<td>0.76</td>
<td>6.19</td>
<td>0.61</td>
<td>0.76</td>
<td>6.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Construction and using models</td>
<td>0.52</td>
<td>0.68</td>
<td>4.87</td>
<td>0.53</td>
<td>0.69</td>
<td>5.07</td>
<td>0.53</td>
<td>0.69</td>
<td>5.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>0.26</td>
<td>0.38</td>
<td>2.56</td>
<td>0.37</td>
<td>0.52</td>
<td>3.49</td>
<td>0.37</td>
<td>0.52</td>
<td>3.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9.13. Summary of data on the Coefficient of reliability
<table>
<thead>
<tr>
<th>Observational and Allied skills</th>
<th>Reliability in the pretest</th>
<th>Reliability in posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Observing</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>2. Measuring</td>
<td>moderate</td>
<td>none</td>
</tr>
<tr>
<td>3. Inferring</td>
<td>low</td>
<td>substantial</td>
</tr>
<tr>
<td>4. Classifying</td>
<td>negligible</td>
<td>low</td>
</tr>
<tr>
<td>5. Predicting</td>
<td>low</td>
<td>substantial</td>
</tr>
<tr>
<td>6. Communicating</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>7. Making of Operational definition</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>8. Formulating the Hypothesis</td>
<td>substantial</td>
<td>moderate</td>
</tr>
<tr>
<td>9. Control of Variables</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>10. Interpreting</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>11. Experimenting</td>
<td>moderate</td>
<td>substantial</td>
</tr>
<tr>
<td>12. Construction and using models</td>
<td>substantial</td>
<td>substantial</td>
</tr>
</tbody>
</table>

Table 9.14. Reliability of items on Observational and Allied skills

The summary of data on the coefficient of correlation in Table 9.13 is interpreted next. This is done by using the criterion for the evaluation of coefficients of correlation in Table 9.28. The results are presented in Table 9.14. It can be seen from this table that items on the measuring skill have an $\tau_{ee}$ value of 0.00 in the posttest administration. The implication of Table 9.28. on these items is that they are not reliable. The $\tau_{ee}$ value for items on the classifying skill is 0.33. This signifies
a low reliability. Items in both these process skills would need attention if students were to be tested again.

The remaining science process skills have $r_{ee}$ values ranging from 0.41 (moderate reliability) through to 0.76 (substantial reliability). This is an acceptable range according to the criterion for the evaluation of coefficients of correlation in Table 9.28.

As indicated in Best (1981:285), the statistical significance of $(r_{ee})$ is checked by the application of the formula for $t_r$ as follows:

$$t_r = \frac{r_{ee}\sqrt{N-2}}{\sqrt{1-r_{ee}^2}}$$

Where $r_{ee}$ = observed coefficient of correlation
$N$ = size of the sample

Using this formula, the values of $t_r$ have been calculated and presented in the third column of Table 9.13.

However, items on the classifying skill could still be accepted because the value of $t_r =1.86$ is statistically significant with $N-2$ (28) degrees of freedom (df) on a two-tailed test only at 5% level of significance. It can be said with 95% certainty that the test items on the classifying skill are reliable.

The $t_r$ values for the other process skills range from 2.39 in the communicating skill through to 6.19 in the experimenting skill. All these values exceed the $t$ critical value in the $t$ distribution table in Appendix E. The coefficient of correlation is, therefore, statistically significant with $N-2$ (28) degrees of freedom (df) on a two-tailed test at 5% and 1% levels of significance. It can be said with 99% certainty that the test items on these science process skills are reliable.
Validity and usability have already been discussed in Chapter 8 and will not be repeated here.

9.2.3. Statistical Analysis and Interpretation of Data

In this section the Pearson's product moment correlation coefficient ($r$) is used to determine whether or not the instructional treatment was effective. The $r$ is aimed at determining the relationship between the posttest and the pretest scores for each of the twelve observational and allied skills. The formula for $r$ is as follows:

$$r = \frac{N \sum XY - (\Sigma X)(\Sigma Y)}{\sqrt{N \sum X^2 - (\Sigma X)^2} \sqrt{N \sum Y^2 - (\Sigma Y)^2}}$$

Where $N$ = Number of testees

$X$ = Scores before instruction

$Y$ = Scores after instruction

The students' raw scores on each one of the twelve observational and allied skills from Tables 9.29 through to 9.39 (see Appendix H) have been transferred into Tables 9.15 through to 9.26 respectively. It should be noted that the values of $X$ in Tables 9.15 through to 9.26 have been derived from the students' raw scores of $X+Y$ in Tables 9.29 through to 9.39 (a) series. They represent the students' raw scores before developing each of the twelve observational and allied skills.

Similarly the values of $Y$ in Tables 9.15 through to 9.26 have been derived from the students' raw scores of $X+Y$ in Tables 9.29 through to 9.39 (b) series. They represent the students' raw
Table 9.15. Worksheet for the calculation of the Coefficient of Correlation (r) and Student's Distribution (t) for scores before and after Developing the Observing skill

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\[ S_{1^2} = 0.48 \]
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Table 9.16. Worksheet for the calculation of the Coefficient of Correlation (\( r \)) and the Student's Distribution (\( t \)) test for scores before and after Developing the Measuring skill
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$S_1^2 = 0.76$

$S_2^2 = 0.40$

Table 9.17. Worksheet for the calculation of the Coefficient of Correlation ($r$) and Student's Distribution ($t$) for scores before and after Developing the Inferring skill.
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**Table 9.19. Worksheet for the calculation of the Coefficient of Correlation \((r)\) and Student's Distribution \((t)\) for scores before and after Developing the Predicting skill**
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\[ M_y = 0.63 \]
\[ S_{x^2} = 0.46 \]
\[ S_{y^2} = 0.38 \]

Table 9.20. Worksheet for the calculation of the Coefficient of Correlation (\(r\)) and Student's Distribution (t) for scores before and after Developing the Communicating
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\[ \sum X = 8 \quad \sum Y = 27 \quad \sum X^2 = 27 \quad \sum Y^2 = 45 \quad \sum XY = 9 \quad \sum x = 0.1 \quad \sum y = 0.00 \quad \sum x^2 = 7.87 \quad \sum y^2 = 20.70 \]

\[ M_1 = 0.90 \]
\[ M_2 = 0.27 \]
\[ S_{1^2} = 0.71 \]
\[ S_{2^2} = 0.27 \]

Table 9.21. Worksheet for the calculation of the Coefficient of Correlation \((r)\) and Student's Distribution \((t)\) for scores before and after Developing the skill of Making Operational Definition
Table 9.22. Worksheet for the calculation of the Coefficient of Correlation (r) and Student's Distribution (t) for scores before and after Developing the skill of Formulating a Hypothesis
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M_2 = 0.23  \\
S_{x} = 0.72  \\
S_{y} = 0.19
\]

Table 9.23. Worksheet for the calculation of the Coefficient of Correlation (r) and Student's Distribution (t) for scores before and after Developing the skill of Controlling and Manipulating of Variables.
### Table 9.24. Worksheet for the calculation of the Coefficient of Correlation ($r$) and Student's Distribution ($t$) for scores before and after Developing the Interpreting skill

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Table 9.24. Worksheet for the calculation of the Coefficient of Correlation ($r$) and Student's Distribution ($t$) for scores before and after Developing the Interpreting skill.
Table 9.25. Worksheet for the calculation of the Coefficient of Correlation (r) and Student's Distribution (t) for scores before and after Developing the Experimenting skill

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N = 30  ΣX = 5  ΣY = 29  ΣX² = 7  ΣY² = 53  ΣXY = 10  Σx = 0.1  Σy = 0.1  Σx² = 6.17  Σy² = 24.97

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M₂ = 0.17
S₁² = 0.86
S₂² = 0.21
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</tr>
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<td>-0.9</td>
<td>0.05</td>
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<td>+0.23</td>
<td>-0.9</td>
<td>0.05</td>
<td>0.81</td>
</tr>
</tbody>
</table>

N= ΣX= 30  ΣY= 27  ΣX²= 11  ΣY²= 47  ΣXY= 12  Σx= 0.1  Σy= 0.1  Σx²= 9.37  Σy²= 22.70

\[ M_1 = \frac{\sum X}{N} = 0.90 \]
\[ M_2 = \frac{\sum Y}{N} = 0.23 \]
\[ S_{x}^2 = \frac{\sum x^2}{N} = 0.78 \]
\[ S_{y}^2 = \frac{\sum y^2}{N} = 0.32 \]

Table 9.26. Worksheet for the calculation of the Coefficient of Correlation (r) and Student's Distribution (t) for scores before and after Developing the skill of Constructing and using models.
<table>
<thead>
<tr>
<th>Observational and Allied skills</th>
<th>Coefficient of Correlation (t)</th>
<th>Student's Distribution (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Observing</td>
<td>0.54</td>
<td>11.29</td>
</tr>
<tr>
<td>2. Measuring</td>
<td>0.30</td>
<td>4.47</td>
</tr>
<tr>
<td>3. Inferring</td>
<td>0.13</td>
<td>3.12</td>
</tr>
<tr>
<td>4. Classifying</td>
<td>0.16</td>
<td>4.29</td>
</tr>
<tr>
<td>5. Predicting</td>
<td>0.24</td>
<td>3.35</td>
</tr>
<tr>
<td>6. Communicating</td>
<td>0.24</td>
<td>4.50</td>
</tr>
<tr>
<td>7. Making operational definition</td>
<td>0.10</td>
<td>3.71</td>
</tr>
<tr>
<td>8. Formulating a hypothesis</td>
<td>0.16</td>
<td>2.94</td>
</tr>
<tr>
<td>9. Controlling and manipulating of variables</td>
<td>0.12</td>
<td>4.35</td>
</tr>
<tr>
<td>10. Interpreting</td>
<td>0.12</td>
<td>4.12</td>
</tr>
<tr>
<td>11. Experimenting</td>
<td>0.42</td>
<td>4.71</td>
</tr>
<tr>
<td>12. Constructing and using models</td>
<td>0.39</td>
<td>3.94</td>
</tr>
<tr>
<td>Average</td>
<td>0.24</td>
<td>4.57</td>
</tr>
</tbody>
</table>

Table 9.27. Summary of data on the Coefficient of Correlation.

scores after developing each of the twelve observational and allied skills.

The values of $x$ are deviations from the mean which are computed from the following formula:

$$x = (X-\bar{X})$$

The values of $y$ are also deviations from the mean which are computed from the formula:
Using the formula for the Pearson's product moment correlation coefficient ($r$) in conjunction with Tables 9.15 through to 9.26, the coefficients of correlation ($r$) for scores before and after developing each of the twelve observational and allied skills is computed. The results are presented in Table 9.27.

Table 9.28 presents a crude criterion according to which the values of the coefficients of correlation may be interpreted.

<table>
<thead>
<tr>
<th>Coefficient of correlation</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 through to 0.20</td>
<td>negligible correlation</td>
</tr>
<tr>
<td>0.20 through to 0.40</td>
<td>low correlation</td>
</tr>
<tr>
<td>0.40 through to 0.60</td>
<td>moderate correlation</td>
</tr>
<tr>
<td>0.60 through to 0.80</td>
<td>substantial correlation</td>
</tr>
<tr>
<td>0.80 through to 1.00</td>
<td>high to very high correlation</td>
</tr>
</tbody>
</table>


It can be seen from Table 9.27 that the observing and experimenting skills each have a $r$ value of 0.54 and 0.42 respectively. If the criterion for the evaluation of coefficients of correlation in Table 9.28 is anything to go by, then the pretest and posttest scores of each of these two skills are moderately correlated.

This moderate correlation between the pretest and posttest scores can be accounted for in a number of ways. It may have been the result of the subjects's prior knowledge. As indicated in section 3.2.2.5. in this study, all epistemically relevant
observation requires the application of background knowledge. From this perspective, subjects who have high pretest scores would be expected to have high posttest scores than subjects who had low pretest scores. This means that the influence of the subjects's background knowledge would tend to produce a high correlation between pretest and posttest scores.

Alternatively, the instructional treatment may have made a moderate difference in the student performance. This line of argument seems to be more logical because as indicated in section 8.3.2.4.1, the subjects were not expected to have had any significant training in science process skills. This is due to the nature of the schools from which they came and the fact that the practical component (where observational and allied skills are developed) only starts in the second year college level.

The remaining science process skills have \( r \) values ranging from 0.10 (negligible correlation) through to 0.39 (low correlation). This low to negligible correlation is an acceptable range for those (like the researcher) who expect higher scores after developing observational and allied skills.

The statistical data as presented in Tables 9.1. through to 9.26 is summarized in Table 9.27. In this latter table the average Pearson's product moment coefficient of correlations (\( r \)) for scores before and after developing all the twelve observational and allied skills is calculated. This average value for \( r = 0.24 \). It is clear from Table 9.28 that this average value of 0.24 signifies a low correlation. This further strengthens the fact that the students' scores on all the twelve observational and allied skills in the posttest are higher than those in the pretest.
The question that should now be raised is "How significant is this low correlation?" This is best answered by the application of the Student's Distribution (t) test for correlated means in each of the twelve observational and allied skills. The t-test compares the mean scores of testees before and after developing their observational and allied skills. The t-test is based upon the following formula:

\[
t = \frac{M_1 - M_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2} - 2r \left( \frac{S_1}{\sqrt{N_1}} \right) \left( \frac{S_2}{\sqrt{N_2}} \right)}}
\]

Where

- \(M_1\) = mean of testees after instruction
- \(M_2\) = mean of testees before instruction
- \(N_1\) = number of testees after instruction
- \(N_2\) = number of testees before instruction
- \(S_1^2\) = variance of testees after instruction
- \(S_2^2\) = variance of testees before instruction
- \(r\) = Pearson's product moment correlation coefficient

As a prelude to determining the t test, a calculation of the means and variances of scores before and after developing the observational and allied skills is made. These are calculated from the following formulas:

Mean of scores after instruction (\(M_1\)) = \(\Sigma Y/N\)

Mean of scores before instruction (\(M_2\)) = \(\Sigma X/N\)

Variance of scores after instruction (\(S_1^2\)) = \(\Sigma y^2/(N_1-1)\)

Variance of scores before instruction (\(S_2^2\)) = \(\Sigma x^2/(N_2-1)\)

Using the formula for the Student's Distribution (t) test for
correlated means the values of t are determined for each of the
twelve observational and allied skills. The results are
presented in Table 9.27.

9.2.3.1. Interpretation of data on Observational and
Allied skills

The values of t on the observational and allied skills as
calculated and presented in Table 9.27 range from 2.94 (skill of
formulating a hypothesis) through to 11.29 (observing skill).
Furthermore, the average value of t in all the twelve
observational and allied skills as summarized in Table 9.27 is
4.57.

For a one tailed test based on both 5% and 1% levels of
significance, all the calculated t values are larger than both
the t critical values (see t distribution table in Appendix E)
for 30-1 or 29 df. This effectively nullifies the possibility of
a sampling error.

The null hypothesis (H⁰) that "There is no significant
difference between the mean scores of students before and after
developing each of the twelve observational and allied skills"
is, therefore, rejected. The observed difference is so
significantly large that this cannot be attributed to sampling
error or chance.

By implication, an alternative hypothesis (H₁) that: "The mean
scores of students after developing each of the twelve
observational and allied skills is significantly higher than
that before" is accepted. This means that the instruction is a
treatment which has made a significant contribution to the
performance of students on their observational and allied
skills.
This does not come as a surprise to the researcher. It confirms the findings in the literature study in section 7.3.7.1. that the ability to use the five senses can be developed within the context of normal classroom activities. In the same way, the ability to use instruments to help the senses can also be developed. As indicated in section 7.3.8.2, the best way to develop the observational and allied skills is to plan science activities which require learners to practice the use of these skills.

It has been asserted in section 7.3.7.2 that the inferring skill can be developed by providing students with material to observe and make interpretations. The Candle Activity [see Appendix A (i)] is perhaps the best student activity that has been designed to develop the inferring skill. It also helps students to distinguish between observation and an inference.

Developing the classifying skill means teaching the criteria on which particular classifications are based. Without these criteria, a learner will not be able to make a scientific classification.

As indicated in section 5.2.1.5., prediction is not just a wild guess, it is based upon the outcome of having observed a similar thing previously. This can be improved by teaching.

The findings of the empirical study confirm the literature study in section 7.3.1. in which it is indicated that classroom activities can be designed to improve the observational process skills in general. This finding clears up the false notion in Miller (1991:50) that the general process skills are, in some sense, "programmed in" to the extent that no formal instruction is required (also see section 7.3.1.1.).
The nature and structure of natural sciences (as discussed in section 6.2.2.) is such that the development of observational and allied skills has to be reflected in its teaching and learning. It enables the teaching, learning and understanding of this particular field of study. The curriculum should strike a balance between the products of science and the processes by means of which these products are generated. Developing observational and allied skills is, therefore, not only a means of teaching and learning, but also the end towards which all scientific endeavours should aim.

Esler and Esler (1981:67) have rightly pointed out that learners require formal instruction in order to develop observational and allied skills in general cognitive processes.

Previous research by Swinehart (1987:429-430) has also shown that observational and allied skills can be combined with specific concepts in the teaching of natural sciences. In the same year, another research by Burkinshaw (1987 developed the observational skills for primary school children in Britain.
9.3. SUMMARY

The statistical analysis in chapter 9 has enabled the researcher to reject the null hypothesis \((H^0)\) that "There is no significant difference between the mean scores of students before and after developing each of the twelve observational and allied skills in Table 5.1. The observed difference is so significantly large that this cannot be attributed to sampling error or chance.

By implication, an alternative hypothesis \((H_1)\) that: "The mean scores of students after developing each of the observational and allied skills in Table 5.1. is significantly higher than that before" is accepted.

This means that the instruction is a treatment which has made a significant contribution to the performance of students in all observational and allied skills. This confirms the findings throughout the literature study that observational and allied skills are not intuitive, they can be developed.

Using the Index of Sensitivity to Instruction shows that the indices of sensitivity to instruction was not effective enough. However, the Item Difficulty Indices indicated that the instructional treatment was able to reduce the difficulty of the items significantly. This is an indication that the instruction has been successful in developing the students' observational and allied skills. This is because all items were satisfactorily answered by a reasonable number of students.

It can be said with 99% certainty that the test instrument before (and after) developing observational and allied skills was reliable. The coefficient of reliability after developing observational and allied skills is higher than that before.
10. SUMMARY, PRINCIPAL FINDINGS, CONCLUSION AND RECOMMENDATIONS
10.1. SUMMARY AND PRINCIPAL FINDINGS

This study has revealed that the development of observational and allied skills is one of the important aims in the natural sciences curriculum. More than being an important aim, it is also a method by which knowledge is gained in this field. Important and worthwhile as this is, studies show that it is a neglected aspect of the secondary school science curriculum in many countries. In South Africa, it is now more than thirty years after implementing the BSCS approach, but the teaching of natural sciences still struggles with the same didactical problems as before.

The above problem has raised several questions with regard to the status of observational and allied skills in the natural sciences curriculum. Are observational and allied skills intuitive or can they be developed? If yes, then how should these skills be developed?

The main purpose of this research was, therefore, aimed at giving answers to these questions. A hypothesis as formulated in this research indicated that the teaching and learning of natural sciences can contribute to the development of observational and allied skills.

The best way of achieving the above aims as seen by the researcher was to undertake both a literature study and an empirical research.

10.1.1. Principal Findings from the Literature study

The researcher acquainted himself with the writings of recognized authorities and of previous research in this field.
10.1.1.1. The Inductivist theory

The literature study in chapter two has successfully challenged the assumptions of the inductivist theory. These assumptions project an image of a natural scientist as an objective, open-minded, unbiased and possessing an all-powerful and infallible method of ascertaining the truth.

This distorted view on the nature of science has resulted in the development of unguided discovery learning methods. It has been shown that this is not an economical approach to learning. There is a considerable discrepancy between the inductivist assumptions and the characteristics of real scientists. The assumptions are not adequate for developing observational and allied skills.

The inductivist theory has very little to say about the role played by language in observation. It is silent about the role of theory, thoughts and human expectations. Furthermore, the unguided discovery learning methods are time consuming. Not all pupils have the ability to discover for themselves. All these arguments all weigh against the use of the inductivist theory to develop observational and allied skills in this study.

10.1.1.2. The General theory of Observation

The general theory of observation as discussed in chapter 3 has shown that there is a dynamic relationship between theory and observation. Scientific theories are explored, developed and tested by observation. They are accepted, modified or rejected, in part on the strength of observational evidence.

What one chooses to observe and the way in which one chooses to observe are dependent on one's knowledge and one's expectations.
Theoretical assumptions are an essential part of observation. Without theories there are no concepts and without concepts no observations are possible. Theoretical interpretations are part of the observation process itself, not subsequent to it.

The implication of this in a didactic situation is that the learner must be equipped with the necessary terminology that enables him to observe and communicate his observation.

It has also been shown that observations are not infallible or beyond the possibility of doubt. Every statement in science is in principle open to question. Sometimes it is the observations, the data themselves, which have to be adjusted and not the theories which they were collected to test.

Observation has also been depicted as a selective process requiring a focus of attention and a purpose. An observer needs an incentive to make one observation, rather than another. The general theory of observation has been adopted in this study.

10.1.1.3. Categories of Observations

Chapter 4 has shown that observation can be categorized into two main groups; they are simple and controlled observations.

In simple observations, treatments are allowed to develop without control or comparison groups. The observer simply notes and records natural phenomena.

Controlled observation is the procedure of deciding by means of action the conditions under which observation is to operate. There are three ways of controlling observations, namely; adjusting the object which is to be observed, designing the observation procedure and selecting the conditions under which observation is to occur.
In indirect observation (a kind of controlled observation) something observed directly is read as evidence of something else not observed. Here some instruments such as microscopes are used to aid observation directly, others such as centrifuges aid observation indirectly.

Categories of observations, therefore, form a continuum of simple to complex observations.

10.1.1.4. Observational and Allied skills

Chapter 5 has described observational and allied skills along similar lines as the categories of observations in chapter 4. Observational and allied skills are attributes of a continuum of science process skills ranging from observing, the most basic skill, through to experimenting, the most complex set of skills.

Observation is an important component at the core of these science process skills. The quality of observation is of significant importance in determining the validity and strength of all the other science processes. The use of these process skills can be realized through an act of observing.

10.1.1.5. The Nature and Structure of Natural Sciences

The fact that natural natural sciences entail a systematic and active field of inquiry has been stressed in chapter 6. This field of knowledge has been shown to be consisting of the substantive and syntactical structures. The substantive structure is the body of accumulated knowledge while the syntactical structure is the processes by means of which knowledge is obtained. These two structures determine the way in which teaching and learning should take place in the natural sciences.
The implication of the nature and structure of natural sciences as indicated in section 6.3. is that learning should strike a balance between the products of science and the processes by means of which knowledge is accumulated.

10.1.1.6. The Development of Observational and Allied Skills

Chapter 7 has shown that there are two main approaches in the development of observational and allied skills; these are the process approach and the content or product approach.

The process approach implies that learners require formal instruction in order to develop observational and allied skills. According to this approach, classroom activities can be designed to improve the observational process skills in general.

The content approach aims at equipping pupils with the prevailing paradigm or relevant theoretical frame of reference which is held in common by scientists.

It has also been established that these two approaches supplement and complement each other. The best way of developing observational and allied skills is, therefore, to strike a balance between the products of science and the processes by means of which these products are generated. Observational and allied skills can, therefore, be developed within the context of normal classroom science activities.

The literature study, therefore, has confirmed the hypothesis that the teaching and learning of natural sciences can contribute to the development of observational and allied skills.
10.1.2. Principal Findings from the Empirical Research

The empirical research has been undertaken to investigate whether or not the findings in the literature study can be confirmed. In order to provide a stronger test of logic which is characteristic of empirical researches, it has been necessary to re-state the hypothesis as a null hypothesis ($H^0$). Thus: "There is no significant difference between the mean scores of students before and after developing the observational and allied skills".

An alternative hypothesis ($H_1$) has also been stated against the null hypothesis thus: "The mean scores of students after developing observational and allied skills is significantly higher than that before".

10.1.2.1. Empirical Research Strategies

The empirical research strategies as followed in this study are outlined in chapter 8. This chapter has revealed that an observational technique underlies all the other methods in the gathering of data. A testing instrument is seen as complementing rather than substituting an observational technique.

In an ideal situation, therefore, the observational and testing methods would have to complement each other in assessing observational and allied skills.

However, such a thorough investigation has been found to be impractical in a research such as this one. A testing method has been applied simply because it is user-friendly. Testing has a better reliability, it is easier to summarize and interpret, it can be administered more efficiently than the observational technique.
The fact that tests are unable to assess learning goals as they occur naturally has been compensated by setting up a test instrument which requires learners to respond in practical terms by doing something (see Appendix C). Most items in this instrument require a learner to perform a relevant practical work before writing down the answer.

The one group pretest-posttest design has been found to be helpful for this kind of study in which a single class is involved. The researcher has endeavoured to protect the best interests of his subjects by avoiding the use of a control group.

10.1.2.2. Pilot study

As indicated in section 8.3.2.4, it has been decided to use the only available class as a nonprobability sample. A group of thirty second year biology student-teachers at Tivumbeni college of education was chosen as the nonprobability sample.

The pilot study has helped the researcher to make a certain amount of adjustments in his test items and to produce the test instrument in Appendix C.

10.1.2.3. Statistical data on Observational and Allied skills

Developing the observational and allied skills does reduce the difficulty index of test items significantly. This has been illustrated in Tables 9.1 and 9.2 in which the difficulty index was shown to be reduced from 93% before instruction to only 3% after instruction.
I. Reliability

With the exception of test items on the measuring and classifying skills, all items on the observational and allied skills showed an acceptable range of \( r \) values from 0.41 through to 0.76. As interpreted in Table 9.28., this shows a moderate to substantial reliability.

Furthermore, the \( t_r \) values of these skills showed a range of 2.39 through to 6.19. All these values exceed the \( t \) critical values in Appendix E. This information shows that the coefficient of reliability is statistically significant with 28 degrees of freedom on a two tailed test at 5% and 1% levels of significance.

II. Rejection of the Null Hypothesis

With the exception of the observing and experimenting skills, the observational and allied skills showed acceptable \( r \) values ranging from 0.10 through to 0.39. This has been interpreted in Table 9.28 as low to negligible correlation.

The values of \( t \) on the rest of the observational and allied skills as presented in Table 9.27 ranged from 2.94 through to 11.29. All these are values larger than the \( t \) critical values in Appendix E.

The statistical analysis above has enabled the researcher to reject the null hypothesis (\( H^0 \)) that "There is no significant difference between the mean scores of students before and after developing each of the twelve observational and allied skills in Table 5.1. The observed difference is so significantly large that this cannot be attributed to sampling error or chance."
By implication, an alternative hypothesis (H₁) that: "The mean scores of students after developing each of the observational and allied skills in Table 5.1. is significantly higher than that before" is accepted.

This means that the instruction is a treatment which has made a significant contribution to the performance of students in all observational and allied skills.

10.2. CONCLUSION

It should be emphasized that this is not an isolated finding. A related empirical study by Friedler et al (1990:173-191) investigated the impact of developing the observing and predicting skills on a group of learners.

In addition to written tests, Friedler et al's study was made more comprehensive by the use of classroom observations and interviews.

However, students did not actually perform the hands-on activities in the laboratory, but they studied experiments as simulated by the computer. This (MBL) computer programme constitutes a new class of technology which allows students to collect, record, and manipulate data.

Classes were assigned randomly into two groups, the observation and the prediction groups. In the observation group only observational skills were developed. In the prediction group only prediction skills were developed.

After a semester's instructional treatment, the posttest has
shown that there is a very low correlation ($r = 0.01$) between the observation and the prediction groups on the scores of the observing skill. The value of $t = 3.01$ as calculated showed that the test scores on the observing skill on the observation group were significantly higher than those on the prediction group. Thus the instructional treatment helped the students in the observation group to develop more skills in observing. The observation group was also able to exclude inferences from their observation logs.

The scores on the predicting skill were found to be higher on the prediction group than on the observation group. This group was able to make detailed predictions and to justify them on the basis of their previous experiments.

These findings suggested that the ability of students to observe and to predict depended on the instruction they received. Friedler et al (1990:189) are emphatic that students should not be expected to learn these skills without being taught.

Another study by Swinehart's (1987:429-430) in the USA showed that observational skills can be combined with specific concepts in the teaching of natural sciences. Another is that of Burkinshaw (1987:24) who had been involved in the development and improvement of observational skills of primary school children in Britain. In South Africa, Huyser (1992:3) came closer to the studies in the USA and Britain. This study has shown that observation has a very important role in the teaching of biology.

It should be concluded that the best way to develop observational and allied skills is to integrate the science process skills within the normal natural sciences lessons.
10.3. RECOMMENDATIONS

Several recommendations should now be made regarding the natural sciences curriculum in general. The researcher is doing this with considerable trepidation because it is a known fact that science teaching is facing enormous difficulties. One does not lightly suggest things that could add to the burden. However, the potential advantages to be gained from these recommendations are so great that one should explore every possible way of doing this. But before forging on with recommendations, an overview of some of the criticisms levelled against the natural sciences curriculum should be given.

The current natural sciences curriculum is discipline-based, outmoded, overloaded and content driven (De Beer 1996:26, Pare, 1995:171). Programmes in which science is taught as an abstract discipline with the application of science tacked on afterwards still artificially separate school science from real life. As a result it is largely irrelevant to the majority of learners who move into non-science careers when they leave school. Furthermore, the teaching is oriented towards the examination. There is also a lack of laboratories and apparatus. Many teachers are either unqualified or underqualified to teach natural sciences.

De Beer (1996:34) warns that when looking for solutions one should remember that there is interaction between the syllabus content, the teaching methods and strategies of the teacher, and the affective behaviour of pupils. It is against this background that the researcher is making the recommendations for improving the situation.
10.3.1. Paradigm Shift on the content of Natural Sciences

The researcher proposes a natural sciences curriculum which takes account of the need for an education-for-life. This will enable learners to live, work and participate in a society which is increasingly scientific and technological. The content of this curriculum should address current problems. The following are examples of themes that could be studied; teenage pregnancy, diseases, world hunger, air pollution, water resources, hazardous wastes, population growth, drug abuse, alcoholism, land use, diets and smoking.

This holistic approach would break down the traditional barriers between biology, physical sciences and earth sciences. The content should be carefully selected and should be revised continuously in accordance with classroom experiences and assessment results. Particular focus should be given to alternative, indigenous and appropriate technologies.

The driving force behind the proposed instructional programme should be societal or technological issues. The starting point of a unit should be an issue or everyday application rather than a scientific concept. The use of everyday contexts is more motivating than the traditional application approach of "science first, applications afterwards".

There is a growing consensus in the science education fraternity that this is the type of education that schools should offer (De Beer 1996:34, Doidge 1995:110, Pare 1995:138-139 and Perold 1995:16). This new reform movement is currently sweeping across the world and has been very successfully used in Britain. It is variously called the science-technology-society (STS) approach (Doidge 1995:109), thematic approach (Pare 1995:138), holistic approach (De Beer 1996:24) or integrated science (Perold...
1995:5). It must be said that in South Africa, the Radmaste centre at the University of the Witwatersrand is currently trying this programme with the first year students at some colleges of education. The new textbooks for junior secondary schools in Botswana (Science by Investigation) use the local context and local technologies to teach science concepts. In South Africa, a few target schools could be selected from each province to test this new approach.

De Beer (1996:27-28) points out that this integrated approach relies largely on important teaching principles such as self-activity and learning through self-discovery. Thus the development of observational and related skills will become more pronounced. These skills should be taught in their own right as well as being integrated into all learning.

The curriculum should include both issue-based and content-based studies, related to the local and national environment. As Pare (1995:141) asserts, the content should be based on a real world situation using materials which can be seen by learners to have relevance to their lives. In order to gain the skills of scientific investigation, pupils should develop the intellectual and practical skills which will allow them to explore and investigate the world of science. This should take place through activities which progressively include more measuring and systematic thinking. It needs to be restructured so as to give equal opportunity for both the teaching of the content and the development of the appropriate science process skills. The new paradigm should strike a balance between the product, in-put curriculum model and a process out-put approach.

10.3.2. Activities to Develop Observational and Allied skills.

The need to develop observational and allied skills has become
so important, and, paradoxically, so neglected to the extent that the aims which are set in most syllabi are not realized.

It has been asserted in chapter 7 that learners require formal instruction in order to develop observational and allied skills. Classroom activities should be designed to improve the observational process skills in general.

Some activities should be aimed at the development of the five senses. Other activities should ask for similarities and differences. Learners must be given the opportunity of learning how to compare different types of matter to find their similarities and differences. They should learn to classify things or events and identify relationships between variables.

Some other activities should aim at developing the ability to observe phenomena or events. There should be activities to develop the ability to describe change in scientific phenomena. Students must learn to recognize basic properties of common solids, liquids and gases. The ability to examine matter in order to identify its properties is basic to additional learning and discovery.

The best way to develop observational and allied skills is to equip learners with the prevailing paradigm held in common by scientists. In developing observational skills, teachers should provide learners with the relevant theoretical frame of reference. This is done by emphasizing distinctive and discriminating features. For instance, in teaching the skills of microscopy slides of the features to be observed should be displayed in advance in order to provide a suitable frame of reference. This will equip the learners with certain expectations that will enable them to make relevant and appropriate observations.
Students may be asked to consider how to design an apparatus to detect certain entities. In this way they will learn to make hypotheses about the properties of matter, otherwise they cannot design instruments to detect these properties.

Developing observational and allied skills is inextricably tied to teaching the models and ideas of natural sciences. It becomes part of the content teaching in natural sciences.

Students should be given opportunities to perform practical activities. Examples are the handling of chemicals, assembling of apparatus, preparing of microscopic sections and calibration of instruments.

Since measuring is a skill requiring graded exercises, the best way to develop such a skill is to plan science activities which require learners to make use of measuring instruments. It should start with simple instruments such as the ruler, thermometer, balance, stop watch, etc., and gradually increase to more complex ones. The accuracy of measurement made with these tools continues for many years to be a function of the pupil's growing skill.

Learners should be given opportunities to design their own tables, represent their data on graphs, charts, flow diagrams, etc. Following directions to use them is not the same as choosing to use them in appropriate circumstances.

10.3.3. Alternatives to Expensive Laboratory Facilities

South Africa's annual education budget is, in terms of percentage ratio, one of the highest in the world. Notwithstanding the above, many schools are still without adequate laboratory facilities.
As a result, little or no hands-on activities take place which could result in the development of observational and allied skills. It does not seem as if it will be possible to address this problem in the foreseeable future.

Science educators do not have to give up their responsibility of developing pupils' observational and allied skills simply because expensive laboratories cannot be afforded.

An alternative to expensive laboratories is proposed. Each school could be provided with a minimum of about 40 seat science and technology centre for every 250 learners. Such centres should have secure storage space, utilities (gas, electricity and water) along the walls, fixed tables along the walls and tables in the central areas.

Furthermore, low-cost laboratory resources in the form of kits should be provided.

The ministry of education should ensure that teachers are workshopped to use these facilities and apparatus to develop observational and allied skills. The conventional science and technology laboratory facilities should still be supplied but only to those schools which have qualified science teachers. Proof of regular use should also be required.

The idea of low-cost laboratory facilities is widely supported by science education practitioners (see De Beer 1995:30-31) and Perold 1995:3).

10.3.4. Shifting the goal-posts on Assessments

The strong influence that assessment has on how subjects are taught is a reality which should not be escaped. Presently, the norm-referenced assessment is in vogue. The practice in this
kind of assessment is to compare the performance of learners to some 'normal' performance which is determined from year to year. Examination marks are adjusted to conform to the 'norm' (Perold 1995:20).

The recall of facts has come to be a major part of the norm-referenced assessment. Assessments have a stranglehold on what is taught and how it is taught. If assessments focus on the testing of factual knowledge, as is the case in South Africa, then the best teaching methods are those which facilitate the transfer of factual knowledge to the learners (Sanders 1993:13). The content-laden tests and examinations leave teachers with very little time for hands-on activities. As a result the very worthwhile syllabus goals of developing observational and allied skills are rarely achieved.

An alternative form of assessment in natural sciences is crucial to improving instruction. Assessments that focus on, among other things, observational and allied skills would send teachers very different messages about the kinds of instructional activities valued.

An integrated natural sciences curriculum needs new forms of assessments which are consistent with the style and purpose of the curriculum. The researcher is proposing for the introduction of a different type of assessment called a criterion-referenced assessment. Here the learner first demonstrates mastery of the required knowledge with an emphasis on understanding, application and interpretation. Secondly the learner demonstrates mastery of the required observational and allied skills before moving on to the next stage. This has an advantage that both the substantive and the syntactical structures as discussed in chapter 6 are assessed.
The development of observational and allied skills is stated as one of the goals in the natural sciences curriculum. Sanders (1993:14) asserts that any goal which is important enough to be in the curriculum is important enough to be assessed.

A variety of techniques could be used in this assessment, for instance, oral work, open book tests, projects and assignments, group work, practical work as well as written tests and examinations.

For purposes of evaluating the curriculum itself, the following aspects as suggested by Perold (1995:20) should be assessed in samples of schools from time to time:

* Attitudes such as interest, motivation, participation and appreciation of scientific procedures.

* Skills such as critical thinking and decision-making.

If the examination is structured so as to ensure that observational and allied skills are assessed, teachers will make sure that these skills are integrated to the curriculum. It is suggested here that the science process skills should form about 40 to 50 percent of the examination. Examinations should be more skills-oriented, they should assess not only what facts can be remembered, but also what can be done by the learners.

Continuous assessment is recommended, with a decision at the end of every stage as to whether the learners have mastered the required competences identified for that stage.

It should be emphasized that this shifting of the goal-posts in assessment should be treated as an evolutionary rather than a revolutionary process.
10.3.5. In-Service Training of Teachers

South Africa has many unqualified and underqualified teachers in areas of natural sciences. This state of affairs must change. It cannot be business as usual in our schools, colleges and technikons. Perold (1995:14) states it emphatically that teachers are the true agents of curriculum reform. They are perceptive and creative curriculum developers in their own right. However, the lack of subject knowledge, conservatism in methods and poor professional attitudes inhibit curriculum transformation.

The researcher is proposing for the stepping up of teacher development programmes. Adequate support in terms of financial resources must be offered to teachers in the form of in-service training so that they can provide good teaching.

The curriculum changes such as the ones being proposed in this research clearly have far reaching implications as far as teacher development is concerned. The introduction of an integrated natural sciences curriculum would immediately deskill teachers when teaching outside their subject areas. In a system where there is a shortage of science teachers, even more in-service training would be needed. The teacher should have a broad cross-disciplinary knowledge.

10.3.6. Pre-service Training of Teachers

As for the pre-service training of teachers, the researcher subscribes to the COTEP (1995:13) document. A ray of hope is emerging from the recommended norms and standards for teacher education in this document. This COTEP document empowers all the nine provinces to undergo metamorphosis from a content based curriculum to a competence based model. This reflects an attempt
to bring about an institutionalized change.

The intention is to improve the quality of teacher education by the development of competences. The teacher must not only know something well, but must be able to do something well. This document does not merely reflect a revision of the criteria, it depicts a radical paradigm shift. Whereas the criteria presented a product, input model, this document presents a process, output approach.

10.4. SHORTCOMINGS AND LIMITATIONS OF THIS RESEARCH

Shortcomings and limitations in this research are found mainly in the empirical study. They are as follows; use of testing methods only, use of a nonprobability sample and the lack of a control group.

10.4.1. The use of a Testing method only

When discussing the methods of assessment in section 8.3. it has been stressed that the ideal situation would be to use both the testing and observation methods. However, the observation method could not be applied because of the disadvantages listed in section 8.3.1.1. It has been decided to use the testing method only because of its usability.

The shortcoming of this method is that it is unable to assess learning goals as they occur naturally.

10.4.2. The use of a Nonprobability sample

As discussed in section 8.3.2.4., the usual strategy to obtain a
representative sample is to draw a random sample. This makes it possible that every unit has exactly the same chance or probability of being included in the sample.

This desirable sampling procedure could not be used in this study because, for a single researcher, it would simply not be possible to obtain a representative sample of the natural sciences learners in South Africa.

Secondly, majority of the test items are of a practical nature requiring certain laboratory equipment which can conveniently be set in one venue, getting a representative sample to such a venue would be very expensive.

The nonprobability sampling procedure has been found to be more affordable because it uses available classes as samples.

Its shortcoming is that it is less representative. It does not accurately reflect the characteristics of the population of interest. As a result it may lead to unwarranted or limited generalizations.

10.4.3. The Application of the one Group Pretest-Posttest Design

The shortcoming of the one group pretest-posttest design as applied in this study is that it is a very weak one because of lack of comparison with a control group. Rather, the same test was given twice to the same group, before and after developing their observational and allied skills.

This design is susceptible to error from all of the extraneous variables which threaten the internal validity of the test. These are history, maturation, effects of testing and instrumentation.
10.5. SUGGESTIONS FOR FUTURE RESEARCH IN THIS TOPIC

The problem that has triggered this research is the lack of observational and allied skills in the teaching and learning of natural sciences. The analysis of this problem in section 1.1.2 revealed that the natural sciences are presented as a detached intellectual activity principally concerned with learning facts. The teacher is regarded as the possessor of knowledge which should simply be passed on to the pupils.

Consequentially, the assessment of student performance places heavy emphasis on the pupils' ability to recall information.

A solution to this problem as seen by the researcher is to develop large-scale instructional and assessment models which are based upon the observational and allied skills. These models should take cognizance of the substantive and the syntactical structure of natural sciences. Examples of instructional models are found in Appendix G. These and similar models could be developed and researched by pilot-testing them in schools.

Jenkins and Macdonald (1989:62-64) have rightly pointed out that the alternative instructional models patterned after the methods of science itself will provide opportunities for developing the science process skills. Teachers in these innovative classrooms would engage learners in such thinking behaviours by using a variety of experimental activities involving structured laboratory exercises. Nearly all of these models should use hands-on or exploratory instructional activities as means to strengthen students' observational and allied skills.

As indicated in section 10.3.4., large-scale hands-on assessment models should also be developed.
10.6. SUMMARY

The problem as identified in this study is the lack of observational and allied skills in the natural sciences curriculum. The researcher's main focus in this study was to determine whether and how observational and allied skills can be developed.

The literature study has shown that an observation process is theory dependent. Theories may be conceived of prior to the making of observations. This finding undermines the inductivist claim that knowledge of the natural sciences always starts with observation.

The implication of this finding is that science educators should pay attention to the learners's intuitive views of the world which often differs from real science. They should provide pupils with experiences which challenge the learners's views of the world.

The observational and allied skills have been described as attributes of a continuum of science process skills ranging from observing through to experimenting.

The common denominator in anyone of the science process skills as discussed in this study is observation.

It has been made explicit from this study that learners, without instruction, are not capable of making scientific observation. Developing observational and allied skills is not only a means of teaching and learning, but it is also the end towards which all scientific endeavours should aim.
The empirical research has enabled the researcher to reject the null hypothesis (H⁰) that "There is no significant difference between the mean scores of students before and after developing each of the twelve observational and allied skills in Table 5.1. The mean scores of students after developing each of the observational and allied skills in Table 5.1. has been found to be significantly higher than that before.

The empirical research, therefore, confirmed the findings throughout the literature study that observational and allied skills can be developed within the context of normal science teaching.
BIBLIOGRAPHY

The bibliography includes only the sources that have been cited in the text.


American Association for the Advancement of Science, 1965. The Psychological Basis of Science - A Process Approach, p. 65-68


COTEP is an acronym for 'The Committee for Teacher Education Programme.' This Committee has been established to set up norms and standards for teacher education in a New South Africa. 1995.


(i) The candle activity

Students are given a candle, a box of matches and a ruler. They are told to describe the unlit candle as completely and accurately as possible, then to light the candle and continue with the description. Students are cautioned not to confuse observations with interpretations. They are told that to say that the top of the burning candle is wet with a colourless liquid is to make an observation, but to suggest a composition for this liquid is to offer an interpretation. Students are told that they cannot report having observed liquid paraffin, presumably because all that can be observed (in the inductivists' view of observation) is that there is something that looks like liquid paraffin. One cannot observe its (chemical) composition. (Chemistry: Experimental Foundations 1970:585).

(ii) How well do you Observe Activity

About fifteen to twenty (15-20) small objects are placed on a tray. The tray is then covered. When the tray is uncovered each student gets 10 seconds to observe the objects on a tray. The teacher keeps time. Once the student has seen the objects on a tray he goes back to his seat and list as many as he can. The student then compares his list with others in class to see who has named the most objects (Heimler & Price 1981).
APPENDIX B

(i) Observing Starlight Deflection

Norris (1985:821) describes how Sir Arthur Eddington observed starlight deflection during a total solar eclipse on 29 May 1919 on the Isle of Principe in the Gulf of Guinea, West Africa. Starlight deflected at the edge of the sun by 1.61 seconds of arc, ±0.30 seconds of arc.

This observation, together with the one made during the same eclipse at Sobral, North Brazil, of 1.98 seconds +/-0.12 seconds, are usually taken as confirmations of Einstein's General Theory of Relativity which predicted a deflection of 1.74 seconds of arc. Norris (1985:821) quotes Eddington's description as follows:

The observers had more than a month on the island to make their preparations. On the day of the eclipse the weather was unfavourable. When totality began the dark disc of the moon surrounded by the corona was visible through cloud, much as the moon often appears through cloud on a night when no stars can be seen. There was nothing for it but to carry out the arranged programme and hope for the best. One observer was kept occupied in changing the plates in rapid succession, whilst the other gave the exposures of the required length in a screen held in front of the object glass to avoid shaking the telescope in any way...Our shadow-box takes up all our attention. There is a marvellous spectacle above, and, as the photographs afterwards revealed, a wonderful prominence flame is poised a hundred thousand miles above the surface of the sun. We have no time to snatch a glance at it. We are conscious only of the weird half-light of the landscape and the hush of nature, broken by the calls of the observers, and the beat of the metronome ticking out the 302 seconds of totality.

(ii) Observing the Center of the Sun

Norris (1985:822) gives an account of how the center of the sun is observed. The observations are made by detecting neutrinos, subatomic particles which are produced when hydrogen atoms at the center of the sun fuse to form helium. Each fusion of four hydrogen atoms into a helium atom produces two neutrinos, which can pass undisturbed through the entire radius of the sun to emerge from its surface with high energy. This is possible since the cross section of interaction of neutrinos with other matter is so low that the chances of a neutrino being absorbed by the sun on its way through the sun's interior is negligible. Neutrinos thus emitted from the sun are detected at the earth by means of a large tank of cleaning fluid buried a mile below the surface of the earth. The cleaning fluid, containing chlorine, serves as a detector when neutrinos reacting with individual atoms of the chlorine convert them into argon, which is, in turn, detectable.

Measuring the intensity of neutrinos falling on the earth is regarded by astrophysicists as an observation of great significance. Norris (1985:822) quotes remarks made by two astrophysicists as follows:
This measurement not only would be an experimental tour de force but would produce an astrophysical datum of great importance. There is no way known other than by neutrinos to see into the solar interior. There is no other known direct experimental observation of nuclear reactions occurring at high temperatures in the center of a star. The rather elaborate theoretical structure of stars is built upon inference from known physical principles rather than from measured facts. Of course, the inferences are cogent ones and are generally accepted as being correct. There can be no doubting, however, the philosophical importance of direct measurement.

At the moment, the sun is the only astronomical object which can confidently be predicted to emit detectable neutrino fluxes. These neutrinos originate in the very hot stellar core, in a volume less than a millionth of the total stellar volume. This core region is so well shielded by the surrounding layers that neutrinos present the only way of directly observing it. Thermonuclear reactions are sufficiently well understood that detailed models of the solar structure can be drawn up... A single measurement of the solar neutrino flux would enable these models to be verified. On the other hand, a definite disagreement would call for a major revision of current thinking on stellar structure and evolution.
APPENDIX C

Test Items for Observational and Allied Skills. This instrument was used for both pretest and post-test.

Name of Student _____________________________

EACH QUESTION IN THIS TEST PAPER SHOULD BE ANSWERED IN THE SPACES PROVIDED FOR THAT PARTICULAR QUESTION.

Most pictures and diagrams in this appendix are included for the benefit of the reader. In most items the students are referred to the actual practical set-up (hands-on activity) which cannot be reproduced here. Model answers are given in Appendix D.

The statements/phrases 1 through to 6 are followed by five possible answers. Only ONE answer is correct. Perform the necessary practical activities where applicable. This will aid you in selecting the correct answer. ENCIRCLE the alphabet corresponding to the correct answer.

Question 1 and 2 are based on the list below:

i. Sight
ii. Thought
iii. Hearing
iv. Smell
v. Taste
vi. Feel
vii. Touch

1. Indicate any two words which do not belong to the list.
   A. i and ii
   B. i and iii
   C. ii and iii
   D. ii and vi
   E. iv and vi

2. One of the aims of biology teaching in the STD syllabus is that students should make their own observations of specimens and experiments. The concept observation as used in this aim has to do with:
   A. i, ii, iii, iv and v
   B. i, iii, iv, v and vi
   C. ii, iii, iv, v and vii
   D. iii, iv, v, vi and vii
   E. i, iii, iv, v and vii

Station 3

Select the necessary materials from this station and prepare a wet mount of the specimen in the petri dish. Observe the
specimen under a microscope and compare it with the diagrams A, B, C, D and E below.

3. Encircle the alphabet against the diagram on the paper which corresponds to the specimen that you see under the microscope.

Station 4

Select the necessary materials from this station and prepare a wet mount of the specimen in the petri dish. Observe the specimen under the microscope and compare it with the diagrams A, B, C, D and E below.

4. Encircle the alphabet against the diagram on the paper which corresponds to the specimen that you see under the microscope.

Station 5.

Measure about 10ml of sunflower oil into the test tube. Place the test tube in the retort stand and heat it in an open flame using a bunsen burner. When it boils, carefully introduce about five maize grains into it.

5. Write down any one observation of the things that happen.

By now it should be clear to you that the final product is a popcorn. When the popcorn has cooled down, make further observations to verify that the product is indeed a popcorn and not something else.

6. Write down any of these further observations of the popcorn.
Station 7

You are provided with about 10ml of a certain substance in test tube A and 10ml of another substance in test tube B. Hold the test tubes in your hands and carefully add the substance in test tube B to the substance in test tube A. What happens?

7. Record your observations

Transfer about one third of the combined contents of test tube A to the evaporating basin. Place the evaporating basin on the tripod stand and heat it gently with a bunsen burner. What happens?

8. Record your observations

Station 9

Questions 9 and 10 are based on the materials provided in station 9. These are a 100ml measuring cylinder, water supply, a small stone with a code number, a very thin nylon string and triple beam balance.

9. Measure the mass of the stone. Code _____ Mass _____ g

10. Measure the volume of the stone. Code _____ Volume _____ ml

Station 11

The label of a solution from a reagent bottle on the teacher's desk has been removed. Collect a small sample of the solution using a test tube. Add two to three drops of iodine into the test tube with the sample of an unknown solution. Observe what happens.

11. From your observation, give the name of the unknown solution.
Figure 8.1. is a picture of an animal you have not studied. Observe its physical features closely.

12. What can you infer (conclude) about its primary diet?

Question 13 and 14 are based on Figure 8.2. Imagine you were a scientist visiting an uninhabited island and discovers the insects shown in the form of diagrams in Figure 8.2.
13. Classify the animals into two groups according to some external characteristic.

14. Write down one characteristic which is common to all the animals of the uninhabited island in Figure 8.2.

Station 15

Study the experimental set-up in this station and answer the questions that follow. The dialysis tube is filled to about three-quarter with sugar solution. The beaker contains eosin coloured water. This experimental set-up has just been made. Hint: The dialysis tube is selectively permeable.

Station 16

Study the experimental set-up in this station and answer the questions that follow. The dialysis tube is filled to about three-quarter with eosin coloured water. The beaker contains sugar solution. This experimental set-up has just been made.

15. Predict what will happen to the dialysis tube after about 12 hours.

16. Predict what will happen to the dialysis tube after about 12 hours.
Questions 17 and 18 concerns graphs A B C D and E below.

17. Which graph best represents the relationship between molecular weight and melting point as indicated by the following data:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molecular Weight</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>32</td>
<td>-97.8</td>
</tr>
<tr>
<td>ii</td>
<td>46</td>
<td>-117.8</td>
</tr>
<tr>
<td>iii</td>
<td>60</td>
<td>-127.0</td>
</tr>
<tr>
<td>iv</td>
<td>74</td>
<td>-136.8</td>
</tr>
</tbody>
</table>

18. Which graph best represents the relationship between volume and temperature of a sample of gas as indicated by the following data:

70°C; 29ml, 30°C; 20ml, 80°C; 31ml, 40°C; 22ml, 60°C; 27ml and 50°C; 25ml.

Station 19

The apparatus in station 19 is intended for an experiment to investigate the effect of light stimulus on the direction of growth of stem tips. Study this apparatus and answer questions 19 and 20.
19. Using this apparatus, how would you make sure that plant A receives light on all sides?

20. Using this apparatus, how would you make sure that plant B receives light only on one side?

Station 21

On the table are three beakers filled with water. In each is an inverted funnel containing several sprigs of fresh Elodea. On the funnels are test tubes. The first set-up A is in direct light provided by a 100 watt lamp. The second set-up B is about one meter distance from the lamp. The third set-up C is completely concealed under a heavy cardboard box. All the set-ups have been made 12 hours ago. A solution of Na₂HCO₃ is provided in a 2L bottle.
21. From your observation of the experimental set-up, give a hypothesis (speculated statement or an educated guess) concerning the problem that is being investigated.

Station 22

Study the apparatus set-up and answer the question that follows.

The test tube with a one-holed stopper has sugar solution and yeast cells. There is a thin film of liquid paraffin over the sugar solution and yeast cells. The test tube without a stopper has lime water. The sugar solution had to be boiled and cooled to room temperature before adding the yeast cells. This is intended to expel any oxygen.

22. What is the aim with this experimental set-up?

Questions 23, 24, 25 and 26 are based on the observational information below.

Khetile had a vegetable garden. In her garden she had cabbages,
lettuce, carrots and potatoes. Khetile observed that many more snails were found on the cabbage plants than on the other vegetables. She then asked herself the following question: Why are snails found most often on cabbage plants? Do snails prefer cabbage leaves than other types of vegetable leaves?

Khetile decided to carry out an investigation on the feeding preferences of snails. First of all, she made the following statement: Snails eat cabbage leaves in preference to lettuce, carrots and potato leaves. To test this statement Khetile did the following:

She placed a snail in a bucket with the lid on for two days. During this time, the snail was not fed. She then chopped up piles of the four different leaves and placed them on a piece of paper as shown. She made sure that there were 10g of each leaf type.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>carrots</td>
<td>potato</td>
<td>lettuce</td>
<td>cabbage</td>
</tr>
</tbody>
</table>

Khetile then put the snail at the point marked X. She observed that the snail moved straight to the cabbage pieces. She concluded that snails prefer to eat cabbage leaf more than any other leaf type.

In this investigation, what is the:

23. dependent variable?

24. independent (manipulated) variable?

25. Indicate one way in which this test was not fair.

26. What is wrong with Khetile's conclusion?
Station 27

Questions 27 and 28 concern the dissected model of the heart in station 27. When you examine this model carefully, you will notice that the ventricular wall is thicker than the atrial wall.

27. Give a reason why this is so.

28. Why is the right ventricular wall thicker than the left ventricular wall?

Question 29

The Watson-Crick model on the structure of DNA is in the form of a double helix. Use the tooth picks and the plasticine supplied to construct a double helix model.

29. Call the teacher when you finished constructing this model.

Station 30

The structural formula for methane is as follows:

```
H
\_\_\_
H - C - H
  |     |
H
```

In the paper, it appears to be two dimensional. Use the tooth picks and the plasticine supplied to construct a methane model to show that it is in fact three dimensional.

30. Call the teacher when you finished constructing this model.
APPENDIX D
MODEL ANSWERS

1. D
2. E
3. B
4. A
5. Maize burst open. There is a popping sound. (Any one)
6. It tastes popcorn. It smells popcorn. (Any one)
7. Increase in temperature (haptic change). Effervescence of gas from a solution (Visual changes). (Any one)
8. Evaporation takes place. Precipitation of a solid from solution. (Any one)
9. Scoring: A learner's response within ± 2,0g of the researcher's determined mass will receive 1 point. A response range greater than ± 2,0g will receive no credit.
10. Scoring: A learner's response within ± 2,0ml of the researcher's determined volume will receive 1 point. A response range greater than ± 2,0ml will receive no credit.
11. Starch
12. It is a herbivore
13. Those with hairy antennae and those without hairy antennae. Or Those with long antennae and those with short antennae. Or Those with a broad abdomen and those with a thin abdomen. Or Those with a tail and those without a tail. Or any other suitable classification. 1 point for any one of these answers.
15. It will absorb the water from the beaker. It will increase in mass and volume. It will become turgid. Any one of these.
16. Water from the dialysis tube will move osmotically into the beaker. It will decrease in mass and volume. It will shrink. Any one of these.
17. B
18. E
19. Plant A is placed vertically on the rotating disc of the clinostat. The plant is then covered with a box with one hole to allow light to enter.
20. Plant B would be placed like plant A, but the clinostat would not be switched on to rotate.
21. An increase in the light intensity has a positive influence on the rate of photosynthesis.

22. To demonstrate that yeast cells can respire anaerobically.

23. The dependent variable is the snail's choice of leaf.
24. The independent variable is the leaf type available.

25. Only one snail was used. 
   Investigation was done only once. 
   Different distances to various leaf types. 
   Distance between piles unequal.

26. Results obtained with one snail cannot be generalised for all snails. The investigation was not for any leaf type, but for only four leaf types. Any one of this.

27. This is because the ventricular wall pumps blood to the lungs and the rest of the body, atrial wall does not pump blood.

28. This is because the right ventricle is responsible for pumping blood to the rest of the body whereas the left ventricle pumps blood only to the lungs.

29.

30.

Double Helix

Methane Model
APPENDIX E

Student's (t) Distribution table for correlated means. This table is aimed at determining whether there is a significant difference between the mean scores of testees before and after developing their observational and allied skills.

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<th>One-tailed 1%</th>
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APPENDIX G

Model Lessons

All lessons are presented to a group of second year biology student-teachers at Tivumbeni College of Education.

Lesson 1

A. Orientation:

When this lesson was first presented during the pilot study, it was assumed that learners had already dealt with the parts of the compound microscope and their uses. This assumption was dropped as part of the improvement when the lesson was presented as treatment for the second time. The researcher gave a short lecture on the names of parts of the microscope and their uses. The lesson is planned for one period of 60 minutes and is presented in the laboratory.

B. Theme and Topic:

Theme: Microscopy.
Topic: The preparation of a wet mount of an onion cell on a microscope slide for observation under the microscope.

C. Aims and Instructional Objectives

Aims: Learners should acquire the skills necessary to:

* use a compound microscope.
* prepare a wet mount for observation under the microscope.

Instructional Objectives: At the end of the lesson the learners should be able to:

* make a wet mount preparation of onion cells on a microscope slide.
* use the high power and low power objectives to focus the object on a microscope slide.

D. Teaching and Learning Activities:

The teaching activities are a combination of laboratory, lecture and demonstration methods. When this was presented for the first time in the pilot study, learners followed instructions in a worksheet on how to make a wet mount preparation of onion cells. During the second presentation of this lesson, learners were not left to follow instructions on the worksheet by themselves. The researcher actually demonstrated the procedure in each paragraph separately.
E. Requirements.

Each learner is supplied with a compound microscope, microscope slide, paper tissue, drop pipette, dissecting needle, dissecting knife, forceps, petri dish, iodine solution, filter paper and glass beaker with distilled water.

F. Procedure:

1. Remove the dry scale leaves from an onion bulb.

2. Cut a segment of the fleshy leaves from an onion bulb using a dissecting knife. Divide the segment lengthwise into thinner strips. Place these strips in a petri dish containing water.

3. Clean a microscope slide with a paper tissue.

4. Place a drop of water in the centre of the microscope slide with a clean pipette.

5. Remove an onion strip from the water with a dissecting needle. Remove the inner membrane (epidermis) from the piece of fleshy leaf by using a pair of forceps.

6. Place the membrane carefully in the drop of water on the glass slide. Stretch the membrane with a dissecting needle to remove folds, if any.

7. Place a tiny drop of iodine solution in the water drop with membrane. This is to stain some parts of cells for more visibility.

8. Carefully place a cover slip over the membrane. (This skill is demonstrated to students by the teacher).

9. Use the filter paper to absorb excess iodine-water solution from the microscope slide and cover slip.

10. Place the microscope slide on the microscope stage under the objective lens with the lowest magnification (10x).

11. Turn the focussing knobs until the membrane is clearly visible.

12. Make a labelled diagrammatic representation of the object under the microscope.

13. Repeat 12 above using the highest magnification (40x).
Lesson 2

A. Orientation

Learners already know the different types of measuring instruments and their uses. These are measuring cylinder, burette, pipette, ruler, calipers, stop-watch, thermometer and triple beam balance. The lesson is planned for two periods of 60 minutes each and is presented in the laboratory. Procedure 1 to 6 takes the first 40 minutes, 7 to 18 the second 40 minutes and 19 to 22 the last 40 minutes.

C. Theme and Topic

Theme: Measurement as a precise kind of observation.
Topic: The measurement of liquid volume, time, distance, mass, diameter and temperature.

D. Aims and Instructional Objectives.

Aims: Learners should be familiar with the uses of a burette, measuring cylinder, pipette, stop-watch, ruler, caliper, triple beam balance and thermometer. They should be able to select an appropriate measuring instrument when faced with a measuring task.

Instructional Objectives: At the end of this lesson learners must be able to:

* use the measuring cylinder, burette and pipette to measure the volume of a liquid.
* use the stop-watch to measure time.
* use the ruler to measure distance.
* use a pair of calipers to measure diameter.
* use a triple beam balance to determine mass.
* use the thermometer to measure temperature.
* write down the correct measuring units.

E. Teaching and Learning Activities

The teaching activities are a combination of laboratory, lecture and demonstration methods.

F. Requirements:

Each learner is supplied with a 50ml burette, retort stand, photographic film canister, 25ml pipette, 100ml measuring cylinder, 250ml glass beaker filled with water, and stop-watch.

G. Procedure.

1. Use the ruler to measure the height of the film canister.
   (The teacher now explains what a fault of parallax is).
2. Write down your observation (measurement) using the correct measuring units. (The teacher explains that the correct measuring units are millimeters), i.e. mm.

3. Use a pair of calipers to measure the external and internal diameters of a film canister.

4. Write down your observation (measurement) using the correct measuring units. (The teacher explains that the correct measuring units are millimeters), i.e. mm.

5. Use the data in 4 above to determine the wall thickness of the film canister. (The teacher explains that this = external diameter minus internal diameter, this is still in mm units).

6. Measure the mass of the film canister using the triple beam balance. (The teacher demonstrates how this is done and explain that the correct measuring units are grams (g)).

7. Use a glass beaker to fill the inverted burette to a zero mark. (The teacher demonstrates how this is done. The concept of 'meniscus' is explained. Learners are warned to avoid the fault of parallax as explained earlier in this lesson.

8. Put the film canister below the tap of the burette.

9. Carefully open the burette tap and fill the film canister to the brim with water.

10. Take a reading on the burette and note it down. (The teacher explains that the correct measuring units are milliliters (ml)).

11. Set the triple beam balance at zero. (The teacher demonstrates how this is done).

12. Carefully lift the film canister with water and put it on the pan of the triple beam balance. Do not spill any water.

13. Determine the mass of water plus container. (The teacher explains that the correct measuring units are grams (g)).

14. Determine the mass of water only. (The teacher explains that this = mass of water plus container minus mass of container. See 6 above for the mass of the container).

15. Carefully empty the film canister into a measuring cylinder and take a reading on the measuring cylinder.

16. Write down your observation (measurement) using the correct measuring units, i.e. ml.

17. Compare this reading with that in 10 above and determine which of the two pieces of apparatus is more accurate.
18. Use a pipette to measure 25ml of water from a glass beaker into the film canister. (This skill is first demonstrated to students, it is also explained that a small column of water that remains at the tip of the pipette does not have to be blown out).

19. Measure the temperature of water in the glass beaker. (The teacher first demonstrates how a thermometer is held and how the reading is taken). The units of measurement here are degrees celsius (°C).

20. Fill the burette to a zero mark as in 7 above.

21. Put the 250ml beaker below the tap of the burette. (At this time the teacher demonstrates to the learners on how to use a stop-watch.

22. Start a stop-watch simultaneously as you open the tap of the burette fully to allow free flow of water. Stop the watch immediately when the level of water reaches a 50ml mark. Record the time taken for 50ml water to flow to a glass beaker. The units should be in minutes or seconds or both.
Lesson 3

A. Orientation

This lesson has been extracted from an inductivist theory of observation (see Appendix A (i)). It is designed to teach the distinction between an observation and an inference. It is planned for a 60 minute period in the laboratory.

B. Theme and Topic:

Theme: The distinction between observation and inference. Topic: Observation of the candle.

C. Aims and Instructional Objectives

Aims: Learners should know what it is to observe and to infer.

Instructional Objectives: At the end of the lesson the learners should be able to:

* distinguish between observation and inference.
* list all the senses that are involved in observing.
* observe using five senses where it is appropriate and safe to do so.
* make an inference based upon an observation.

E. Teaching and Learning Activities

The teaching activities are a combination of laboratory and lecture methods. Learning is by observing and inferring.

F. Requirements:

Learners are supplied with small pieces of candles and a box of matches.

G. Procedure.

1. Observe the unlit candle as completely and accurately as possible. Write down your observations.

2. Light the candle and observe what happens. Write down all your observations.
H. Discussion

Learners are told to discuss their observations. They are told that observation involves the use of five senses, namely; sight, hearing, touch, smell and taste. Hence it should not be confused with an inference. They are told that to say that the top of the burning candle is wet with a colourless liquid is to make an observation, but to suggest a composition for this liquid is to make an inference. Learners are told that they cannot report having observed liquid paraffin, because all that can be observed is that there is something that looks like liquid paraffin. One cannot observe its (chemical) composition.
Lesson 4

A. Orientation

Usually an investigation begins when a scientist's curiosity is aroused as he observes and makes notes about something that interests him. Hlulani noticed that beetles are always found resting under large stones and never seem to be found elsewhere. In order to satisfy his curiosity, he asked himself a question: "Why are beetles found only under stones? Is it because it is moister there than in other places? Is it because it is darker there than in other places? Is it because it is cooler there than in other places?"

B. Theme and Topic

Theme: Science Process skills
Topic: The development of skills allied to observation.

C. Aims and Instructional Objectives:

Aims: Students should master the science process skills allied to observation, they should be able to investigate natural phenomena.

Instructional Objectives: At the end of the lesson learners must be able to:

* formulate a hypothesis based on observed facts
* make predictions based on observed facts
* control experimental variables
* make operational definition

D. Teaching and Learning Activities

The teaching and learning activities are a combination of discussion and lecture methods. Learners are divided into several groups of about 4 to 5 students each. The groups discuss a given experimental procedure.

1. Hlulani's tentative explanation is that it is moister there than on the exposed earth.

2. He believed that the beetles would move away from the stones if the surrounding soil became moister.

Hlulani's tentative explanation could be verified by undertaking the following activity:
E. Procedure

3. A glass chamber could be constructed and partitioned by means of a glass wall. About two holes could be made on the glass partition for beetles to crawl through at will.

4. In one chamber a drying agent could be placed in order to create a dry air condition. The other chamber could be fitted with a wet cotton wool to create damp air condition.

5. Three beetles could be placed in the dry chamber, another three in the wet chamber. They could be left undisturbed for about two days.

6. If the beetles collect at the wet side of the chamber and leave the dry side, it could be concluded that Hlulani's tentative explanation was correct.

Learners are told that, Hlulani's tentative explanation in 1 above is regarded as the hypothesis. Hlulani's belief in 2 above is regarded as the prediction. The activity that could be undertaken to verify Hlulani's hypothesis is regarded as an experiment.

The setting of a question which can be answered by performing an experiment is the first step in the scientific method. This is known as making of operational definition. The next step is to suggest a likely answer to the question. A hypothesis is the name given to a statement that attempts to provide a reasonable answer to a scientific question.

The creation of dry air condition in one chamber and wet air condition in another air chamber (see 4 above) is regarded as the control of variables. The air condition (humidity) is a variable that is under the control of the experimenter. This is regarded as the manipulated or independent variable. It is the factor that the experimenter deliberately changes during the experiment to note what effect it has.

The number of beetles in each chamber at the end of the experiment (see 6 above) indicates the condition that changes when the independent variable changes. This condition is regarded as the responding or dependent variable.
Lesson 5

A. Orientation

Students know that in some species of plants, pollen grains germinate in water. In others it is known that a solution of sugar of a very specific concentration is necessary to stimulate the germination of pollen grains. This lesson is planned for one period of 60 minutes in the laboratory.

B. Theme and Topic:

Theme: Development of higher order science skills.
Topic: The development of interpreting and predicting skills. Controlling of experimental variables.

C. Aims and Instructional Objectives

Aim: Learners should know what it means to interpret observed facts and make predictions from observed facts. They should know what it means to control experimental variables.

Instructional Objectives: At the end of the lesson the learners should be able to:

* formulate a conclusion based on the observed facts
* predict experimental results from observed facts
* control experimental variables

E. Teaching and Learning Activities

The teaching activities are a combination of laboratory and lecture methods. Learners are divided into several groups of 2 to 3 students each. Learning is by interpreting, predicting and controlling of variables.

F. Requirements:

Each group of learners is supplied with the following:

pollen grains of Aloe, distilled water, thermometer, petri dishes, various solutions of glucose, microscope, cavity microscope slides and cover slips.

G. Procedure.

1. Pollen grains from young flowers of Aloe are placed in distilled water for 24 hours at 25°C.

2. Pollen grains are then put into various solutions of glucose on cavity slides and kept at the same temperature for several hours.
3. Examine each slide under a microscope and calculate the percentage germination of the pollen grains.

4. Tabulate your results.

<table>
<thead>
<tr>
<th>Glucose Concentration g/litre</th>
<th>Percentage Germination</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>71</td>
</tr>
<tr>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>90</td>
<td>67</td>
</tr>
<tr>
<td>120</td>
<td>21</td>
</tr>
<tr>
<td>150</td>
<td>4</td>
</tr>
<tr>
<td>180</td>
<td>1</td>
</tr>
<tr>
<td>210</td>
<td>0</td>
</tr>
<tr>
<td>140</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5. The effect of glucose on pollen germination

H. Discussion

Learners are told that glucose concentration is under the control of the experimenter and is, therefore, a manipulated or independent variable. The percentage germination is the responding or dependent variable.

The interpretation of Figure 5. is that the germination of pollen grains is directly proportional to the concentration of glucose. That is, for every increase in glucose concentration up to 60 g/litre there is a corresponding increase in the germination of pollen grains. Germination of pollen grains drops gradually beyond 60g/litre.
Lesson 6

A. Orientation

Living things can be sorted into groups on the basis of features which are shared. A dichotomous key can be used to find out to which species an organism belongs. Modern classification systems are based on a careful study of all the main features of organisms including body shapes, different types of limbs and skeletons, the arrangements of internal organs etc. In this lesson the learners should be familiar with the technical names for the parts of insects.

B. Theme and Topic:

Theme: Producing and using a dichotomous key.
Topic: How organisms are classified and identified

C. Aims and Instructional Objectives

Aim: Learners should be familiar with the way in which scientists classify and identify living organisms.

Instructional Objectives: At the end of the lesson the learners should be able to:

* construct a dichotomous key that can be used to identify biological organisms
* identify biological organisms using a dichotomous key

E. Teaching and Learning Activities

The teaching activities are a combination of question-and-answer, lecture and discussion methods. Learners are shown the animal pictures in Figure 8.2. The procedure in F below is followed to construct a dichotomous key in Table 8.2.

F. The Procedure of Constructing a Dichotomous key

1. Study Figure 8.2. carefully and write notes about the main features of each insect. Begin by choosing one feature which can be used to sort them into two groups. For example, those with and those without wings.

2. Sort the two groups into smaller groups by choosing other differences.

3. Finally, find one feature which separates each insect from all the others.

4. Produce a key using the features you have chosen. Arrange the features into numbered pairs as in Table 8.3. The first pair of features should separate the insects into two groups.
Subsequent pairs should either identify the insect or lead to another pair of features.

5. When your key is complete, it should enable someone to choose an insect at random and work through the pairs of features until its name is found.

6. Write out the key neatly, put your name at the top and hand it to your teacher.

Figure 8.2. Dichotomous Key
### Key

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Go To</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>wings absent</td>
<td>go to 2</td>
</tr>
<tr>
<td></td>
<td>wings present</td>
<td>go to 6</td>
</tr>
<tr>
<td>2</td>
<td>antennae not clearly visible</td>
<td>cat flea F</td>
</tr>
<tr>
<td></td>
<td>antennae clearly visible</td>
<td>go to 3</td>
</tr>
<tr>
<td>3</td>
<td>abdomen ends in a pair of pincers</td>
<td>earwig G</td>
</tr>
<tr>
<td></td>
<td>abdomen does not end in a pair of pincers</td>
<td>go to 4</td>
</tr>
<tr>
<td>4</td>
<td>long antennae</td>
<td>go to 5</td>
</tr>
<tr>
<td></td>
<td>short antennae</td>
<td>body louse J</td>
</tr>
<tr>
<td>5</td>
<td>abdomen ends in two long bristles</td>
<td>bristle tail B</td>
</tr>
<tr>
<td></td>
<td>abdomen ends in one long bristle</td>
<td>spring tail A</td>
</tr>
<tr>
<td>6</td>
<td>one pair of wings</td>
<td>go to 7</td>
</tr>
<tr>
<td></td>
<td>two pairs of wings</td>
<td>go to 8</td>
</tr>
<tr>
<td>7</td>
<td>legs longer than body</td>
<td>cranefly H</td>
</tr>
<tr>
<td></td>
<td>legs not longer than body</td>
<td>housefly E</td>
</tr>
<tr>
<td>8</td>
<td>wings have hairy edges</td>
<td>thrips D</td>
</tr>
<tr>
<td></td>
<td>wings do not have hairy edges</td>
<td>damselfly E</td>
</tr>
</tbody>
</table>

### G. The Procedure of using a Dichotomous key

The dichotomous key above can be used to identify anyone of the insects in Figure 8.2. Suppose the animal below is to be identified. Study the animal and follow the procedure.

![Dichotomous key example](image)

1. Begin at the first pair of descriptions and decide which one fits the organism to be identified. The key either names the organism or gives the number of the next pair of descriptions which must be consulted. This procedure is continued until an identification is made.
## APPENDIX H

Worksheets for the calculation of Reliability.

### Table 9.29 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Observing skill (i.e. items 1 through to 8).

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>26</td>
</tr>
<tr>
<td>Y</td>
<td>27</td>
</tr>
<tr>
<td>X'</td>
<td>46</td>
</tr>
<tr>
<td>Y'</td>
<td>39</td>
</tr>
<tr>
<td>XY</td>
<td>19</td>
</tr>
<tr>
<td>X+Y</td>
<td>53</td>
</tr>
</tbody>
</table>

### Table 9.29 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Observing skill (i.e. items 1 through to 8).

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>72</td>
</tr>
<tr>
<td>Y</td>
<td>73</td>
</tr>
<tr>
<td>X'</td>
<td>220</td>
</tr>
<tr>
<td>Y'</td>
<td>212</td>
</tr>
<tr>
<td>XY</td>
<td>162</td>
</tr>
<tr>
<td>X+Y</td>
<td>148</td>
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</table>
Table 9.30 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Measuring skill (i.e. items 9 and 10).

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9 10</th>
<th>1 1 1 1 1 1 1 1 1 1 1 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Y</td>
<td>1 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>X²</td>
<td>0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Y²</td>
<td>1 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>XY</td>
<td>0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Y+X</td>
<td>1 0 0 0 2 0 2 0 1 0 0 0 0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

**IX = 4**
**IY = 5**
**IX² = 4**
**IY² = 5**
**IXY = 2**
**I(X+Y) = 9**

Table 9.30 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Measuring skill (i.e. items 9 and 10).

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9 10</th>
<th>1 1 1 1 1 1 1 1 1 1 1 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>1 1 1 1 1 0 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Y</td>
<td>1 1 0 1 0 1 0 1 0 1 0 1</td>
</tr>
<tr>
<td>X²</td>
<td>1 1 1 1 1 0 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Y²</td>
<td>1 1 0 1 0 1 0 1 0 1 0 1</td>
</tr>
<tr>
<td>XY</td>
<td>1 1 0 1 0 0 1 0 1 0 0 0</td>
</tr>
<tr>
<td>Y+X</td>
<td>2 2 1 2 1 1 2 2 1 0 2 1 1</td>
</tr>
</tbody>
</table>

**IX = 15**
**IY = 14**
**IX² = 15**
**IY² = 14**
**IXY = 7**
**I(X+Y) = 29**
<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 9.31 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Inferring skill (i.e. items 11 and 12)

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 9.31 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Inferring skill (i.e. items 11 and 12)

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 9.32 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Classifying skill (i.e. items 13 and 14)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL Score |
|         | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 |
|         | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 |

|          |     | IX = 5 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|          |     | IX² = 5 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|          |     | IXY = 1 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|          |     | IX(X+Y) = 12 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

### Table 9.32 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Classifying skill (i.e. items 13 and 14)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL Score |
|         | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |
|         | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |

|          |     | IX = 15 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|          |     | IX² = 15 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|          |     | IXY = 9 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|          |     | IX(X+Y) = 30 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
### Table 9.32 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Predicting skill (i.e. items 15 and 16)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL | SCORE |
|---------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 15      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |   | 1  | 1 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   | 6   |
| 16      | 1 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   | 4   |
| X       | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |   | X = 4 |
| Y       | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | Y = 6 |
| X²      | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | X² = 4 |
| Y²      | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | Y² = 6 |
| XY      | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | XY = 0  |
| Y+X     | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | (Y+X) = 10  |

### Table 9.32 (b) Worksheet for the calculation of the reliability according to Split-half method after developing the Predicting skill (i.e. items 15 and 16)

<p>| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL | SCORE |
|---------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 15      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |   | 1  | 1 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   | 14  |
| 16      | 1 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   | 13  |
| X       | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |   | X = 13 |
| Y       | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |   | Y = 14 |
| X²      | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |   | X² = 13 |
| Y²      | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |   | Y² = 14 |
| XY      | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |   | XY = 10  |
| Y+X     | 2 | 1 | 1 | 0 | 2 | 0 | 2 | 0 | 2 | 2 | 0 | 2 | 1 | 2 | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |   | (Y+X) = 27  |</p>
<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>18</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>

| X | 1 0 0 1 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 |
| Y | 0 1 1 0 1 0 0 0 0 0 1 1 0 1 0 1 0 1 0 1 1 0 0 0 0 0 0 1 0 0 | IX = 8 |
| X² | 1 0 0 0 1 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 |
| Y² | 0 1 1 0 1 0 0 0 0 0 1 1 0 1 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 |
| XY | 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| X+Y | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |

Table 9.33 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Communicating skill (i.e. items 17 and 18).

<table>
<thead>
<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>18</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>

| X | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |
| Y | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |
| X² | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |
| Y² | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |
| XY | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 |
| X+Y | 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 |

Table 9.33 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Communicating skill (i.e. items 17 and 18).
Table 9.34 (a) Worksheet for the calculation of reliability according to Split-half method before developing the skill of making Operational definition (i.e. items 19 and 20)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL SCORE |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| 19      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 14 |
| 20      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| X       | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | IX = 13 |
| Y       | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | IY = 14 |
| Y²      | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | IX² = 13 |
| XY      | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | IXY = 9 |
| Y+X     | 0 | 2 | 1 | 1 | 2 | 1 | 2 | 0 | 1 | 2 | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 1 | 2 | 0 | 2 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | I(X+Y) = 27 |

Table 9.34 (b) Worksheet for the calculation of reliability according to Split-half method after developing the skill of making Operational definition (i.e. items 19 and 20)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | TOTAL SCORE |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| 19      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 14 |
| 20      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| X       | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | IX = 13 |
| Y       | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | IY = 14 |
| Y²      | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | IX² = 13 |
| XY      | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | IXY = 9 |
| Y+X     | 0 | 2 | 1 | 1 | 2 | 1 | 2 | 0 | 1 | 2 | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 1 | 2 | 0 | 2 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | I(X+Y) = 27 |
### Table 9.35 (a) Worksheet for the calculation of reliability according to Split-half method before developing the skill of formulating a hypothesis (i.e. items 21 and 22)

<table>
<thead>
<tr>
<th>Testees</th>
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<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td>7 5</td>
</tr>
</tbody>
</table>

| 21 22 | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | 7 5 |

| X 0 1 0 0 0 1 0 1 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 | IX = 5 |
| Y 0 1 0 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 0 0 | IX = 5 |
| X X 0 1 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 | IX X = 7 |
| Y Y 0 1 0 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 0 0 | IX Y = 7 |
| XY 0 1 0 0 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 | IX Y = 4 |
| Y X 0 1 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 | IX Y X = 4 |

Table 9.35 (b) Worksheet for the calculation of reliability according to Split-half method after developing the skill of formulating a hypothesis (i.e. items 21 and 22)

<table>
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<tr>
<th>Testees</th>
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<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
<td>14 13</td>
</tr>
</tbody>
</table>

| 21 22 | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | 14 13 |

<p>| X 1 1 0 1 1 0 1 0 1 0 1 0 0 0 0 1 0 0 1 0 0 1 0 0 1 1 1 1 0 0 0 0 | I X = 13 |
| Y 1 0 0 1 1 0 1 0 1 0 1 0 0 0 1 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1 0 | I Y = 14 |
| X X 1 1 0 1 1 0 1 0 1 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 1 1 0 0 0 0 0 | I X X = 13 |
| Y Y 1 0 0 1 1 0 1 0 1 0 1 0 0 0 1 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1 0 | I Y Y = 14 |
| XY 1 1 0 1 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | I X Y = 9 |
| Y X 2 1 0 2 2 0 2 0 2 0 1 0 1 0 0 2 1 0 2 1 1 1 2 1 0 0 0 1 0 | I X Y X = 27 |</p>
<table>
<thead>
<tr>
<th>Testees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
</tr>
<tr>
<td>23 1</td>
</tr>
<tr>
<td>24 1</td>
</tr>
</tbody>
</table>

| X | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Y | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| X² | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| Y² | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| XY | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y+X | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 9.36 (a) Worksheet for the calculation of reliability according to Split-half method before developing the skill of controlling and manipulating of Variables (i.e. items 23 and 24)

<table>
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<tbody>
<tr>
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</tr>
<tr>
<td>23 1</td>
</tr>
<tr>
<td>24 1</td>
</tr>
</tbody>
</table>

| X | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Y | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| X² | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Y² | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| XY | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y+X | 1 | 2 | 0 | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 9.36 (b) Worksheet for the calculation of reliability according to Split-half method after developing the skill of controlling and manipulating of Variables (i.e. items 23 and 24)
### Table 9.37 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Interpreting skill (i.e. items 25 and 26)

<table>
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<tr>
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</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>25</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>26</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>

- $X = 4$
- $Y = 3$
- $X^2 = 4$
- $Y^2 = 3$
- $XY = 1$
- $(X+Y)^2 = 7$

### Table 9.37 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Interpreting skill (i.e. items 25 and 26)

<table>
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<tr>
<th>Testees</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30</td>
</tr>
<tr>
<td>25</td>
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</tr>
<tr>
<td>26</td>
<td>1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1</td>
</tr>
</tbody>
</table>

- $IX = 15$
- $IY = 13$
- $IX^2 = 15$
- $IY^2 = 13$
- $IYX = 9$
- $(I+Y)^2 = 20$
### Table 9.38 (a) Worksheet for the calculation of reliability according to Split-half method before developing the Experimenting skill (i.e. items 27 and 28)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 27      | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 2 |
| 28      |   | 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | 3 |
| X       | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y       | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X²      | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y²      | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| XY      | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y+X     | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**TOTAL SCORE:**

- IX = 3
- IY = 2
- IX² = 3
- IY² = 2
- IXY = 1

### Table 9.38 (b) Worksheet for the calculation of reliability according to Split-half method after developing the Experimenting skill (i.e. items 27 and 28)

| Testees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 27      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16 |
| 28      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 14 |
| X       | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Y       | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| X²      | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Y²      | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| XY      | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| Y+X     | 2 | 2 | 0 | 1 | 2 | 0 | 2 | 0 | 1 | 2 | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 1 | 2 | 2 | 0 | 0 | 2 | 0 | 2 | 1 | 0 | 0 | 2 | 1 | 0 | 0 | 2 | 1 | 0 | 0 | 2 |

**TOTAL SCORE:**

- IX = 14
- IY = 16
- IX² = 14
- IY² = 16
- IXY = 12
- I(X+Y) = 30
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Table 9.39 (a) Worksheet for the calculation of reliability according to Split-half method before developing the skill of constructing and using Models (i.e. items 29 and 30)

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Table 9.39 (b) Worksheet for the calculation of reliability according to Split-half method after developing the skill of constructing and using Models (i.e. items 29 and 30)