UNDERSTANDING THE NATURE OF SCIENCE: THE PERCEPTION OF SCIENCE AND SCIENCE EDUCATION UNDERGRADUATES IN AHMADU BELLO UNIVERSITY ZARIA, AND GRADUATE SCIENCE TEACHERS IN SECONDARY SCHOOLS AND COLLEGES IN KADUNA AND ZARIA, NIGERIA,

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The undersigned certify that they have read, and recommend to the Faculty Board of Education for acceptance, a thesis entitled: Understanding the Nature of Science: The Perception of Science and Science Education Undergraduates in Ahmadu Bello University, Zaria, and Graduate Science Teachers in Secondary Schools and Colleges in Kaduna and Zaria, Nigeria.

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ABSTRACT

The development of understanding of the nature of science is today considered a very important science teaching aim in many parts of the v/orld for several reasons. But, in Nigeria, this science teaching aim is almost totally neglected in science education, and there has been no report of research into the level of understanding of the nature of science in respect of any populations in the Nigerian educational scene.

In view of the foregoing, this study was designed to provide information regarding understanding of the nature of science among science and science education undergraduates in a Nigerian university (Ahmadu Bello University, Zaria), and graduate science teachers in secondary schools and colleges in Kaduna and Zaria, Kaduna State, Nigeria. The following major findings were obtained: (1) There were indications of the existence of room for improvement in the general level of understanding of the nature of science expressed by the populations studied. (2) There was a significant difference (.05 level of confidence) in the level of understanding of the nature of science expressed by

science education undergraduates and that expressed by science undergraduates, with the science education undergraduates showing a better understanding of the nature of science than the science undergraduates. (3) Science undergraduates did not differ significantly in their understanding of the nature of science as a function of their subjects of specialization. (4) There was a significant difference (.05 level of confidence) in understanding of the nature of science as expressed by graduate science teachers with professional teaching qualification and graduate science teachers without professional teaching qualification, with the former showing a better understanding of the nature of science than the latter. (5) No significant difference was found in understanding of the nature of science as expressed by graduate science teachers with long teaching experience and graduate science teachers with short teaching experience.

Many of the findings of this study led to the suggestion that instructions in the philosophy of science may be a good way of improving understanding of the nature of science, and that this could be particularly effective during undergraduate training. It was also suggested that private reading as well as in-service training could be good ways of improving understanding of the nature of science among practicing science teachers.

DEDICATION

This work is dedicated to all sincere lovers of knowledge who pursue knowledge for its own sake rather than for immediate material gains.

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TABLE OF CONTENTS

		Pages
Chapter 1	STATEMENT OF PROBLEM -- -- --	1
1.1	Introduction -- -- -- --	1
1.2	The Nigerian Scene -- -- --	6
1.3	Statement of the Problem -- --	9
1.4	Hypotheses -- -- -- --	10
1.5	Significance of the Study -- --	11
1.6	Assumptions -- -- -- --	12
1.7	Definition of Terms -- -- --	13
1.8	Abbreviations -- -- --	15
1.9	Limitations of the Study -- --	15
Chapter 2	REVIEW OF LITERATURE -- --	17
	THE NATURE OF SCIENCE -- -- --	17
2.1	Defining Science -- -- --	17
2.2	Assumptions of Science -- -- --	22
2.3	Ethics of Science -- -- --	25
2.4	Methods of Science -- -- --	30
2.5	Processes of Science -- -- --	31
2.6	Products of Science -- -- --	44
2.7	Relationship of Science Products and Processes -- -- -- --	46

Pages

Chapter 2

2.8 Tactics and Strategy in Scientific Research -- -- -- -- -- 46

2.9 The Mind of Scientists -- -- -- 51

2.10 The Life of Scientists -- -- -- 53

2.11 Summary -- -- -- -- -- 56

UNDERSTANDING THE NATURE OF SCIENCE-CURRENT RESEARCH -- -- -- -- -- 59

2.12 Measuring Understanding of the Nature of Science Among Different Groups -- -- 59

2.13 Science Curricula and the Development of Understanding of the Nature of Science 64

2.14 Instruments for Measuring Understanding of the Nature of Science -- -- -- 66

Chapter 3 DESIGN AND PROCEDURE -- -- -- 68

3.1 Samples and their Selection -- -- 68

3.2 The Research Instrument -- -- -- 75

3.3. Designs for Testing Hypotheses -- -- 86

Chapter 4 DATA ANALYSIS AND RESULTS -- -- 93

Chapter 5 SUMMARY, GENERALIZATIONS, IMPLICATIONS, LIMITATIONS, AND RECOMMENDATIONS -- 113

5.1 Summary -- -- -- -- -- -- 113

5.2 Generalizations -- -- -- -- -- 118

5.3 Implications -- -- -- -- -- 120

	Pages
Chapter 5	
5.4 Limitations -- -- -- -- --	124
5.5 Recommendations -- -- -- --	125
BIBLIOGRAPHY -- -- -- -- -- --	127
APPENDIX A -- -- -- -- -- --	132
APPENDIX B -- -- -- -- -- --	144

LIST OF TABLES

			Pages
Table	1	Summary of Samples Selected: Science and Science Education Undergraduates	71
Table	2	Summary of Samples Selected: Graduate Science Teachers -- --	74
Table	3	Results of NOSS Validation Test: Contrasted Groups of S.B.S. Students and Teachers -- -- --	82
Table	4	Results of NOSS Validation Test: Analysis of Variance Among Scores of Contrasted Groups of S.B.S. Students and Teachers -- -- -- --	84
Table	5	NOSS Test Results: Science and Science Education Undergraduates -- --	94
Table	6	NOSS Test Results: Graduate Science Teachers -- -- -- --	95
Table	7	Analysis of Variance Among NOSS Scores of Science Education Undergraduates and Science Undergraduates (Biological Sciences) -- -- -- -- --	99
Table	8	Analysis of Variance Among NOSS Scores of Science Education Undergraduates and Science Undergraduates (Chemical Sciences) -- -- -- -- --	100
Table	9	Analysis of Variance Among NOSS Scores of Science Undergraduates (Biological Sciences) and Science Undergraduates (Chemical Sciences)	102
Table	10	Analysis of Variance Among NOSS Scores of Graduate Science Teachers with Professional Teaching Qualification and Graduate Science Teachers without Professional Teaching Qualification --	104

Pages

Table 11 NOSS Test Results: Graduate Science Teachers with Long Teaching Experience and Short Teaching Experience -- -- -- -- -- 106

Table 12 Analysis of Variance Among NOSS Scores of Graduate Science Teachers with Long Teaching Experience and Graduate Science Teachers with Short Teaching Experience -- -- 107

Chapter 1

STATEMENT OF PROBLEM

1.1 Introduction

It is common knowledge today that science and technology now constitute an indispensable part of the environment and culture of all peoples. This pressing fact once led Fafunwa (1971:1) to sound the following warning:

> We are living in a world where science and technology have become an integral part of the world's culture and any country that overlooks this significant truism does so at its own peril.

In economic terms, the material wealth of a country depends on the production of goods and services through the co-ordinated use of the available supplies of human skills, capital, land, and natural resources. Both science and technology contribute immensely to these. Mention any form of material comfort today and its root is traceable to science. Distance has been virtually abolished, cognisance of events has become simultaneous throughout the world, and in the words of Balfour (1946:1)

> Science is the great instrument of social change, and its silent appropriation of this dominant function ---- is the most vital of all the revolutions which have marked the development of modern civilization.

The effects of science on human life and thought have become so great, and are potentially so much greater that those who have no understanding of them, and of the science which produced them, cannot be considered properly educated or truly cultured and therefore are unable to participate fully in the life of their time.

How to gain advancement in science and technology has become a vital goal of every sovereign nation as well as a cause for much competition among the leading nations. For example, the traumatic shock of Sputnik I launched in 1957 by Russia left marks still visible today. Determined never to be so humiliated again, the United States of America reorganised its science education, science funding and scientific research (Nigeria Standard, October 7, 1977:1). Such a measure has today led the United States to the forefront in science and technology, for she remains the first and only nation, as yet, to land man on the moon and bring him safely back to earth. Furthermore, many of the ~~Noble~~ Nobel prizes awarded each year for science and related fields continue to be won by citizens of this same nation. One may say therefore that what has led that nation to her supreme position in

science and technology lies not in an overnight importation of them, as is being attempted by developing countries, but, rather, in their ability to organise and give proper guidance to their science education programs, science funding, and scientific research.

Of these three measures, the ability to organise and give proper guidance to their science education programs seems to be the most fundamental and most crucial, particularly in terms of the long term effect. Science education programs in the United States and many developed countries today rest on the following threefold aims for teaching science listed by The National Society for the Study of Education in its 59th yearbook as cited by MacKay (1971:57):

> First to teach some facts and principles of science; second to inculcate higher virtues, such as accuracy, critical thinking, scientific honesty and more generally scientific method; and third to develop an understanding and appreciation of science and scientists.

The third of these aims, which is concerned with the development of an understanding of the nature of science, has been described by Kimball (1967-68:110) as one of the most commonly stated objectives for science education. Saunders (1955:12) also referred to this aim as "probably the most important purpose for science

teaching". Concern for this aim has been evidenced in many countries as exemplified by the following instances given by Mackay (1971:57):

> The American Association for the Advancement of Science has established a Commission on Science Education with the stated purpose "to foster, in every way possible, scientific literacy among the American people". In England, the Association of Science Education, in its policy statement on Science and Education has stressed the importance of developing an understanding of the nature of science among school pupils. The International Conference on the Education of Professional Physicists included among its recommendations that the development of this objective "should be given most serious consideration in the modernization of physics education". The Organization for Economic Cooperation and Development has stressed the importance of this objective in its Policy for Science Education drawn up at a seminar in Istanbul in 1961.

Furthermore, the literature is full with the writings of leading scientists, science philosophers and science educators who continue to stress that an understanding of the nature of science is important for several reasons, among which are the following:

1. It would enable citizens to be more capable of making the right decisions in terms of policies related to science. On this general need for scientific literacy, Conant (1951:1) once said:

> It is important that all of us, whether we be businessmen, teachers, lawyers or housewives understand and appreciate the role of science in modern life. Such broad understanding will help us achieve spiritual harmony with our environment, and exercise our duties as citizens in making political decisions which more and more are influenced by latest scientific discoveries.

2. An understanding of the true nature of science would create in citizens an awareness of the fact that certain liberal education values such as curiosity, honesty, open-mindedness, objectivity, pursuit of truth, respect for logic, among others, are characteristic of the "Spirit of Science". In realisation of the value of knowledge of this spirit underlying science to citizens, the Educational Policies Commission of the United States (1969:21) declared:

> The profound changes men have wrought in the world by their uses of science and technology have been for better and for worse. But the spirit underlying science is a highly desirable spirit. It can enable entire peoples to use their minds with breadth and dignity and with striking benefit to their health and standard of living.

3. Knowledge of the nature of science is important to scientists in that it serves as a foundation for originality in scientific ideas by providing an awareness of the professional techniques and ethics for practicing real science. According to Weatherall (1968:vii):

> That foundation is not any particular body of factual knowledge but a way of thinking and acting which together form the scientific method. Science, in fact, is what scientists do. Study of scientific method is the study of how they do it, and is properly a branch of

> psychology particularly important to all practicing scientists and to anyone who is interested in scientists and science.

4. A sound understanding of the nature of science is highly desirable on the part of science teachers because in order to lead their students into realizing this objective, teachers themselves would need to be well-versed in these same tenets. Besides, teaching students so that they can attain a better understanding of the nature of science cannot be successfully done through indoctrination, for the spirit of certainty upon which indoctrination rests is contradictory to the spirit of science (Educational Policies Commission, 1966:15-27). Therefore, this objective calls for a careful planning and integration of the processes of science into the teaching activities and instructional programs. This places further value on knowledge of the nature of science on the part of science teachers.

1.2 The Nigerian Scene

As presented above, the development of an understanding of the nature of science is today a highly reverred aim of science teaching. But, in Nigeria, this foundation aim of science teaching appears to be almost totally neglected in science education.

A review of science syllabuses, science textbooks, and patterns of science examinations currently in use in

Nigerian Schools and colleges will clearly reveal the almighty emphasis given to the teaching of facts and principles of science. While there is no quarrel with the teaching and learning of facts and principles of science, a total emphasis on this aim at the expense of other aims of science teaching reflects a serious imbalance in the science education program of a country. Something must be done to arrest this situation and to put Nigerian science education on a firm philosophic foundation.

Many Nigerian science educators have become aware of this problem. For instance, the Science Teachers Association of Nigeria (1970) prepared a new syllabus for integrated science which replaced the earlier general science syllabus. Based on this new integrated science syllabus, Bajah, et al (1971), The Science Teachers Association of Nigeria (1972) as well as Maxwell, et al (1973) produced integrated science texts which are in common use in the junior forms in Nigerian Secondary Schools today. These texts are among Nigeria's best attempts to present a course in science that is reflective of the nature of science. However, for such texts to be fruitfully utilised, the teachers must be conversant with the nature of science. It was probably in realisation of such bottlenecks that Adesoji (1976:36) pointed out that "To teach science well, it is necessary to know what

science is; what its purpose and meanings are, ---". Moreover, since an understanding of the nature of science is such a highly reverred science teaching aim, provisions for realising it should not be limited to only the junior forms in the secondary schools, but should also pervade all arms of our educational system. This calls for investigations into the existing level of understanding of the nature of science among the various school populations to suggest possible corrective or improvement measures where necessary. Unfortunately, investigations into the level of understanding of the nature of science have not been reported in the Nigerian educational scene. This research was born, therefore, out of the need to provide information regarding understanding of the nature of science among:

1. undergraduate science students training to become future scientists and who would require such knowledge as a foundation for the professional practice of science;

2. undergraduate science education students training to become future professional science teachers and who would need such knowledge to be able to train their students;

3. Practicing graduate science teachers in secondary schools and colleges who are supposed to teach their

students to achieve a better understanding of the nature of science.

1.3 Statement of the Problem

In the light of the above, this study was directed to provide possible answers to the following specific questions:

1. What is the level of understanding of the nature of science as expressed by science and science education undergraduates, and graduate science teachers in the populations studied?

2. How does the level of understanding of the nature of science as expressed by science undergraduates compare with that expressed by science education undergraduates?

3. Do science undergraduates differ in their understanding of the nature of science as a function of their subjects of specialization?

4. Do graduate science teachers with professional teaching qualification show a different understanding of the nature of science from graduate science teachers without professional teaching qualification?

5. Do graduate science teachers with long teaching experience show a different understanding of the nature of science from graduate science teachers with short teaching experience?

1.4 Hypotheses

The hypotheses tested in respect of the above questions are given below. All hypotheses were stated in the null form.

Question 1.

In the absence of a standard or norm for the research instrument, no specific hypothesis was tested in respect of this question. Only a general description of the scores obtained on the instrument by the various groups of subjects was used to indicate their level of understanding of the nature of science. Such statistics as the mean, range, variance, and standard deviation of subjects' scores were computed for descriptive purposes.

Question 2.

Hypothesis: There is no significant difference in the level of understanding of the nature of science as expressed by science undergraduates and science education undergraduates.

Question 3.

Hypothesis: Science undergraduates do not differ significantly in their understanding of the nature of science as a function of their subjects of specialization.

Question 4.

Hypothesis: Graduate science teachers with professional teaching qualification do not show a

significant difference in understanding of the nature of science from graduate science teachers without professional teaching qualification.

Question 5.

Hypothesis: Graduate science teachers with long teaching experience do not show a significant difference in understanding the nature of science from graduate science teachers with short teaching experience.

1.5 Significance of the Study

The findings of this research should be of specific use to the Faculties of Science and Education of Ahmadu Bello University, Zaria, as well as to all those interested in the education of scientists and science teachers in the following ways:

Earlier research in this field compared graduate scientists and science teachers in terms of their understanding of the nature of science (Welch and Pella 1967-68), (Kimball 1967-68) but did not compare future scientists and science teachers in training at the undergraduate level. This latter information would be provided by the findings under question 2, where the understanding of the nature of science expressed by undergraduate scientists would be compared with that expressed by undergraduate science teachers. Findings obtained just before the scientists and science teachers

go into their respective professions may provide some ideas about the degree to which preparation programs develop an understanding of the nature of science.

Although Kimball (1967-68:110) identified the need to distinguish between professionally qualified science teachers and non-professionally qualified science teachers before relating teachers' understanding of the nature of science to their training programs, there exists no evidence in the literature to show that professionally qualified science teachers show a different understanding of the nature of science from non-professionally qualified science teachers. Such evidence may be provided by the findings under question 4.

In his studies on scientists and science teachers, Kimball (1967-68:114) found that experience may not be significantly related to the concept of the nature of science expressed by the population he studied. Kimball's findings could be verified by the results under question 5.

1.6 Assumptions

In carrying out this study it has been assumed that:

(1) the concept of the nature of science held by an individual (which to some extent is a matter of opinion) can be reasonably measured;

(2) the study samples adequately represent the

populations studied; (3) the responses of the subjects to the items on the instrument are a true reflection of their understanding of the nature of science.

1.7 Definition of Terms

Some important terms used in this study require operational definitions. The terms and their operational definitions are presented below:

1. science undergraduates = university students reading for the degree of bachelor of science in the Faculty of Science of Ahmadu Bello University, Zaria. They take more science courses than science education undergraduates but do not take any courses in education in the Faculty of Education as the science education undergraduates do. They are generally trained as future scientists.
2. science education undergraduates = university students reading for the degree of Bachelor of Science (Education) in the Faculty of Science and Faculty of Education of Ahmadu Bello University, Zaria. They take less science courses than science undergraduates in the Faculty of Science, but take courses in education in the Faculty of Education which the science undergraduates in the Faculty of Science do not. They are generally trained as future professional science teachers.
3. biological sciences = common name used for botany and

zoology, both of which are subjects of study for the B.Sc. degree in the Faculty of Scienc e of Ahmadu Bello University, Zaria.

4. chemical sciences = common name used for Chemistry and biochemistry, both of which are subjects of study for the B.Sc. degree in the Faculty of Science of Ahmadu Bello University, Zaria.
5. graduate science teachers = university graduates holding at least a bachelor's degree with a major in science, and who by the time of this study, were teaching any of the science subjects (chemistry, physics or biology) in a secondary school or college.
6. graduate science teachers with professional teaching qualification = graduate science teachers who possess such degrees as B.Sc. (Ed), B.Ed., M.Ed (or equivalent), Ph.D in Education (or equivalent), or Diploma in Education (or equivalent).
7. graduate science teachers without professional teaching qualification = graduate science teachers who do not possess any of the qualifications listed under No. 6 above.
8. graduate science teachers with long teaching experience = graduate science teachers who have taught science for a period of more than five years.
9. graduate science teachers with short teaching

experience = graduate science teachers who have taught science for a period of five years or less.

1.8 Abbreviations

B.Ed. = Bachelor of Education

B.Sc. = Bachelor of Science

B.Sc.(Ed) = Bachelor of Science (Education)

M.Ed. = Master of Education

Ph.D. = Doctor of Philosophy

Dip. Ed. = Diploma in Education

N.O.S.S. = Nature of Science Scale

S.P.I. = Science Process Inventory

T.O.U.S. = Test on Understanding Science

Bot. = Botany

Zoo. = Zoology

Bio. Sciences = Biological Sciences

Chem. Sciences = Chemical Sciences

Chem. = Chemistry

Biochem. = Biochemistry

d.f. or v = degree of freedom

S^2 = Variance

S.D. = Standard deviation

1.9 Limitations of the Study

Being a thesis for a masters degree, this study was

scheduled to be completed within a limited period of time. The fund available for the study was also limited. In view of these constraints of time and funds it was not possible to study larger populations than those studied, as would have been preferred.

Under these constraints it would also have been extremely difficult, if not impossible, to develop a new and better research instrument than the one used.

Chapter 2

REVIEW OF LITERATURE

The review of literature as reported in this chapter was designed to serve two major purposes. One is to establish the theoretical background constituting the nature of science. The second is to bring out current research on understanding of the nature of science.

THE NATURE OF SCIENCE

The nature of science is something that is quite difficult to ascertain with exclusive precision in view of the very complexity that characterises its conceptual and operational fabrics. However, for the sake of this research, certain major issues in the practice of science have been selected and, in this section, efforts have been made to establish the views held on such issues by distinguished scientists, philosophers of science, and science educators.

2.1 Defining Science

The conception of science as held by laymen, is indeed highly amorphous. Among laymen, views of science range from its personification as serious men in white lab coats who hardly have any time for or interest in their

wives and children. Some regard it as the highest thing, a heavenly goddess; to another it is a productive and proficient cow, who supplies him with butter. On TV, a scientist may be a mad genius, or an iron-willed and hard-driving researcher, and science is space rockets, computers and miracle coatings that make razor blades last longer and cut closer (Roberts, 1969:3). Thus, the layman's view of science is often in terms of the scientists who carry on the process of science or the products of their work as applied in various forms as technology.

However, the quest for a truer definition of science must go far beyond these views of science as held by the layman. Most scientific writers and researchers distinguish clearly between science and its application - technology. Weaver (1969:3) spoke of science as follows:

> Science is not technology, it is not gadgetry, it is not some mysterious cult, it is not a great mechanical monster. Science is an adventure of the human spirit. It is essentially an artistic enterprise, stimulated largely by disciplined imagination, and based largely on faith in the reasonableness, order, and beauty of the universe of which man is part.

Weaver's definition applied to original science or "pure science" as it is often called to distinguish it from it's application in technology which is also often placed under the name of "applied science". To further the distinction between pure and applied science,

Florey (1967:362) once said that pure scientists are those who:

> freely follow the drifts and logic of their thoughts in trying to unravel the details of natural processes and states, while trying to reduce them to wider and wider generalizations.

The applied scientists, he said, were those who apply known scientific principles to particular problems, although they too often make striking additions to knowledge, and are responsible for the production of many of the agreeable, as well as some of the disagreeable things of life. It is important, at this point, to make it clear, that, for the sake of this research, emphasis has been placed on "pure science" as opposed to "applied science" or technology. This distinction was necessary because even though there is no fundamental distinction in the methods employed by both, as Florey (1967:362) remarked, the practice of applied science or technology is more goal-conscious as far as the human community is concerned than that of pure science.

Toward the further definition of pure science (more freely referred to in this paper as "science") there exists a rich contribution in scientific literature (both educational and professional). On the educational sector, the view of the UNESCO Committee on "science-in-the-primary-school" (UNESCO, 1962:19) is particularly worth noting. This committee wrote:

> What is science then? It is a study of the problems that are found wherever children live. More formally stated, it is a study of the natural environment - not merely pieces of Chemistry and Physics and Biology and Astronomy and Geology - its content is connected with those subjects but it is a study of problems that pop into curious children's minds as they live and grow from one day to the next, such as: what makes the wind blow? What's a cloud? What's a stone made of? How can a seed grow into a tree? What makes a rainbow? Anyone who has ever worked with primary school girls and boys knows that most of them are full of questions like this and like to know the answers to them. Well, finding the answers to such questions - that is science.

This definition is closely in line with that given by Weaver , quoted earlier, because it also places emphasis on the "adventure of the human spirit". When the children are so led into finding the answers to their own questions, they would then be led also through the various processes which characterise scientific practice. So, these definitions seem to view science as an investigation into nature, whetted by curiosity.

Further on the definition of science, Conant (1951:37) had the following views:

> As a first approximation we say that science emerges from the other progressive activities of man to the extent that new concepts arise from experiments and observations and the new concepts in turn lead to further experiments and observations.

This definition introduces emphasis on the formation of generalizations in the form of concepts, and, as such

concepts are fruitful of further experiments and observations, presents the image of science as a continuous process.

In its own contribution the New Encyclopaedia Britannica (1975:382) defines science in the following way:

> The task of science is to explain actual events, processes, or phenomena in nature; and no system of theoretical ideas, technical terms, and mathematical procedures - or mathematical procedures alone-qualifies as scientific unless it comes to grips with those empirical facts at some point and in some way and helps to make them more intelligible.

This definition emphasises the importance of direct involvement with the facts of nature in the practice of science, by declaring all forms of armchair theorizing which lacks a direct contact with the actual facts of nature as 'non-science.'

These definitions of science from different sources encountered in the general scientific literature seem to suggest that science might well be defined as follows:

An investigation into natural phenomena nourished by curiosity; such investigation leading to the collection and impartial treatment of data about natural phenomena with the aim of evolving meaningful generalizations that could further lead to still more investigations.

2.2 Assumptions of Science

Generally, the first truths of science are assumed. Such assumptions, or axioms, serve as basic beliefs which all scientists accept and which provide a stepping stone or foundation for all scientific progress. The Wisconsin Department of Public Instruction (Bulletin No.161:2) made the following observations about the assumptions of science:

> Although there is no preponderance of evidence that indicates the final proof of assumptions, observable positive facts and absence of negative evidence makes assumption possible. Thus, the very high credibility of an assumption allows the scientist to use it as a point of departure in his investigations. If at any time evidence is presented that indicates the assumptions are false, they must be revised and the investigations based upon them redone.

The assumptions of science are as follows:

Reality. This assumption maintains that everything that exists does so in some measurable amount and is therefore perceivable in one form or the other. For example, space is real. Space is measurable and exists in a three dimensional form namely, vertical, horizontal and depth. To measure it, we need a reference point and this is often done in terms of distance in relation to ourselves and other objects. Describing the location of an object in space requires the use of a lot of frames of reference.

Time is also real: Scientists believe that time, like space, has a limit only it has not yet been possible with the available knowledge to estimate the limits precisely. However, arbitrary limits or reference points are set to work out periods of time. Time is also continuous and irreversible. It exists in three dimensions namely, past, present, and future.

Matter is also real: Matter exists in time and space and can be identified in terms of how it affects our senses. It is tangible, has weight and occupies space. Matter can therefore be observed and can be measured by some means.

Consistency. There is consistency or uniformity in the organisation of the universe and the events that occur therein. Given the same conditions particular events can be repeated. One of the aims of science is to determine the nature of this orderliness in nature. This is then expressed in the form of scientific generalizations or laws or concepts or even as mathematical principles.

Determinism or Causality. In nature nothing is caused spontaneously without preceeding events. That means every occurence in nature has a cause and science aims at investigating the ultimate cause of all events. To get to the ultimate or initial cause is often rigorous, and the effort is further complicated by the fact that a

large number of events might inpinge on a particular overt event. Further limitations in asserting causes arise from inadequancies in the techniques and instruments of measurement used. In investigating the possible causes of events, a good scientist has to bear in mind that the occurence of two events simultaneously does not necessarily mean that both events are caused by the same factor. In the same vein, if one event precedes the other it does not have to mean that the first event brings about the second.

Comprehensibility. This assumption maintains that man is capable of understanding events that occur in the universe. Man is also capable of establishing the relationship between events that occur in the universe.

Repeatability. In the conduct of scientific investigations the use of the same method under the same conditions and with the same materials should lead to the same result. This situation has greatly contributed to the advancement of science because it makes it possible for the findings of one scientist to be subjected to verifying tests by other scientists, therefore establishing the credibility of such findings.

Probability. Scientists recognise the possibility of error both in the conduct of investigations as well as in the results obtained. This is despite the fact that all

efforts are made to avoid such error by ever increasing the precision of their measuring instrument and taking of necessary precautions to avoid personal bias of the investigator in measurements, observations, and drawing of conclusions from results obtained.

Tentativeness. All scientific findings are accepted only on tentative basis until the discovery of better ideas. In this regard even the most highly regarded scientific concepts or laws today are not infallible in the eyes of scientists. There is no such thing as a final truth as far as science is concerned.

Contingency. Scientific statements or conclusions are made only when all the assumptions hold true. When any assumption is faulty, then the whole process has to be repeated.

Such are the assumptions on which the entire scientific enterprise is based. Remove any of them and the foundation of science gives way. (Reed, 1976:Lectures). (Wisconsin Dept of Public Instruction: Bulletin No.161)

2.3 Ethics of Science

Although there is no written code of conduct, there are certain ethical considerations which are generally recognised by scientists. Among such ethical considerations are the following:

Empiricism. The empirical nature of science means that in their investigations, scientists gather relevant information based on actual observations of phenomena. Such observations could be direct or indirect and where possible special techniques and relevant instruments are generally used to enhance the accuracy of observations. The empirical nature of science is one of the major causes of the respect generally given to scientific knowledge. Commenting on the importance of the empirical nature of science, the Wisoonsin Department of Public Instruction (Bulletin No.161:3) wrote:

> Empiricism is opposed to simple dependence upon intuition and to the philosophies of totalitarianism, rationalism and subjectivism. Pure logical thinking will almost certainly yield a distorted view of the characteristics and relationships of the natural world.

Openmindedness. It is of extreme importance that scientists maintain an open and objective mind both in the process of conducting their investigations as well as in the reporting of their findings to the entire scientific world. In the reporting of an investigation, the author is under an obligation to give due credit to previous work which he has drawn upon and to anyone who has assisted materially in the investigation. On the need to ensure complete honesty in scientific work Cramer (1896) once said:

> In the long run it pays the scientist to be honest, not only by not making false statements, but by giving full expression to facts that are opposed to his views. Moral slovenliness is visited with far severer penalties in the scientific than in the business world.

On the need to show tolerance for and recognition of scientific work carried out in countries other than theirs Beveridge (1974:146) wrote:

> Even in the scientific world, unfortunately one occasionally encounters national jealousies. These are manifest by lack of appreciation or acknowledgement of work done in other countries. Not only is this to be deplored as a quite indefensible breach of ethics and of the international spirit of science, but it rebounds on the offenders, often to the detriment of themselves and their country. The person failing to appreciate advances in science made elsewhere may be left in the backwater he deserves, and he shows himself a second-rate scientist. Among the great majority of scientists there exists an international freemasonry that is one of the main reasons for faith in the future of mankind, and it is depressing to see this marred by petty selfishness on the part of a few individuals.

Parsimony. Scientists are generally agreed that where several statements can be used to describe a certain phenomenon or to formulate a scientific concept, that statement which accounts for all observations in the simplest manner is to be preferred. This principle which is also sometimes referred to as "Occam's razor" is a measure taken to avoid unwanted length and superfluous statements in the reporting of scientific work. In the presence of many theories explaining the same thing, the

one that does the explanation in the shortest or most precise terms is to be chosen. In science, conscious efforts are also always made to combine all possible events into the smallest possible statements and this latter is sometimes referred to as "reductionism." (Reed, 1976: Lecture).

Immunity or Amorality. In the true sense of it, science is amoral. Thus the scientist pursues his work toward a further comprehension of nature without owning responsibility for whatever use the public decides to make of his findings. However, many writers today are making pronouncements which tend to question the appropriateness of allowing science to continue to enjoy such immunity. They seem to argue that science should be given definite directions of concentration to be determined by the urgent demands of mankind. A look through the following lines creditable to Crowther (1967:4) will pass some of this message:

> While the development and application of science has produced appalling weapons, it has also stimulated the idea of applying science to the management of human affairs, so that they should be conducted with maximum knowledge and wisdom. This applies to science itself. Science may be applied to the management of science, so that science may be of the maximum benefit to mankind, and is not allowed to become a menace.

Closely in line with the above views of Crowther is the

following extract from the New Encyclopaedia Britannica (1975:375):

> At the present time the intimate connection of science with industry, defense, and politics has rendered the ideal of pure science obsolete and has confronted society with the need for a working conception of the natural world different from the reductionist model of the physicist.

It was the view of other writers however that an attempt to make all scientific research go the applied way would yield dangerous results. For one thing, such measure would definitely lead to stagnation in knowledge of the universe about which there is yet much to learn, and such stagnation in scientific knowledge would boomerang to plague the preferred applied research. For example, Weatherall (1968:193) wrote:

> .... applied research is often held up for lack of particular advances in 'pure' research, and in practice some industrial organizations make considerable contributions towards basic research as well as supporting investigations likely to be of immediate commercial value to themselves.

Relevancy. In his investigations, the scientist works with relevant questions and hypotheses. The questions are formed on the basis of earlier observations and usually precede an attempt to evaluate a situation or event. Such questions, when precisely stated, serve as the problems to be solved through the application of the other science processes. The other science processes (discussed later) should also be relevant to the problems being investigated

as delineated by the questions.

2.4 Methods of Science

In their bid to gain more understanding of nature and to describe such understanding, scientists engage in a lot of activities. In so doing, they resort to a variety of methods of investigation. What particular method is to be used for a given investigation strictly depends on the nature of such an investigation. This means, therefore, that there is no single scientific method which all scientists must honour in the conduct of their investigations. What is generally referred to in some texts as "the scientific method" is only an arbitrary ordering of what scientists are known to do when making investigations. It is neither followed strictly in that order in actual scientific investigations nor are some of the steps therein actually honoured in certain types of investigations. In this connection, Weatherall (1968:2-3) wrote the following comment:

> Scientists make discoveries in many ways, according to the subject they are studying, the means at their disposal, and their individual temperaments. Scientific method is a rather simplified account of what goes on, or what might go on, in the process of making discoveries. A description of scientific method is related to original research rather as grammar is related to everyday language, or even to poetry. Some sort of formal structure lies behind what is done and said and written, but the most fruitful research, like the most efficient communication or attractive poetry, is often rather unmethodical and apparently breaks as many rules as it keeps to.

2.5 Processes of Science

When carrying out scientific investigations, scientists engaged in several processes. The Wisconsin Department of Public Instruction (Bulletin No. 161:7) stated eleven major science processes which were also said to include the great majority of student activities appropriate for school experience. The processes were given as observing; classifying; inferring; predicting; measuring; communicating; interpreting data; making operational definitions; formulating questions and hypotheses; experimenting; formulating models.

A more detailed discussion of these science processes is probably necessary for the sake of this research.

Observing. Observation is a process that is central to all scientific activities. Being an attempt to understand things, events, quantities, qualities or relationships, observation may be made in a variety of ways using direct or indirect methods. Because all scientific inferences are based upon observation, it is of great importance that observation should be as precise as possible. Wherever possible quantitative observations are made as a way of improving upon precision. In making observations it is usually important to watch out for unexpected occurences because there are abundant examples of important scientific discoveries which were made through accidental or chance

observations that were followed up, among which was the discovery of Penicillin by Fleming. However it may be noted that the need to increase precision by automatizing observation tends to reduce the opportunities of chance discoveries. For instance Crowther (1967:4) wrote this comment:

> ---- computer - controlled equipment has been devised for examining and automatically analysing the millions of photographs of colliding particles produced in the giant particle accelerators. Visual examination by a team of men and women would take years and would not be practicable. But the automatic machine only records and analyses what it is designed to do. It is generally not able, like the human observer, to record what is not being looked for, and which may be the really new and important thing. Thus this automatization of observation, achieved by ingenious design and construction may contribute to overplanning.

Classifying. Classification is the scientific process of organising objects or phenomena unified by a common attribute or property into certain useful groupings. The process of classification is an artifice often resorted to in order to simplify the approach to a given problem by narrowing its broader elements and ramifications on the basis of categorical distinctions. Thus, objects and events may be classified on the basis of observations into an established scheme. Such classificational schemes have been described as arbitrary and are imposed upon nature by the scientists for their

own convenience particularly in storing and retrieving information. (Kimball, 1967-68), (Winconsin Department of Public Instruction, Bulletin No. 161:8). The process of classification is widely used in science particularly in the field of biological sciences.

Inferring. According to Wood (1966:420), inference "is the process of deriving propositions on the evidence of other propositions whose truth is known to be established". Inference is thus strongly based on inductive and deductive logic and is of the following two types:

(i) Deductive Inference, and (ii) Inductive inference. According to Wood (1966:420) the method of deduction as characterises deductive inference proceeds in the following manner:

> (1) The general principle or premise which must be true, is stated; (2) A special case is adduced as an instance of the general principle (and hence must fall under the coverage of this principle); (3) The inference, conclusion, proof or demonstration results therefrom.

Thus, deductive inference involves reasoning from general premises to specific instances derived from such general premises.

On the other hand, inductive inference involves deriving general propositions from the evidence of specific cases, and is therefore opposite to deductive inference. The method of inductive inference was described by

Wood (1966:420) as follows:

> (1) Many particular instances with common characteristics point to the formulation of certain conclusions, in the form of general laws or principles; (2) These characteristics must be common to all instances and, theoretically, an infinite number of cases must be taken as examples and proof; (3) Accordingly, in most cases under this method of investigation, the conclusion drawn is only a probability, whose accuracy increases as the number of cases represented increases.

The drawing of inferences is a very important science process particularly in the prediction of phenomena and interpretation of data.

Predicting.. One of the ultimate goals of science is to be able to make valid predictions of natural phenomena. Prediction is the formulation of an expected result based on past experience. The reliability of a prediction varies from event to event, while prediction itself is usually based upon inference. The reliability of a prediction could be verified by use of appropriate experimental plans.

Measuring. The process of measurement is fundamental to all science activities. Nearly all scientific experiments involve measurement of one type or the other. Measurement may be accomplished by the direct method which involves comparing the attributes being measured with one another, or by the indirect method which involves comparing the attributes with arbitrary units. Usually arbitrary units of measurement are standardised in order to facilitate

scientific communication, and a variety of such standard units exist for many of the attributes measured in scientific investigations.

Communicating. Scientists are bound by their own ethical standards to communicate their research findings to the world body of scientists. Much of such communication is done by publishing articles in relevant journals so as to enable other scientists to test and confirm validity of the findings. Attempts to cheat or steal other people's ideas without due acknowledgment are all deplored by the scientific world. In order to provide for good communication in science, accurate records of all works done must be carefully kept and preserved so that other interested parties can refer to them. Normally, a report of scientific findings in journals should contain enough descriptive information on the procedures used to enable others to replicate such experiments.

Before an investigator sends out his results for publication it is usually advisable for him to submit to friends for criticism. According to Beveridge (1974:119) "He is a bold man who submits his paper for publication without it having first been put under the microscope of friendly criticism by colleagues".

Interpreting data. Data interpretation is a principal component of every scientific investigation

because it is what gives meaning to facts, and it is such meaning that is most important to the progress of science. According to the Wisconsin Department of Public Instruction (Bulletin No. 161:10):

> Interpreting data requires the application of other basic process skills ---- in particular, the processes of inferring, predicting, classifying and communicating. It is through this complex process that the usefulness of data is determined in answering the question being investigated. Interpretations are always subject to revision in the light of new or more refined data.

Beveridge (1974:115-119) identified several possible pitfalls in data interpretation which must be avoided. These are summarised below.

1. "post hoc", "ergo propter hoc", that is, to attribute a causal relationship between what has been done and what follows, especially to conclude in the absence of controls that the outcome has been influenced by some interference.

2. Wrongly assuming that when an association between two events is demonstrated, the relationship is necessarily one of cause and effect.

3. Attributing a causal role to a newly introduced factor whereas, in fact, the cause lies in the withdrawal of the factor which replaced it.

4. Applying conclusions reached from experimentation in one species to another species,

5. Failure to realise that there may be several alternative causes of one process.

6.. Drawing conclusions about the incidence of some condition in a population after basing the observation on a section of the population which is not representative of the whole.

Making Operational definitions. Operational definitions are important particularly as a means of facilitating communication about the phenomena investigated as well as the materials and procedures of investigation. Operational definitions are usually made as precisely as possible, and where feasible mathematical relationships could be used as a way of enhancing precision. Essentially, operational definition means stating precisely the meaning of important terms, materials and procedures of investigation in the particular context in which they have been used, so as to differentiate these from other similar phenomena. In fact one may say that operational definitions help to mark out the identity of an investigation more sharply.

Formulating questions and hypotheses. The formulation of questions usually comes after preliminary observations, while questions themselves come before the actual investigation of a phenomenon. Questions when properly stated are supposed to be pointers to specific problems to be solved.

The formulation of hypothesis on the other hand depends directly upon the research questions. The Encyclopaedia Britannica (1969:997) described a hypothesis as "something supposed or taken for granted with the object of following out its consequences." In carrying out scientific investigations the scientist not only accumulates facts but also wants to discover the linkages between the facts. To achieve this goal he works with a tentative hypothesis. Such a hypothesis is usually made to fit in with the existing body of doctrine in that field, and is so framed that with its help the scientist can deduce that under certain factual conditions (initial conditions) certain other facts would be found if the hypothesis were correct. When used in this way, as is often the case in scientific investigations, the word "hypothesis" could be more explicitly defined as follows (Webster, 1956);

> A proposition, condition or principle which is assumed, perhaps without belief, in order to draw out its logical consequences, and by this method to test its accord with facts which are known or may be determined.

The concepts involved in the hypothesis need not themselves refer to the observable objects. But, the initial conditions should be able to be observed.

Hypotheses can be of several types, depending on the nature of the research problem. For example:

(1) A hypothesis may assert that something is the

case in a given instance, that a particular object, person, situation or event has a certain characteristic.

(2) A hypothesis may have to do with the frequency of occurence or of association among variables. It may thus state that something occurs a certain proportion of the time, or that something is usually greater or less than something else.

(3) Other hypotheses assert that a particular characteristic or occurence is one of the factors which determine another characteristic or occurence. Hypotheses of this type are referred to as hypotheses of causal relationship or simply as causal hypothesis.

Weatheral (1968:36) suggested that most hypotheses involved one or more of:

simple logical relationships;

quantititative relationship;

spatial relationships;

generality;

simplicity.

Still on the types of hypotheses, Conant (1951:105-106) also wrote:

> An hypothesis or conjecture may be on the grand scale in which case we may designate it a conceptual scheme. It may be fruitless and short-lived as illustrated by Galileo's explanation of the failure of water to rise more than thirty-four feet in a lift lump .... It may be long-lived and useful, as witness: the concept of the atmosphere of Torricelli ....

On the importance of hypothesis formulation in scientific investigations Cohen and Nagel (1934) wrote:

> We cannot take a single step forward in any inquiry unless we begin with a suggested explanation or solution of the difficulty which originated it. Such tentative explanations are suggested to us by something in the subject matter and by our previous knowledge. When they are formulated as propositions, they are called hypotheses.

As a pointer to another aspect of the role of hypothesis formulation in scientific research one might need to examine this comment by Cohen (1956:148)

> There is ... no genuine progress in scientific insight through the Baconian method of accumulating empirical facts without hypotheses or anticipation of nature. Without some guiding idea we do not know what facts to gather. Without something to prove, we can not determine what is relevant and what is irrelevant,

Experimenting. This process involves planning, gathering data and testing hypothesis. All good experiments are preceeded by an experimental plan which has been carefully thought out. This thinking phase is important because the adequacy of testing of the consequences deduced

from the hypotheses depends on how suitable the experimental design may be in testing what is to be tested. All good experimental plans must contain adequate provisions to ensure maximum control of unwanted variables.

Conant (1951:107) pointed out that in the process of experimentation there are many areas of difficulties which must be recognized and provided for. Among these suggested areas of difficulty are those summarised below:

1. As there are always many variables in one experiment, failure to identify the significant variables and control them within limits will vitiate the result.

2. Often it is not easy to answer a simple question unambiguously by experiment, therefore, the researcher must commit all of his ingenuity and tact to the planning and execution of experiments.

3. Almost all experiments involve measurement. In such experiments, if the $\Sigma^{results}$ are to have significance, the numerical values obtained must bear a certain relation to accidental variations in the numbers.

4. Erroneous observations or interpretations of experiments frequently persist and confuse the development of new concepts. In this regard Beveridge (1974:23) had the following to say:

> As a corrective to any tendency to put excessive faith in experimentation, it is as well here to remind the reader that experiments also can at times be quite misleading. The most common cause of error is a mistake in technique. Reliance cannot be placed on results unless the experimenter is thoroughly competent and familiar with the technical procedures he uses. Even in the expert's hands technical methods have to be constantly checked against known 'positive' and 'negative' specimens.

Wood (1966:419) gave some advantages of the experimental method of investigation as summarised below:

1. It makes possible a more reliable analysis in that, the observer may repeat the experiment over and over again at will and thus greatly lessen the probable error of his determinations.

2. The investigation may be more or less easily divided into parts, thus facilitating the research and making possible more accurate inference as to the connection between various phases of the experiment.

3. The controlled investigation may be carried out under a variety of conditions and circumstances, each of which may be important to a true understanding of the problem.

Formulating models. Models are of so high preponderance in science that it could be safely assumed that much of science is concerned with the making of models. Scientific models are of several types, the most notable of which are given below:

1. Theoretical Models: These are devised on the basis of acceptable hypotheses or hypotheses which are yet to be tested. Theoretical models are used to describe and explain the inter-relationships of ideas. In many cases, the model implies new hypotheses, and if the testing of these hypotheses results in new information, the model must be altered to include it. (Wisconsin Department of Public Instruction, Bulletin No.161:12)

2. Ikonic model: This is an immitation of the real object in a three dimensional form, for example, a solid model of the human eye. (Reed, 1976: Lecture)

3. Analogue model: It is a two dimensional model, for example a map or a picture. Analogue models can be used to represent intangible entities, for example, the representation of "time" in graphs, or "speed" or "force" all of which could be represented with some space on a piece of graph paper and related to other items in graphs. (Reed, 1976: Lecture)

4. Symbolic model: This is often a mathematical representation of events which could be in the form of a formula. For example, the formula "$V = \frac{1}{2} gt^2$" is a symbolic model used to describe the speed with which an object falls. Such a model could be used under various conditions and at any time (Reed, 1976: Lecture)

2.6 Products of Science

In scientific circles the products of science are considered to be the concepts (or principles or generalizations) which have resulted from scientific investigations. Progress in science therefore is judged by scientists in terms of how much growth has been attained in the accumulation of scientific concepts, and not in terms of material goods which result from the application of such concepts. Conant (1951:35) wrote the following comment in this respect:

> Indeed, to the non academic mind the word progress as applied to man's activities immediately evokes thoughts of synthetic drugs and cars and radios, not Newton's three laws of motion or the quantum theory or Einstein's equation.... The difference between invention and scientific discovery may in a few instances seem slight but a confusion between the history of the practical arts and the development of science is a fruitful source of misunderstanding about science.

Science and its application in industries, agriculture, medicine, commerce, among others, are closely knit and symbiotic in nature, but still distinct.

In its continuous effort to gain more understanding of natural phenomena so as to be more capable of describing, explaining and predicting such phenomena, science continues to grow and enrich itself with the formation of more and more concepts. Such science concepts are of three major types:

Classificational concepts. These are concerned with the description and grouping of objects, events and phenomena in the universe. Classificational concepts enable us to store and retrieve knowledge about nature.

Correlational Concepts. These are concerned with the establishment of the patterns of relationship that exist between objects, events, and phenomena that occur in nature. Correlational concepts enable us to explain the continuity and causality of events and phenomena.

Theoretical Concepts. Theoretical concepts are concerned with the building up of explanations about nature based upon available facts.

In its attempt to uncover the pattern of orderliness in the affairs of nature, science can be said to be on a continuous search for the truth, but never at any time claiming discovery of a final truth. So, science concepts having been formed from facts are supposed to lead to the collection of more facts about nature. According to the Wisconsin Department of Public Instruction (Bulletin No. 161:7):

> ---- the conceptual structure of science is dynamic rather than a static body of knowledge. Each concept has certain limitations depending on the observations on which the concept is based and the mental processes used to devise the concept. The precision of the observations determines the validity of the concept as does the degree to which the observations represent all possible observations. Each concept is restricted in its

> applicability since it may be used only in situations similar to those in which original observations were made.

2.7 Relationship of Science Products and Processes

The products of science and the processes of science are intimately related. Science concepts generally arise from an interplay of the various mental and motor processes of science given earlier in this chapter. The series of observations resulting from these processes lead to the formulation of a science concept. After its formulation the science concept generates further investigations, thus necessitating further use of the science processes. The interrelationship is therefore a continuous one whereby processes lead to concepts and concepts lead to processes. Science concepts are inferred from observations, while the concepts are used to predict similar occurences as a means of verifying the usefulness of such concepts. (Wisconsin Department of Public Instruction, Bulletin No. 161:7)

2.8 Tactics and Strategy in Scientific Research

A high grade controversy has always hung over how the planning and organization of scientific research should be handled. Extremists on one side of the matter consider that all scientific research should be "planned" in such a way that any research embarked upon has the benefit of the society in mind in one way or the other.

Such ones consider "pure science" research an elegant and time wasting amusement. The other extreme is occupied by those who are of the opinion that the researcher who is organised becomes only a routine investigator because, with the loss of intellectual freedom, originality cannot flourish. Any thought of a possible compromise between these two opposed views might first lead through a consideration of the following observations made by Weatherall (1968:192).

> Scientists are nearly all employed either by universities or by government departments or by industry, and the facilities which they need are provided mainly by the body which employs them. 'He who pays the piper calls the tune', and even with the best principles of intellectual freedom an employing body has in practice considerable influence on what research can actually be done, both by setting conditions of employment and by providing, or not providing, space, apparatus and assistance.

This view of Weatherall is widespread today, that is, scientists cannot just embark on any type of research they like, since their conditions of employment or otherwise are such that their areas of research concentration are regulated from outside in one way or the other. Two very important points need to be put forward in regard to this influence of sponsoring agents on the research interest and areas of concentration of research scientists:

(1) A total shift of research from 'pure science' to 'applied science' by sponsoring bodies can have

> a stagnating effect on progress in the favoured applied science. This is because applied science research depends largely on advances in pure science research for its own progress. (Weatherall, 1968:193).

(2) Whether it be in terms of "applied science" or "pure science" there is a certain level of control or planning which the sponsoring body can impose on the working scientists, and such a level must not be exceeded if they are to get the best out of the scientists.

In considering point (2) above Beveridge (1974:121) broke up planning, as it affects scientific research, into three levels and made recommendations concerning who should make the planning at each of three levels.

The first level, Beveridge ascribed to the "actual conduct of an investigation by the worker engaged in the problem." This level corresponds with "tactics in warfare"; is short term, and seldom goes beyond the next experiment. The investigation should at this level be left to the person actually doing the research to work out his own tactics as the investigation unfolds. This was recommended very strongly on the grounds that the principal elements in most researches are intensely individual efforts in:-

"(a) recognising the unexpected discovery and following it up, and, (b) concentrated prolonged mental effort resulting in the birth of ideas."

The second level involves "planning further ahead on broad lines and corresponds with strategy in warfare." Planning at this level, is not confined to the man engaged in the problem, but is also often the concern of the research director and the technical committee. The principal function of the director in this case is to give guidance to his team and to help when difficulties are met in the conduct of the investigations. For the director of research, the successes of those under his direction are a measure of his understanding of the nature of scientific investigation.

Finally, the third level, which Beveridge ascribed to the "Planning of Policy". This type of planning is mostly done by a committee which decides what problems should be investigated and what projects or workers should receive support. It would be dangerous for a committee to attempt to plan investigations at the tactical level because as research is, for most workers, an individualistic thing, initiative could be easily discouraged by too much supervision, for a man would seldom put his whole heart into a problem unless he felt that it was his own (Beverdige, 1974:122). Further on the role of research committees, Beveridge (1974:122) quoted Topley as follows:

> Committees are dangerous things that need most careful watching. I believe that a research committee can do one useful thing and one only. It can find the workers best fitted to attack a particular problem, bring them together, give them the facilities they need, and leave them to get on with the work. It can review progress from time to time, and make adjustments; but if it tries to do more, it will do harm.

On the advisability, or otherwise, of the use of teams of researchers in scientific investigations, one may say that while teams could be used to advantage in many research ventures, this practice may not be regarded as superior to individually conducted investigations. In fact, it is a general view that even where teams of workers must be used, the individuality of the workers should be recognised and provided for. This view was well expressed in the following statement about the principle of team work credited to Erlich by Beverdige (1974:124): "Centralisation of investigation with independence of the individual". Many scientists have, in fact, raised objections against team work, particularly on the grounds that those discoveries which arise from unexpected side issues will be missed if the worker is not free to digress from his investigation. For example, Fleming (1945:796) pointed out that had he been working in a team he would not have been able to drop what he was doing and follow the clue that led to penicillin.

2.9 The Mind of Scientists

Attempts have been made to describe the pattern in which the mind of scientists operate. Often, such attempts have resulted in the arbitrary division of scientists into two types. However, it is the general feeling of scientists that such a sharp division might not hold in all cases, and that, rather, the majority of scientists fall somewhere between the two extremes, combining many of the characteristics of both.

Different words have been used by different scientists to describe the two arbitrary divisions of scientists with regard to their pattern of thinking. For example, Bancroft (1928:167) called one type the "guessers" in the sense that these ones make a shrewd judgement or hypothesis in advance of the facts. They are thus said to follow mainly the deductive or Aristotlelian methods whereby they get their hypothesis first or early in the investigation, and then test it by experiment. The other type Bancroft called the "accumulators" in the sense that they accumulate data until the generalization or hypothesis is obvious. This group is said to follow the inductive or Baconian method.

In agreement with Bancroft's classification was that by Henri Poincare - (1914) and Jacques Hadamard (1945) who classified mathematicians as either "intuitive" or "logical" according to whether they worked largely by intuitions or by

gradual systematic steps. Beveridge (1974:148) however, preferred to use the terminology "speculative" and "systematic" as this to him seemed "the simplest way of indicating the principal difference between the two types".

Bancroft (1928:167) illustrated the outlook of the different types of scientists with the following examples:

Among the systematic type he named Kelvin and Sir. W. Hamilton whom he quoted as follows:

> "Accurate and minute measurement seems to the non-scientific imagination a less lofty and dignified work than looking for something new, yet nearly all the grandest discoveries are made this way".
>
> "In physical sciences, the discovery of new facts is open to any blockhead with patience and manual dexterity and acute senses."

This last statement is however in sharp contrast with the following made by Davy (Beveridge, 1974:149):

> "I thank God I was not made a dextrous manipulator; the most important of my discoveries have been suggested to me by my failures."

The view that most mathematicians are the speculative type receives support from the following remarks credited to Newton, Whewell and Gauss respectively (Beveridge 1974:149)

"No great discovery is ever made without a bold guess"

"Advances in knowledge are not commonly made without some boldness and licence in guessing."

"I have the result but I do not yet know how to get it."

Most of the outstanding discoverers in biology have also been of the speculative type. Huxley once wrote: (Beveridge 1974:149)

> "It is a popular delusion that the scientific enquirer is under an obligation not to go beyond generalisation of observed facts ... but anyone who is practically acquainted with scientific work is aware that those who refuse to go beyond the facts, rarely get as far."

Pasteur's views on this point were revealed in the following comments credited to him on different occasions: (Beveridge 1974:149)

> "If someone tells me that in making these conclusions I have gone beyond the facts, I reply: 'It is true that I have freely put myself among ideas which cannot be rigorously proved. That is my way of looking at things.'"

"Only theory can bring forth and develop the spirit of invention."

It was the view of Beveridge (1974:150) that the systematic type of scientist is probably more suited to developmental research and the speculative type to exploratory research; the former to team work and the latter either to individual work or as leader in a team; the speculative and systematic types represent extremes and probably most scientists combine some of the characteristics of both.

2.10 The Life of Scientists

As was pointed out in the introduction to this paper, laymen tend to regard scientists as serious men in lab. coats

who scarcely have time for their own family. While things need not of necessity be taken to this extreme, scientists need to devote a good part of their time and life to the practice of science, if they are to make any substantial contribution to knowledge.. A review of what noted scientists have had to say on this point may provide some illustration. Beveridge (1974:154) quoted W.B. Cannon on the issue of the time factor and scientists as follows:

> This time element is essential. The investigator may be made to dwell in a garret, he may be forced to live on crusts and wear dilapidated clothes, he may be deprived of social recognition but if he has time, he can steadfastly devote himself to research. Take away his free time and he is utterly destroyed as a contributor to knowledge.

Platt and Baker (1974:155) on the other hand suggested that a research worker may have to choose between having a reputation as being good natured and easily accessible to visitors but mediocre, or, on the other hand, temperamental but successful. That visitors to laboratories who are merely scientific sightseers ought to be severely discouraged, but most research workers are glad to make time to talk to visitors who have a genuine and serious interest in their work.

On the general disposition of scientists, Pavlov (1936:36) wrote:

> What can I wish to the youth of my country who devote themselves to science? Firstly, gradualness. About this most important condition of fruitful scientific work I can never speak without emotion.

> Gradualness, gradualness, gradualness .... never begin the subsequent without mastering the preceding .... But do not become the archivist of facts. Try to penetrate the secret of their occurence, persistently searching for the laws which govern them. Secondly, modesty . . . do not allow haughtiness to take you in possession. Due to that you will be obstinate where it is necessary to agree, you will refuse useful and friendly help, you will lose your objectiveness. Thirdly, passion. Remember that science demands from a man all his life. If you had two lives that would not be enough for you. Be passionate in your work and your searching.

From these quotations it can be seen that most scientists of the earlier days were devotees who could hardly envisage any other sort of life commitment outside of science. All their pleasure came from science. Demitri Mendeleev (1868) once said:

> Knowing how contented, free and joyful is life in the realm of science, one fervently wishes that many would enter its portals.

Also Albert Einstein (1932) wrote:

> Personally I am inclined to agree with Schoepenhauer in thinking that one of the strongest motives that lead people to give their lives to art and science is the urge to flee from everyday life, with its drab and deadly dullness, and, thus, to unshackle the chains of one's own transient desires, which supplant one another in an interminable succession so long as the mind is fixed on the horizon of daily environment.

While a sufficient amount of devotion to the practice of science is still a necessity, and aesthetic gratification in the realm of science as reflected by Mendeleev continues to be enjoyed to this day by scientists, a more balanced view of the life of scientists as perceived in modern times can be

felt in the following comments by Beverdige (1974:151)

> If one is willing to regard research as a calling and to become what Einstein calls a true devotee, all to the good, but there are plenty of examples of great and successful scientists who have not only lived normal family lives but have managed also to find time for many outside interests. Until recent times research was carried on only by the devotees, because the material rewards were so poor, but nowadays research has become a regular profession. However, it cannot be conducted successfully on a strict 9 a.m. to 5 p.m. basis and some evening study is a practical necessity. One needs to have a real interest in science and it must be part of one's life and looked upon as a pleasure and a hobby.

2.11 Summary

The nature of science as established in the foregoing discussions could be summarised as follows:

Science may be regarded as an investigation into natural phenomena nourished by curiosity; such investigation leading to the collection and impartial treatment of data about natural phenomena with the aim of evolving meaningful generalizations that could further lead to more investigations.

The practice of science rests on several assumptions among which are a belief in the reality, consistency, causality and comprehensibility of natural phenomena. It is also assumed in the practice of science that the processes and products of the scientific enterprise are repeatable, probable, tentative, and contingent.

Although there is no written code of conduct, scientists generally recognize the following ethical considerations:

empiricism of investigations, openmindedness, parsimony, amorality of science, and the need to work with relevant questions and hypotheses.

There is no one "scientific method" which must be honoured by all scientists in all investigations. What particular method of investigation used depends on the investigator and the nature of the investigation.

In the practice of science scientists use a variety of processes among which are observing, classifying, inferring, predicting, measuring, communicating, interpreting data, making operational definitions, formulating questions and hypotheses, experimenting, and formulating models.

In scientific circles the products of science are considered to be the concepts (or principles or generalizations) which have resulted from scientific investigations. Progress in science is therefore judged by scientists in terms of how much growth has been attained in the accumulation of scientific concepts, and not in terms of material goods which result from the application of such concepts.

There is an intimate relationship between the products of science (concepts) and the processes of science, in that, the processes lead to the formulation of concepts and the concepts in turn lead to more investigations calling for use of the processes. This is why science is regarded as a continuous process.

Scientific research is for most workers an individualistic thing and initiative can be easily discouraged by too much supervision. Therefore even where teams of researchers must be used, freedom of the individual should be guaranteed as much as possible.

Organizations which sponsor scientific research tend to exert more than their fair share of control on the purpose and planning of research, preferring only that research that is of immediate benefit to man. However , scientific knowledge has attained its present status through the amorality of scientific investigations, and, an erosion of this amorality will consequently lead to a shortage in the amount of scientific knowledge available to draw from even where such knowledge is to be used for the benefit of man. Funding of scientific research should therefore be done with a broad mind so that research geared purely toward the advancement of knowledge should be given equal recognition as that which is to be of immediate use to man.

Some scientists use the deductive or Aristotlelian way of thinking whereby they get their hypothesis first or early in the investigation, and then test it by experiment; others follow the inductive or Baconian method of thinking by accumulating data until the generalization or hypothesis is obvious, while the majority fall somewhere between the two extremes, combining many of the characteristics of both.

While scientific work demands extra time from the practitioner, it is not true to say that scientists cannot live a normal life, because, there are plenty of examples of great and successful scientists who have not only lived normal family lives but have managed also to find time for many outside interests.

UNDERSTANDING THE NATURE OF SCIENCE - CURRENT RESEARCH

In view of the recognition given to the development of an understanding of the nature of science as an important aim of science teaching, much research has been carried out in this field. Some measured understanding of the nature of science among different groups, others evaluated science curricula in terms of how efficient they were in leading to the development of an understanding of the nature of science, while a few sought to develop valid and reliable instruments for measuring understanding of the nature of science.

2.11 Measuring Understanding of the Nature of Science Among Different Groups

In his studies on understanding of science, Miller (1963:510-513) revealed that a "sizeable group of high school teachers had less understanding of science than their students", even though the teachers' overall mean score was higher than that of the students. The instrument he used for this study was the Test on Understanding Science (TOUS) developed by Cooley and Klopfer (1961).

Schmidt (1967-1968: 365-366) replicated Miller's study and drew the same conclusions as Miller. Like in Miller's study, no levels of significance were reported for the observed differences. He further observed that significant gains in the understanding of science were made as students progressed through the science education sequence, and that working scientists scored best on the TOUS; levels of significance were not given though. He noted the need to seek ways of improving understanding of the scientific enterprise for the in-service teacher and recommended experience in science with scientists instead of more courses in science as a means of improving understanding of the scientific enterprise for the in-service teacher. Schmidt also pointed out the need to enquire into how science teachers at all levels could better convey their understanding of science to their students.

Welch and Pella (1967-68:64-68) developed an instrument for inventorying knowledge of the processes of science - the Science Process Inventory (SPI). While seeking validation information on this instrument, Welch and Pella reported that the mean SPI score of a sample of 19 scientists was significantly higher than the mean SPI score of a sample of 16 science teachers, while the mean SPI score of science teachers was significantly higher than that of 1283 high school students. These results were in

agreement with those that Schmidt and Miller reported. Also in agreement with Miller and Schmidt, the results of Welch and Pella revealed that some high school students scored higher on SPI than some science teachers. Some science teachers also scored higher than some scientists. The background qualifications of the teachers and scientists relative to each other was, however, not stated.

Kimball (1967-68:110-120) observed that researchers who had investigated understanding of the nature of science among high school students had concluded that, for whatever reason, American secondary school students typically had not acquired a valid understanding of what was meant by the nature of science, and that the inference usually made was that science teachers were not teaching the nature of science. Considering the fact that recommendations from such studies usually centred on changes in teacher education programs, Kimball compared three groups of subjects, namely: properly qualified science teachers who were the products of such training programs; professional scientists with similar background in science as the teachers; and philosophy majors, in terms of their understanding of the nature of science. Using the Nature of Science Scale (NOSS) which was developed in the course of the study as the measuring instrument, and an overall sample of about 419 scientists, 78 science teachers, and

87 philosophy majors. Kimball reported findings which could be summarised as follows:

1. No significant difference was found in the nature of science concept held by scientists and by qualified science teachers with similar academic backgrounds, although in seven of the eight subgrouping comparisons of teachers and scientists, the teachers scored higher. 2. Neither experience nor time since graduation may be significantly related to the concept of the nature of science expressed by the population studied. 3. Philosophy majors had a significantly better (.01 level of confidence) understanding of the nature of science than the science majors (scientists and science teachers). 4. No. significant difference was observed between science teachers and philosophy majors. 5. The professional scientist group scored lower than the philosophy majors, at the .01 level of confidence. 6. Irrespective of school of graduation, the philosophy majors had significantly higher test scores than did the science majors. 7. No systematic differences were discovered between scientists and science teachers when their scores on individual items of the NOSS were compared.

In the concluding remarks Kimball noted that while earlier studies had found a severe deficiency among the teachers and had recommended changes in science teacher

education programs, it seemed (from the findings), that if deficiencies existed, they were at least equal for the professional scientists, and that for qualified teachers who were prepared with a major in science, the situation was not so dark as had been reported elsewhere. It was further noted that the significantly higher scores of the philosophy majors suggested that one area of attention might be the inclusion of the study of philosophy of science in the undergraduate preparation of science majors in general and prospective science teachers in particular. With regard to the apparent lack of change in understanding of the nature of science with time or experience, he remarked that this was another argument in favour of influencing students during their undergraduate years, since the concept of the nature of science was fairly well established by the time of graduation from college. He also noted the possibility of including work toward better understanding of the nature of science in teacher in-service training programs.

Broadhurst (1967:17-23) administered the TOUS, Form W, to a group of 108 senior secondary-school chemistry students and their teachers in non-departmental schools in Sydney and reported that when the scores of all the pupils were compared with all the teachers, the teachers' scores were significantly better.

2.12 Science Curricula and the Development of Understanding of the Nature of Science

Much research has been carried out with the purpose of evaluating various science curricula particularly in terms of how efficient they were in leading to the development of an understanding of the nature of science.

Mackay (1971:57-66) used Form W of the TOUS to measure some of the changes that occured in students' understanding of the nature of science as they studied integrated science courses in grades 7 to 10 in Victorian high schools in Australia. A total of 1556 students were tested on the first occasion which was at the beginning of the 1968 school year, while 1203 students were tested on the second occasion, which was at the end of the 1968 school year. Mackay reported that there was no improvement in the probability of correctly answering items on TOUS from first to second testing in respect of male students in grade 8, 9 or 10, while there was an increase in the probability of correctly answering TOUS items between the first and second testing in respect of males in grade 7 and females in grades 7, 8, 9, and 10. She also reported that the proportion of students correctly answering in the grade 10 group was significantly higher than for the grade 7 group on the majority of items. Mackay further identified a number of common deficiencies in students understanding of

the nature of science among which were a "lack of appreciation" of the functions of scientific models; the roles of theories and their relationship to research; the distinctions between hypotheses, laws, and theories; the difference between science and technology.

Tamir (1972:239-245) used the SPI to evaluate the level of understanding of the processes of science by high school students exposed to different science curricula in Israel. Using a total sample of 3,500 students in 9th, 10th, 11th, and 12th grades from all types of Israeli high schools, Tamir established norms for these grades of students in Israel with the SPI as a measure of understanding of the processes of science. Tamir also identified major misconceptions of Israeli high school students regarding the nature and processes of science. His studies further revealed that students in occupational schools were at a disadvantage compared with students in other types of schools regarding their understanding of the processes of science, and noted that this "may be a result of the more conventional nature of occupational schools which place high premium on stable factual knowledge." Tamir also found that "BSCS biology as compared to CHEM Study chemistry and PSSC physics had the greatest impact on understanding the processes of science as measured by performance in SPI."

Seymour and Sutman (1973:159-163) used the SPI to evaluate a new chemistry course guide developed for use in the Philadelphia school district in terms of how much the new course guide led to the realization of the objective of a better understanding of the processes of science. Using all eleventh grade chemistry students and a matched group of non-chemistry students in "two representative comprehensive public high schools in Philadelphia" during the 1969-70 school year as samples, Seymour and Sutman reported that "the Guide and its implementation totally failed to increase students' knowledge of the processes of science."

2.13 Instruments for Measuring Understanding of the Nature Of Science

From all the above cited instances of current research into understanding of the nature of science, it would be noticed that three instruments have been mentioned, namely:

1) The Test On Understanding Science (TOUS) developed by Cooley and Klopfer (1961)

2) The Science Process Inventory (SPI) developed by Welch and Pella (1967-68:64-68).

3) The Nature of Science Scale (NOSS) developed by Kimball (1967-68:110-120).

Of these three instruments, the TOUS was the earliest and most popular in use, followed by the SPI.

However, the NOSS was chosen for use in the present study rather than the other two for the following reasons:

1. Many doubts have been expressed as to the validity and reliability of the TOUS. (Ramsey and Howe, 1969:62-70), (Welch, 1969:429-443), and (Tamir, 1972:239-245).
2. The NOSS has fewer items on it than the TOUS or SPI, making for easier administration and scoring.
3. The NOSS seems to have been developed with a bias for measuring understanding of the nature of science among graduate level subjects, because, validity and reliability information on NOSS were based on pilot tests on graduate level subjects. On this basis the NOSS may be more suitable for measuring understanding of the nature of science among graduate level subjects (as required by this study) than the TOUS or SPI.
4. The declarations which formed the model of the nature of science on which the items on the NOSS were based (see Chapter 3) showed agreement with the model of the nature of science as drawn up in the literature review of this paper.

Chapter 3

DESIGN AND PROCEDURE

In this chapter the samples selected as well as the procedure for their selection are discussed. Also the research instrument used for this study is described and its validity and reliability re-established. Finally, the designs used for testing the null hypotheses arising from the research questions as enumerated in chapter 1 are presented.

3.1 Samples and their Selection

The study was carried out using two major groups of subjects, namely (i) science, and science education undergraduates in Ahmadu Bello University, Zaria, and (ii) graduate science teachers in secondary schools and colleges in Kaduna and Zaria. Samples were selected from each major group as required by the study and in the manner reported below.

(1) Science and science education undergraduates. One sample of science education undergraduates and two samples of science undergraduates were obtained from the Ahmadu Bello University, Zaria, made up of:

27 students reading for the degree of B.Sc. (Education) with Biology as the major teaching subject, and identified as "science education undergraduates".

27 students reading for the degree of B.Sc. in the biological sciences (Botany, and Zoology), and identified as "science undergraduates (biological sciences)"

20 students reading for the degree of B.Sc. in the chemical sciences (Chemistry, and Biochemistry) and identified as "science undergraduates (chemical sciences)".

As is the practice in Ahmadu Bello University, science education undergraduates take many science courses together with the science undergraduates in the area of their major teaching subjects. However, on the whole, the science undergraduates who are trained as future scientists take more science courses than the science education undergraduates, while the latter who are trained as future professional science teachers take courses in education which the science undergraduates do not. In all cases the samples were obtained from among the Part Three undergraduates who were in the second term of their final year of their respective courses by the time of the study. The samples were not extended to the first or second year undergraduates because it was considered that only the final year students would have benefitted nearly completely from the instructional programs of their respective courses,

and would therefore make more suitable samples for the interests of this study. The figures in the above samples were arrived at after some stratification with regard to the immediate population (the total number in class) from which they were drawn. Thus, the figure for science education undergraduates represents 70 percent of the total number of students registered for the degree of B.Sc. (Education) with Biology as the major teaching subject. It may be noted that students with Chemistry as the major teaching subject could not be included in this sample of science education undergraduates because they were too few to be properly utilised for the study. There were no students at all with Physics as a major teaching subject. In the case of science undergraduates (biological sciences), 70 percent of the total number of students registered for the degree of B.Sc. (Botany) were selected, and 70 percent of the total number of students registered for the degree of B.Sc. (Zoology) were selected. For science undergraduates (chemical sciences), 70 percent of the total number of students registered for the degree of B.Sc. (Chemistry) were selected, and 70 percent of total number of students registered for the degree of B.Sc. (Biochemistry) were selected. The details of this strategy are presented in Table 1 below. 70 percent was used as the

sample size in order to include a reasonable proportion of the students in the sample, and was maintained throughout for the sake of uniformity.

Table 1

Summary of Samples Selected: Science and Science Education Undergraduates

Samples:	Science Education Undergrad.	Science Undergraduates (Bio. Sciences) Bot. + Zoo	Science Undergraduates (Chem. Sciences) Chem + Biochem
Total number in class =	39	25 + 13	13 + 15
70 percent of total number in class =	27	18 + 9	9 + 11
Number included in sample =	27	27	20

After the number of students to be included in the study samples from each class had been determined on the 70 percent criterion, the actual selection of individuals was done randomly. Each member of a class was assigned a number, and starting from a randomly selected point in the table of random numbers, (Kerlinger, 1973:714) individuals whose numbers came up as progress was made along the table were included in the sample until the number of individuals corresponding to that required by the 70 percent criterion in respect of each class was obtained. The research instrument was then administered to the randomly selected subjects by face contact, and on individual basis, each subject being given enough time to respond to all items on the instrument.

(2) Graduate Science teachers. Graduate science teachers making about 55 percent of the total staff strength in the science subjects were randomly selected from each of nine institutions (secondary and post secondary) in Kaduna and Zaria, Kaduna State, Nigeria. See Table 2. In each institution, numbers were assigned to all the science staff available at the time of investigation. Then, starting from a randomly selected point in the table of

random numbers (Kerlinger, 1973:714), graduate science teachers whose numbers came up as progress was made along the table were included in the sample until the number of graduate science teachers in the sample was up to about 55 percent of all the science staff in each institution. The actual number of graduate science teachers selected from each institution, and the corresponding science staff strength by the time of investigation are shown in Table 2. below. The choice of the 55 percent criterion was a compromise between adequate representation in the sample of science teachers from each institution and manageableness, in the light of the constraints of time and fund as earlier noted in this paper.

The nine secondary and post secondary institutions from which random samples of graduate science teachers were obtained were themselves randomly selected from among similar institutions in the area of investigation (Kaduna and Zaria). The number of selected institutions was limited to nine out of about sixteen, after due consideration to limitations of time and funds.

The total number of teachers in the randomly selected sample was 74. The instrument was then administered to the subjects and each was given enough time to respond to all items on it.

TABLE 2

Summary of Samples Selected:Graduate Science Teachers

School	Science Staff strength	Number in sample
Rimi College, Kaduna	11	6
Queen Amina College, Kakuri	7	4
Govt. Girls Sec. School, Kawo	7	4
Federal Govt. College, Kaduna	9	5
Barewa College, Zaria	11	6
Govt. Sec. School, Zaria City	11	6
K. C. A. S. T., Zaria	20	11
Advanced Teachers College, Zaria	20	11
School of Basic Studies, Ahmadu Bello University, Zaria	39	21
Total	135	74

The completed instruments were rearranged into two groups according to whether the teachers possessed a professional teaching qualification. This information along with some other personal information relevant to this study had been sought in a separate questionnaire attached to the instrument. See Appendix B for a copy of the questionnaire.

With regard to professional teaching qualification therefore the 74 graduate science teachers were regrouped into: 28 teachers with professional teaching qualification; and 46 teachers without professional teaching qualification.

Another subgrouping of the graduate science teachers, necessitated by one of the problems investigated in this study, was into: graduate science teachers with long teaching experience (more than five years), and graduate science teachers with short teaching experience (five years or less). In this regard the 74 graduate science teachers were regrouped into: 28 teachers with short teaching experience of five years or less, and 46 science teachers with long teaching experience of more than five years. The mean number of years of teaching experience for the short-experience teachers was 3.4 years, while that for the long-experience teachers was 12.8 years.

3.2 The Research Instrument

Due to the inherent difficulty of instrument construction and the lack of time and funds to embark upon such a project, a new instrument could not be constructed for the purposes of this study. However, from the review of literature an instrument considered suitable for use in this study was discovered and adopted.

Of the three instruments in common use for this type of study as revealed by the available literature, namely: Test On Understanding Science (Cooley and Klopfer, 1961); Science Process Inventory (Welch and Pella, 1967-68:64-68); and Nature of Science Scale (Kimball, 1967-68:110-120), the Nature of Science Scale (NOSS) was selected for use in this study. The reasons for selecting the NOSS rather than the other two were given under the literature review in Chapter 2. The relevant portions of the account of the development of the NOSS as reported by the developer (Kimball, 1967-68:110-120) are presented below:

> To provide a basis for group comparisons, a theoretical model of the nature of science was developed out of extensive study of the literature on the nature and philosophy of science. Its function was to provide a comprehensive statement against which to measure deviations of opinion by the subject groups studied. The model was composed of 8 assertions about important characteristics of science. While this model was only one of many possibilities, it was consistent in its agreement with views expressed by Conant and Bronowski; and additional support for each assertion was found among the writings of other philosophers of science. The declarations forming the model are stated in the following paragraphs:

(1) The fundamental driving force in science is curiosity concerning the physical universe. It has no connection with outcomes, applications, or uses aside from the generation of new knowledge.

(2) In the search for knowledge, science is process-oriented; it is a dynamic, on-going activity rather than a static accumulation of information.

(3) In dealing with knowledge as it is developed and manipulated, science aims at ever-increasing comprehensiveness and simplification, emphasising mathematical language as the most precise and simplest means of stating relationships.

(4) There is no one"scientific method" as often described in school science textbooks. Rather, there are as many methods of science as there are practitioners.

(5) The methods of science are characterised by a few attributes which are more in the realm of values than techniques. Among these traits of science are dependence upon sense experience, insistence on operational definitions, recognition of the arbitrariness of definitions and schemes of classification or organization, and the evaluation of scientific work in terms of reproducibility and of usefulness in furthering scientific inquiry.

(6) A basic characteristic of science is a faith in the susceptibility of the physical universe to human ordering and understanding.

(7) Science has a unique attribute of openness, both openness of mind, allowing for willingness to change opinion in the face of evidence, and openness of the realm of investigation, unlimited by such factors as religion, politics, or geography.

(8) Tentativeness and uncertainty mark all of science. Nothing is ever completely proven in science, and recognition of this fact is a guiding consideration of the discipline.

.....

An initial pool of over 200 short statements about the nature of science was prepared for use in the research instrument, all of them based on the assertions in the model. The first list was analysed by a panel made up of 2

experienced science teachers, 2 school science supervisors, 3 science professors, and 2 professors of science education. Items approved by the panel after several revisions were arranged in a pilot instrument. The pilot instrument was administered to 54 subjects, 32 of whom held degrees in a biological or physical science, and the rest of whom had degrees in nonscience fields. Data obtained from the pilot test were used to select items that (1) had few neutral responses; (2) showed agreement with the model, as judged by at least 7 of the 9 judges on the panel; (3) discriminated in favor of the science graduates, as determined by a weighting based on the phi coefficient; and (4) showed a logical progression of weightings among the three choices, without internal inversions; .... The 31 items which survived this selection process were organised into a second form of the instrument.

This second form of the instrument was administered to 97 new subjects, about half of whom majored in science as undergraduates. The split-half reliability for this form, as corrected by the Spearman-Brown formula, was .72. On the basis of comparison of the top 27% and the bottom 27% in total score, two items were discarded as not showing sufficient discrimination. The remaining 29 items were arranged in a Likert-type scale, which became the Nature of Science Scale (NOSS), ... The scale was scored by counting 2 points for each response in agreement with the model, 1 point for a neutral response, and 0 points for a response opposite to the response predicted by the model.

Scoring the instrument. The scoring pattern for items on the NOSS as used by Kimball was "2 points for each response in agreement with the model, 1 point for a neutral response, and 0 points for a response opposite to the response predicted by the model". But, the present study noted the following reservations about such scoring pattern:

(i) Awarding 1 point for a neutral response may lead to awarding too many points to those who may be really ignorant of the items.

(ii) Providing for a choice of neutral response would encourage too many respondents to this response. This would have the serious disadvantage of lowering the discriminating power of the instrument.

Because of the above reservations it was decided that for the sake of this study the items on the NOSS would be scored as follows: 1 point for a response that agreed with the model, and 0 points for a response opposite to that predicted by the model. Thus, the respondents were invited to indicate whether they "agree" or "disagree" with the items on the NOSS with no obvious provision for a neutral response. This measure was thought to be capable of increasing or sharpening the discriminating power of the instrument. A copy of the NOSS as used for this study can be seen in Appendix B.

Re-establishing the validity of the instrument.

Despite the extensive measures taken by the developer of the instrument to ensure its validity, it was still considered appropriate to attempt to re-establish the validity of the instrument in the Nigerian setting, particularly in its ability to discriminate between groups of varying competency in understanding of the nature of science. Fox (1969:377) considered it a "critical" requirement that a research instrument should be sensitive enough to make the discriminations required for the

research problem. It may be noted that while this desired characteristic of an instrument (the ability to discriminate between groups of varying competency in the property being measured) was classified as "Sensitivity" by Fox (1969:377), Welch and Pella (1967-68:66) classfied it under "construct validity".

In order to validate the NOSS in terms of its ability to discriminate between groups of varying competency in understanding of the nature of science it was predicted that a group of science teachers would score better on the NOSS than their own students as was established by earlier workers using related instruments (Miller, 1963:510-513), (Schmidt, 1966-67:365-366), (Broadhurst, 1967:17-23), (Welch and Pella, 1967-68:64-68). Insofar as this prediction was borne out, the validity of the NOSS would be supported, but if it failed to be verified, then doubt would be cast on the validity of the NOSS, the theorizing, or both. It may be noted that an approach similar to this was used by Welch and Pella (1967-68:64-68) in validating the SPI.

To test the above prediction, the following null hypothesis was investigated: there is no significant difference in the NOSS scores of science teachers in the School of Basic Studies (S.B.S) of Ahmadu Bello University, Zaria, and the NOSS scores of their own students. The samples used to test this null hypothesis were obtained as

follows:

About 55 percent of all graduate science teachers employed to teach physics, chemistry, and biology in the School of Basic Studies of Ahmadu Bello University, Zaria, were selected randomly, using a table of random numbers. This gave 21 science teachers in the sample. Also about 55 percent of the students registered for courses in pnysics, chemistry, and biology in the School of Basic Studies of Ahmadu Bello University, Zaria, were selected randomly, using a table of random numbers. This gave 55 students in the sample. The table of random numbers was used in each case by assigning random numbers from such table (Kerlinger, 1973:714) to (1) all the graduate science teachers, and (2) all the science students reg istered for courses in physics, chemistry, and biology, in the School, at the time of investigation. In each case, by starting with a randomly selected point in the table of random numbers, subjects whose numbers came up as progress was made along the table were included in the sample until the number of subjects corresponding to the 55 percent criterion was obtained in respect of each sample. The 55 percent criterion was used as a compromise between adequate representation and manageableness, in the light of the limitations of time and funds as earlier noted. The NOSS was then administered to all the subjects in the samples in February,

1978, and each subject was given enough time to respond to all items on it. When all subjects had responded, their responses were scored by awarding 1 point for a response that agreed with the model answer, and 0 point for a response opposite to that predicted by the model answer. Thus, the maximum possible points = 29, and minimum = 0. The scores were treated statistically and produced the results shown in Table 3. For details of raw scores see Tables A1 and A2 of Appendix A.

Table 3

Results of NOSS Validation Test: Contrasted Groups of S.B.S. Students and Teachers

		S.B.S. Students	S.B.S. Teachers
N	=	55	21
Range	=	3-14	7-17
Mean	=	8.84	11.62
Variance	=	5.07	8.55
S.D.	=	2.25	2.92

The difference between the scores of the two samples was then tested for statistical significance using the one-way analysis of variance (two groups). But before then the assumption of equal variance of the scores

in the populations from which the samples were taken had to be ascertained. This was done by computing the variance ratio from the best estimates of the population variances with the formula:

$$F = \frac{S_1^2}{S_2^2}$$

where S_1^2 = larger variance (teachers'), and S_2^2 = smaller variance (students'). Both variances ~~being~~ were the best estimates of their respective population variances, having been obtained by dividing the sums of squares by their respective degrees of freedom (Mulholland and Jones, 1968:203).

As obtained from the above formula, F = 1.6864, while F required for significance at the .05 level should be greater than 1.7480. Therefore 1.6864 was not significantly large, and the assumption of equal variance in both populations was accepted.

The one-way analysis of variance (two groups) was then computed to test the hypothesis: there is no significant difference in the NOSS scores of the sample of S.B.S. science teachers and the NOSS scores of the sample of their own students. The results of this analysis are shown in Table 4. Alpha level = .01.

Table 4

Results of NOSS Validation Test: Analysis of Variance Among Scores of Contrasted Groups of S.B.S. Students and Teachers

Source of Variance	Sum of Squares	df	Mean Square	F
Between groups	117.71	1	117.71	19.59*
Within groups	444.45	74	6.01	
TOTAL	562.16	75		

*$p < .01$

The F ratio of 19.59 was considered significant in that the probability of chance occurence of the values was less than the critical level of .01. Therefore the null hypothesis was rejected in favour of the alternative hypothesis, that is, there is a significant difference in the NOSS scores of the sample of S.B.S. Science teachers and the sample of their own students. The teachers, by having a higher meanscore than the students, (see Table 3 page 82) have also shown a better understanding of the nature of science, as measured by the NOSS, than their students. By its ability to so discriminate between groups of varying competency in understanding of the nature of science and in the expected direction, evidence

has been produced in support of the validity of the NOSS instrument by use of Nigerian samples.

Re-establishing the reliability of the instrument. It was considered necessary to re-establish the reliability of the NOSS as used in this study and in the Nigerian setting. The NOSS scores of the sample of 21 graduate science teachers in the School of Basic Studies of Ahmadu Bello University which were used to re-establish the validity of the NOSS, were also used to compute the split-half reliability of the NOSS. The product-moment correlation coefficient between the odd and even scores was computed using the following formula:

$$r = \frac{\sum zXzY}{N}$$ (Meyer, 1966:355)

r as obtained in above formula = .60.

This was then adjusted by the Spearman-Brown formula:

$$rf = \frac{2r}{1 + r}$$

to give an estimated Spearman-Brown reliability of the whole instrument as .75

Since one's concept of the nature of science as measured by the NOSS is to a large extent a matter of opinion, the Spearman-Brown reliability of .75 obtained for the NOSS as used in this study is acceptable. (Fox, 1969:362). It may be interesting to note that this figure is even slightly greater than the figure of .72 obtained by

Kimball (1967-68:112) during the development of the instrument.

Administering the instrument. Having obtained the research samples as described earlier in this chapter, the research instrument was then administered to all subjects in the period of February to March, 1978, by face contact, and on individual basis. All subjects were given enough time to respond to each item on the instrument, and, after which, they were collected. The responses of all subjects were then scored on the basis of 1 point for any response in agreement with that suggested by the model response, and 0 point for a response opposite to that suggested by the model response. Scores were then summed up for each subject on a 29-point maximum and 0-point minimum basis and recorded for all subjects in each sample in appropriate tables as shown in Appendix A, in readiness for further analysis.

3.3 Designs for Testing Hypotheses

In the statement of problem, specific questions were identified for investigation by this study. These questions are re-stated below with the null hypothesis tested in respect of each question. The designs used for testing each hypothesis is also described.

Question 1: What is the level of understanding of the nature of science as expressed by science and science

education undergraduates, and graduate science teachers in the populations studied?

In the absence of any norm for the research instrument, no specific hypothesis was tested in respect of this question. Only a general description of the NOSS scores of the various groups of subjects have been used to indicate their level of understanding of the nature of science. Such statistics as the mean, range, variance, and standard deviation of the subjects' NOSS scores were computed for descriptive purposes. The samples of science and science education undergraduates were considered in their separate groups namely:

science education undergraduates.

science undergraduates (biological sciences)

science undergraduates (chemical sciences)

The entire sample of graduate science teachers was considered in two separate groups for question 1, namely: graduate science teachers with professional teaching qualification, and graduate science teachers without professional teaching qualification.

In order to identify the frequency of correct responses to the individual items on the NOSS, a table (Table A.8 of Appendix A) was ~~drawn~~ drawn up to show the percentage of subjects in each sample whose responses were in agreement with those suggested by the model for each item.

Furthermore, those items which elicited a low percentage of correct responses (from less than 40 percent of subjects in all samples) were specifically identified and recorded.

Question 2:

How does the level of understanding of the nature of science as expressed by science undergraduates compare with that expressed by science education undergraduates?

Hypothesis:

There is no significant difference in the level of understanding of the nature of science as expressed by science undergraduates and science education undergraduates.

Design:

Using the NOSS scores of subjects as their expression of understanding of the nature of science, a one-way analysis of variance (two groups) was used to compare the samples of undergraduates as follows: 1. science education undergraduates versus science undergraduates (biological sciences); 2. science education undergraduates versus science undergraduates (chemical sciences). The results of the above comparisons were used to draw conclusions for the null hypothesis under question 2.

Question 3:

Do science undergraduates differ in their understanding of the nature of science as a function of their subjects of specialization?

Hypothesis:

Science undergraduates do not differ significantly in their understanding of the nature of science as a function of their subjects of specialization.

Design:

To test this hypothesis, the NOSS scores of the sample of science undergraduates (biological sciences) were compared with the NOSS scores of the sample of science undergraduates (chemical sciences), using the one-way analysis of variance (two groups).

Question 4:

Do graduate science teachers with professional teaching qualification show a different understanding of the nature of science from graduate science teachers without professional teaching qualification?

Hypothesis:

Graduate science teachers with professional teaching qualification do not show a significant difference in understanding the nature of science from graduate science teachers without professional teaching qualification.

Design:

Using the NOSS scores of subjects as a measure of their understanding of the nature of science, a one-way analysis of variance (two groups) was used to compare the NOSS scores of graduate science teachers with professional teaching qualification and the NOSS scores of graduate science teachers without professional teaching qualification as a test of the hypothesis under question 4 above.

Question 5:

Do graduate science teachers with long teaching experience show a different understanding of the nature of science from graduate science teachers with short teaching experience?

Hypothesis:

Graduate science teachers with long teaching experience do not show significant difference in understanding of the nature of science from graduate science teachers with short teaching experience.

Design:

To test this hypothesis, the NOSS scores of the sample of graduate science teachers with long teaching experience (more than five years) was compared with the NOSS scores of the sample of graduate science teachers with short teaching experience (five years or less), using the

one-way analysis of variance (two groups).

In using the analysis of variance technique to test the null hypotheses as indicated in all cases above, the following assumptions were made:

1. That the samples were random samples from normal distributions.

2. That the normal populations all have equal variances.

With regard to assumption 1., all the samples used for this study were random samples, while the normality of distributions was assumed.

With regard to assumption 2., the equality of variances of populations was tested in all cases of paired comparisons under questions 2-5. In each case this was done by computing the variance ratio from the following formula:

$$F = \frac{S_1^2}{S_2^2}$$ (Mulholland and Jones, 1968:203)

where in each case S_1^2 = larger variance and S_2^2 = smaller variance. Both variances being the best sample estimates of their respective population variances, having been obtained by dividing the sums of squares by their respective degrees of freedom (N-1) rather than by N. Using an alpha level of .05 it was establised that in all cases the estimated population variances for each pair of

samples compared by the analysis of variance technique were not significantly different. (The actual figures for the variance ratios are given in chapter 4).

The procedures for the one-way analysis of variance (two groups) as used in this research were taken from Kerlinger (1973:224-226). It may be noted here that the simple one-way analysis of variance (two groups) had been used in preference to other methods involving three or more groups or a multivariate analysis because of the nature of the hypotheses and the study samples. In all cases an alpha level of .05 was used to accept or reject the null hypotheses.

Statistics such as the mean, range, variance, and standard deviation were computed by use of the usual formulae in statistics texts.

Mean $= \frac{\Sigma x}{N}$ (after Hayslett, 1967:17)

Variance $= \frac{\sum x^2 - \frac{(\Sigma x)^2}{N}}{N - 1}$ (After: Hayslett, 1967:34) and (Gregory et al, 1969:17-19)

Standard deviation $= \sqrt{\text{Variance}}$

All computations were done with a desk calculator.

Chapter 4

DATA ANALYSIS AND RESULTS

In this chapter the data in the form of NOSS scores of subjects were analysed to test appropriate hypotheses as set out in Chapter 3. The results of such analysis in relation to the hypothesis tested in each case are pointed out.

Question 1:

What is the level of understanding of the nature of science as expressed by Science and Science Education undergraduates, and graduate science teachers in the populations studied?

As was pointed out in the design in Chapter 3, no particular hypothesis was tested in respect of this research question. Only a general description of the NOSS scores of the various groups of subjects was used to indicate their level of understanding of the nature of science. Such statistics as the mean, range, variance, and standard deviation of the subjects' NOSS scores were computed for descriptive purposes. The computation was done with the aid of formulae as earlier stated in the designs in Chapter 3. Tables 5 and 6 show these statistics as computed from the NOSS scores of the various samples. The actual scores or raw scores can be seen in Tables A3-A7

of Appendix A.

Table 5

NOSS Test Results: Science and Science Education Undergraduates

Samples:	Science Education Undergrad	Science Undergrad. (Biol. Sciences)	Science Undergrad. (Chem. Sciences)
N =	27	27	20
Range =	8-15	4-13	6-15
Mean =	11.26	9.89	9.60
Variance =	4.12	6.56	4.46
S.D. =	2.03	2.56	2.11

Considering that the NOSS was scored on a 29-point maximum basis, it follows that if expressed in percentages, the range of scores in respect of the various samples in Table 5 above would be:

science education undergraduates = 28% - 52%

science undergraduates (biological sciences) = 14% - 45%

science undergraduates (chemical sciences) = 21% - 52%

Also the mean scores would be:

science education undergraduates = 38.8%

Science undergraduates (biological sciences) = 34.1%

Science undergraduates (chemical sciences) = 33.1%

It may be observed here that the lack of a standard or norm against which to judge the NOSS scores of the subjects made it impracticable to evolve categorical statements about the adequacy of the subjects' understanding of the nature of science as reflected in their NOSS scores above. However, it may be noted that the mean NOSS score did not reach the 40 percent mark in respect of any of the samples.

The NOSS test results of the samples of graduate science teachers are presented in Table 6 in respect of graduate science teachers with professional teaching qualification, and graduate science teachers without professional teaching qualification.

Table 6

NOSS Test Results: Graduate Science Teachers

Samples:		Teachers with Professional Qualification	Teachers without Professional Qualification
N	=	28	46
Range	=	7-17	6-16
Mean	=	11.43	10.13
Variance	=	7.66	6.20
S.D.	=	2.77	2.49

Since the NOSS was scored on a 29-point maximum basis it follows that if expressed in percentages, the range of NOSS scores of the samples of graduate science teachers as in Table 6 above would be as follows:
Teachers with professional teaching qualification = 24% - 59%
Teachers without professional teaching qualification = 21% - 55% and the mean scores as follows:
Teachers with professional teaching qualification = 39.4%
Teachers without professional teaching qualification = 34.9%

As was pointed out in the case of the undergraduates, the lack of a standard or norm against which to judge the NOSS scores of the subjects had made it difficult to make any categorical statements about the adequacy of the teachers' understanding of the nature of science as indicated by their NOSS scores. It may be interesting, however,,to point out that like the undergraduates, the teachers' mean NOSS scores did not reach the 40 percent mark in respect of any of the samples. The rather low level of mean scores (less than 40 percent) in respect of all samples (undergraduates and graduates) may be indicative of a low level of understanding of the nature of science by the populations studied.

Toward a further description of the level of understanding of the nature of science as expressed by the various subjects, the percentage of subjects in each sample who gave correct responses to each of the items on the NOSS were computed (See Table A8 of Appendix A). Using this information, those items which elicited a low level of correct response from subjects in all the samples were identified. Thus, it was discovered that for twelve of the 29 items on the NOSS, less than 40 percent of the subjects in each sample were able to give correct responses as suggested by the model answers. The twelve items were: 1, 3, 4, 5, 7, 8, 13, 20, 21, 23, 24, and 29. The wordings of these items and the corresponding model responses are presented in Table A9 of Appendix A.

Question 2:

How does the level of understanding of the nature of science as expressed by science undergraduates compare with that expressed by science education undergraduates?

In the process of answering this question, the following null hypothesis was tested: there is no significant difference in the level of understanding of the nature of science as expressed by science undergraduates and science education undergraduates. To test this hypothesis the NOSS scores of the single sample of science education undergraduates were compared with those

of each of the two samples of science undergraduates in the following pattern:

1. science education undergraduates versus science undergraduates (biological sciences).
2. science education undergraduates versus science undergraduates (chemical sciences).

The raw NOSS scores of each of the samples may be seen in Tables A3-5 of Appendix A. The mean, range, variance and standard deviations of these scores are as presented in Table 5 (page 94).

The paired comparisons indicated above were made by means of the one-way analysis of variance (two groups) as reported below:

1. science education undergraduates versus science undergraduates (biological sciences):

The variance ratio (F) = 1.5922 ($df_1 = 26, df_2 = 26$) was not significant at .05 level of confidence. Therefore the assumption of equality of population variances was upheld. The result of the one-way analysis of variance in respect of this comparison is presented in Table 7.

Table 7

Analysis of Variance Among NOSS Scores of Science Education Undergraduates and Science Undergraduates (Biological Sciences)

Source of Variance	Sum of Squares	df	Meansquare	F
Between groups	25.34	1	25.34	4.7453*
Within groups	277.86	52	5.34	
Total	303.20	53		

*$p < .05$

The results of the analysis of variance in Table 7 show that there was significant difference (.05 level of confidence) in NOSS scores of science education undergraduates and science undergraduates (biological sciences). The null hypothesis was therefore rejected in respect of this comparison. It may be recalled (Table 5, page 94) that the mean NOSS score of the sample of science education undergraduates was higher than the mean NOSS score of the sample of science undergraduates (biological sciences).

2. science education undergraduates versus science undergraduates (chemical sciences):

The variance ratio (F) = 1.0825; ($df_1 = 19, df_2 = 26$) was not significant at .05 level. Therefore the assumption of equality of population variances was accepted.

of variance
The results of the one-way analysis/is presented in Table 8.

Table 8

Analysis of Variance Among NOSS Scores of Science Education undergraduates and Science undergraduates (Chemical Sciences)

Source of Variance	Sum of Squares	df	Meansquare	F
Between groups	33.56	1	33.56	7.1526*
Within groups	211.14	45	4.69	
Total	244.70	46		

*P < .05

The results of the one-way analysis of variance in Table 8 showed a significant difference (.05 level of confidence) in the NOSS scores of the sample of science education undergraduates and the sample of science undergraduates (chemical sciences), and thus the rejection of the null hypothesis. It may also be recalled that the mean NOSS score of the sample of science education undergraduates was higher than the mean NOSS score of the sample of science undergraduates (chemical sciences)(see Table 5, Page 94).

From the results of the analysis of variance (Tables 7 and 8) it was accepted that there was significant

difference (.05 level of confidence) in the level of understanding of the nature of science as expressed by science undergraduates and science education undergraduates. It was also inferred that since the science education undergraduates had a higher mean NOSS score (See Table 5) than the science undergraduates, they have shown a better understanding of the nature of science, as measured by the NOSS than the science undergraduates.

Question 3:

Do science undergraduates differ in their understanding of the nature of science as a function of their subjects of specialization?

Toward answering this question, the following null hypothesis was tested: science undergraduates do not differ significantly in their understanding of the nature of science as a function of their subjects of specialization. To test this hypothesis, the NOSS scores of the sample of science undergraduates (biological sciences) was compared with the NOSS scores of the sample of science undergraduates (chemical sciences), using the one-way analysis of variance. The raw scores for the two samples are presented in Table A.4 and A.5 of Appendix **A**

The variance ratio (F) = 1.4709 ($df_1 = 26, df_2 = 19$) was not significant at .05 level. Therefore the assumption of equality of population variances was upheld,

and the use of the analysis of variance technique justified.

The results of the one-way analysis of variance of NOSS scores of both samples is presented in Table 9.

Table 9

Analysis of Variance Among NOSS Scores of Science undergraduates (Biological Sciences) and Science undergraduates (Chemical Sciences)

Source of Variance	Sum of Squares	df	MeanSquare	F
Between groups	1.32	1	1.32	0.2163*
With groups	274.62	45	6.103	
Total	275.94	46		

*P > .05

The results of the analysis of variance in Table 9 shows that there was no significant difference in the NOSS scores of science undergraduates (biological sciences) and the NOSS scores of science undergraduates (chemical sciences). The null hypothesis was accepted and the conclusion drawn that the science undergraduates do not differ significantly in their understanding of the nature of science as a function of their subjects of specialization.

Question 4.

Do graduate science teachers with professional teaching qualification show a different understanding of the nature of science from graduate science teachers without professional teaching qualification?

The following null hypothesis was tested in respect of this question:

Graduate science teachers with professional teaching qualification do not show a significant difference in understanding of the nature of science from graduate science teachers without professional teaching qualification.

Using the NOSS scores of subjects as a measure of their understanding of the nature of science, a one-way analysis of variance (two groups) was used to compare the NOSS scores of graduate science teachers with professional teaching qualification and the NOSS scores of graduate science teachers without professional teaching qualification. In testing the assumption of equality of variances in both populations, the variance ratio (F) was 1.2355. With $df_1 = 27$ and $df_2 = 45$, this variance ratio was not significant at .05 level of confidence, therefore the assumption of equality of variances was justified as well as the use of the analysis of variance technique for making the required comparisons. The raw NOSS scores for both samples are shown in Tables A6 and A7 of Appendix A. The

mean, range, variance and standard deviation for each sample are as shown earlier in Table 6 (Page 95). The results of the one-way analysis of variance are given in Table 10.

Table 10

Analysis of Variance Among NOSS Scores of Graduate Science Teachers with Professional Teaching Qualification and Graduate Science Teachers without Professional Teaching Qualification

Source of Variance	Sum of Squares	df	MeanSquare	F
Between groups	29.33	1	29.33	4.3452*
Within groups	486.08	72	6.75	
Total	515.41	73		

*P < .05

The results of the analysis of variance in Table 10 shows a significant difference (.05 level of confidence) between the NOSS scores of graduate science teachers with professional teaching qualification and the NOSS scores of graduate science teachers without professional teaching qualification. The null hypothesis was rejected and the conclusion drawn that, for the samples used, there was significant difference (.05 level of confidence) in

understanding of the nature of science as expressed by graduate science teachers with professional teaching qualification and graduate science teachers without professional teaching qualification. Also since the mean NOSS score of the sample of graduate science teachers with professional teaching qualification happened to be higher than the mean NOSS score of the sample of graduate science teachers without professional teaching qualification (See Table 6 Page 95) it was inferred that the sample of graduate science teachers with professional teaching qualification had shown a better understanding of the nature of science (as measured by NOSS) than the sample of graduate science teachers without professional teaching qualification.

Question 5.

Do graduate science teachers with long teaching experience show a different understanding of the nature of science from graduate science teachers with short teaching experience?

In seeking an answer to the above question, long experience as defined earlier in this paper is a teaching experience of more than five years and short experience is a teaching experience of five years or less. To obtain samples that would be used for verifying the question posed above the entire sample of graduate science teachers

(N=74) was rearranged into two samples on the basis of experience as defined above. Thus the sample of teachers with short experience = 28, while the sample of teachers with long experience = 46. The raw NOSS scores in respect of these samples are displayed in Tables A10 and A11 of Appendix A. The mean, range, variance and standard deviation as computed from the NOSS scores are shown in Table 11.

Table 11

NOSS Test Results: Graduate Science Teachers with Long Teaching Experience and Short Teaching Experience

Sample:	Teachers with Long Experience	Teachers with Short Experience
N =	46	28
Range =	6-17	6-17
Mean =	10.72	10.46
Variance =	6.92	7.52
S.D. =	2.63	2.74

In further search of possible answers to question 5 the following null hypothesis was tested, using the one-way analysis of variance:

Graduate science teachers with long teaching experience do not show significant difference in

understanding of the nature of science from graduate science teachers with short teaching experience. In testing the above null hypothesis the NOSS scores of the samples of teachers with long and short experience were used as the measure of their understanding of the nature of science.. The results of the analysis of variance are presented in Table 12 below. Assumption of equality of population variances was justified because F value of 1.0867 , ($df_1 = 27, df_2 = 45$) was not significant at .05 level of confidence.

Table 12

Analysis of Variance Among NOSS Scores of Graduate Science Teachers with Long Teaching Experience and Graduate Science Teachers with Short Teaching Experience

Source of Variance	Sum of Squares	df	Mean Square	F
Between groups	1.12	1	1.12	0.1569*
Within groups	514.29	72	7.14	
Total	515.41	73		

*P > .05

Based on the results of the analysis of variance as in Table 12, the null hypothesis was accepted with the conclusion that with the samples used, graduate science

teachers with long teaching experience did not show significant difference in understanding of the nature of science from graduate science teachers with short teaching experience.

Summary

In this chapter the data in the form of NOSS scores of subjects were analysed according to the demands of the research questions, and in the pattern laid down in the designs in Chapter 3. The findings produced by the data analysis may be summarised as follows:-

Question 1: What is the level of understanding of the nature of science as expressed by science and science education undergraduates, and graduate science teachers in the populations studied? Findings: For the science and science education undergraduates the level of understanding of the nature of science as indicated by the NOSS scores showed that the sample of science education undergraduates had a mean NOSS score of 11.26 (38.8 percent), followed by the sample of science undergraduates (biological sciences) with a mean NOSS score of 9.89 (34.1 percent), and the sample of science undergraduates (chemical sciences) with a mean NOSS score of 9.60 (33.1 percent). The range, variance, and standard deviations for the NOSS scores were also calculated and can be seen in Table 5,(Page 94) of this

chapter.

For the graduate science teachers, the mean NOSS score of the sample of graduate science teachers with professional teaching qualification was 11.43 (39.4 percent), while the mean NOSS score of the sample of graduate science teachers without professional teaching qualification was 10.13 (34.9 percent). The range, variance, and standard deviation of the NOSS scores were also calculated and can be seen in Table 6 (Page 95) of this chapter.

It was generally observed that the lack of a standard or norm against which to judge the NOSS scores of the subjects made it difficult to evolve any categorical statements about the adequacy or otherwise of the subjects' level of understanding of the nature of science as reflected in their NOSS scores. However, it was noted that the mean NOSS scores did not reach the 40 percent mark in respect of any of the samples of science and science education undergraduates, and graduate science teachers. It was further discovered that for twelve of the 29 items on the NOSS, less than 40 percent of the subjects in each sample were able to give correct responses as suggested by the model answers.

Question 2: How does the level of understanding of the nature of science as expressed by science undergraduates compare with that expressed by science education undergraduates?

Findings: Based on the NOSS scores, it was found that there was a significant difference (.05 level of confidence) in the level of understanding of the nature of science as expressed by the sample of science education undergraduates and the sample of science undergraduates (biological sciences). A significant difference (.05 level of confidence) was also found in the level of understanding of the nature of science as expressed by the sample of science education undergraduates and the sample of science undergraduates (chemical sciences). Since the mean NOSS score of the sample of science education undergraduates was higher in each case, it was further inferred that the sample of science education undergraduates had expressed a better understanding of the nature of science than each of the two samples of science undergraduates.

Question 3: Do science undergraduates differ in their understanding of the nature of science as a function of their subjects of specialization?

Findings: Based on their NOSS scores it was found that science undergraduates did not differ significantly in their understanding of the nature of science as a function

of their subjects of specialization.

Question 4: Do graduate science teachers with professional teaching qualification show a different understanding of the nature of science from graduate science teachers without professional teaching qualification?

Findings: Analysis of the NOSS scores showed that there was a significant difference (.05 level of confidence) in understanding of the nature of science as expressed by graduate science teachers with professional teaching qualification and graduate science teachers without professional teaching qualification. Since the mean NOSS score of the sample of graduate science teachers with professional teaching qualification was higher than that of the sample of graduate science teachers without professional teaching qualification, it was inferred that the former has expressed a better understanding of the nature of science than the latter.

Question 5:

Do graduate science teachers with long teaching experience show a different understanding of the nature of science from graduate science teachers with short teaching experience?

Finding: From the analysis of their NOSS scores there was no significant differences in understanding of the nature of science as expressed by the sample of graduate

science teachers with long teaching experience and the sample of graduate science teachers with short teaching experience.

Chapter 5

SUMMARY, GENERALIZATIONS, IMPLICATIONS, LIMITATIONS, AND RECOMMENDATIONS.

In this Chapter, a brief statement of the problem, the procedures used as well as the findings are presented in summary. The generalizations made o n the basis of the findings are presented. The implications of the findings and generalizations are discussed, while the limitations of the study as well as recommendations for further research are reported.

5.1 Summary

This research was born out of the need to provide information regarding understanding of the nature of science among:

1. Undergraduate science students training to become future scientists and who would require such knowledge as a foundation for the professional practice of science.

2. Undergraduate science education students training to become future professional science teachers and who would need such knowledge to be able to train their students.

3. Practicing graduate science teachers in secondary schools and colleges who are supposed to teach their

students to achieve a better understanding of the nature of science.

In the light of the above, this study was directed to provide possible answers to the following specific questions:

1. What is the level of understanding of the nature of science as expressed by science and science education undergraduates, and graduate science teachers in the populations studied?

2. How does the level of understanding of the nature of science as expressed by science undergraduates compare with that expressed by science education undergraduates?

3. Do science undergraduates differ in their understanding of the nature of science as a function of their subjects of specialization?

4. Do graduate science teachers with professional teaching qualification show a different understanding of the nature of science from graduate science teachers without professional teaching qualification?

5. Do graduate science teachers with long teaching experience show a different understanding of the nature of science from graduate science teachers with short teaching experience?

The populations studied in this research were final

year science and science education undergraduates in Ahmadu Bello University, Zaria, and graduate science teachers in secondary schools and colleges in Kaduna and Zaria, Kaduna State, Nigeria. The samples which were obtained by the stratified random sampling technique were as follows: One sample of 27 science education undergraduates; and two samples of science undergraduates made up of 27 science undergraduates (biological sciences), and 20 science undergraduates (chemical sciences). There was a grand sample of 74 graduate science teachers which was split into smaller samples as required by the study, namely: 28 teachers with professional teaching qualification, and 46 teachers without professional teaching qualification; then into 28 teachers with short teaching experience, and 46 teachers with long teaching experience.

Through an extensive review of literature which led to the formulation of a model of the nature of science, a research instrument considered suitable for the purposes of this study was discovered and adopted.

The research instrument - the Nature of Science Scale (NOSS), was then administered to all subjects in the various samples by face to face contact in the period February - March, 1978. All subjects were given enough time to respond to all items on the NOSS, and after which the NOSS was scored and the scores recorded for each subject

in appropriate tables for analysis. During analysis, such statistics as the mean, range, variance, and standard deviation were computed from the NOSS scores and used for describing the level of understanding of the nature of science as expressed by the various samples. The one-way analysis of variance technique was used to compare the NOSS scores of different samples as required by the null hypotheses tested. The following findings were obtained from the analysis of the NOSS scores of the various samples:

The sample of science education undergraduates had a mean NOSS score of 11.26 (38.8 percent), followed by the sample of science undergraduates (biological sciences) with a mean NOSS score of 9.89 (34.1 percent), and the sample of science undergraduates (chemical sciences) with a mean NOSS score of 9.60 (33.1 percent). The sample of graduate science teachers with professional teaching qualification had a mean NOSS score of 11.43 (39.4 percent), while the sample of graduate science teachers without professional teaching qualification had a mean NOSS score of 10.13 (34.9 percent). Values were also obtained for the range, variance, and standard deviation of the NOSS scores of each sample. Although the lack of a standard or norm against which to judge the NOSS scores of the subjects made it difficult to evolve any categorical statements about

the adequacy of their level of understanding of the nature of science as reflected by the NOSS scores, it was noted that the mean NOSS scores did not reach the 40 percent mark in respect of any of the samples. It was further discovered that for twelve of the 29 items on the NOSS, less than 40 percent of the subjects in each sample were able to give correct responses as suggested by the model answers.

There was a significant difference (.05 level of confidence) in the level of understanding of the nature of science as expressed by the sample of science education undergraduates and the sample of science undergraduates (biological sciences), with the former showing a better understanding of the nature of science than the latter. There was also a significant difference (.05 level of confidence) in the level of understanding of the nature of science as expressed by the sample of science education undergraduates and the sample of science undergraduates (chemical sciences), with the science education undergraduates showing a better understanding of the nature of science than the science undergraduates (chemical sciences).

It was found that science undergraduates did not differ significantly in their understanding of the nature of science as a function of their subjects of specialization.

There was a significant difference (.05 level of confidence) in understanding of the nature of science as expressed by the sample of graduate science teachers with professional teaching qualification and the sample of graduate science teachers without professional teaching qualification, with the former showing a better understanding of the nature of science than the latter.

No significant difference was found in understanding of the nature of science as expressed by the sample of graduate science teachers with long teaching experience and the sample of graduate science teachers with short teaching experience.

5.2 Generalizations

The following generalizations were drawn on the basis of the findings of this study. In all cases the generalizations apply to the populations studied.

1. Although it was not possible to say precisely whether the level of understanding of the nature of science as expressed by the various populations was adequate (this was due to the lack of a standard or norm on which to base such judgement), the finding that the mean score on the measuring instrument was not up to the 40 percent mark in respect of any of the samples, as well as the finding that only less than 40 percent of subjects in each sample could

respond correctly to as many as twelve of the 29 items on the instrument may be indicative of the need to improve upon the general level of understanding of the nature of science in the populations studied.

2. A significant difference (.05 level of confidence) was found in the level of understanding of the nature of science expressed by science education undergraduates and that expressed by science undergraduates, with the science education undergraduates showing a better understanding of the nature of science than the science undergraduates.

3. Science undergraduates did not show significant difference in their understanding of the nature of science as a function of their subjects of specialization.

4. There was a significant difference (.05 level of confidence) in understanding of the nature of science as expressed by graduate science teachers with professional teaching qualification and graduate science teachers without professional teaching qualification, with the former showing a better understanding of the nature of science than the latter.

5. No significant difference was found in understanding of the nature of science as expressed by graduate science teachers with long teaching experience and graduate science teachers with short teaching experience.

5.3 Implications

The above generalizations have the following implications:

1. If the level of understanding of the nature of science as expressed by the various populations needs to be improved upon, as it seems to be, then urgent steps must be taken to ensure such improvement by the various authorities concerned with these populations. The Faculties of Science and Education of Ahmadu Bello University, must come out with ways to develop a better understanding of the nature of science among the science and science education undergraduates. The authorities concerned with the productivity of the graduate science teachers must be alerted to the urgent need to make the necessary provisions for these teachers to improve upon their understanding of the nature of science.

2. That there was a significant difference in the level of understanding of the nature of science expressed by science education undergraduates and that expressed by science undergraduates, with the science education undergraduates showing a better understanding of the nature of science than the science undergraduates, has important implications. For one thing this finding may be indicating that the science education program in Ahmadu Bello University is better suited to the development

of an understanding of the nature of science than the science program. This is more so when it is recalled that the samples used for the comparison were just at the end of their instructional programs in the university prior to entry into their respective professions. Secondly, since the science undergraduates in this university take more science courses than the science education undergraduates, while the science education undergraduates take some instructions in the philosophy of science as part of the science methods course, which science undergraduates do not, it may be inferred that taking courses in the philosophy of science may lead to the development of a better understanding of the nature of science than taking more courses in science. This latter inference however calls for more experimental investigations for its confirmation.

3. The finding that there was no significant difference in understanding of the nature of science among the science undergraduates when compared according to subjects of specialization seems to suggest that the undergraduate preparation programs in the various subject areas in the Faculty of Science of Ahmadu Bello University at the time of investigation were not different in terms of how much they contributed to the development of an

understanding of the nature of science. Recommendations as to how to develop a better understanding of the nature of science in undergraduate science students may therefore hold true for one of these subject areas as for the others.

4. The finding that graduate science teachers with professional teaching qualification showed a significantly different and better understanding of the nature of science when compared to graduate science teachers without professional teaching qualification lends credence to the observation made by Kimball (1967-68:110) that studies which aimed at drawing inferences about teachers' understanding of the nature of science in relation to their training programs should first distinguish between professionally qualified science teachers and non-professionally qualified ones before drawing such inferences.

5. Another implication of the better understanding of the nature of science by graduate science teachers with professional teaching qualification compared to graduate science teachers without professional teaching qualification is that the teachers with professional teaching qualification may be better prepared to develop in their students an understanding of the nature of science, in view of their better knowledge of same, than the graduate science teachers

without professional teaching qualification. This information may therefore lend further support to the need to staff Nigerian schools with professionally qualified teachers as a means of improving upon the standard of teaching and learning.

6. Since both the graduate science teachers with professional teaching qualification and graduate science teachers without professional teaching qualification had majors in science, another implication of the better understanding of the nature of science expressed by graduate science teachers with professional teaching qualification is that this may be due to the fact that the teachers with professional teaching qualification took instructions in the philosophy of science as part of their science methods courses. This further speaks for the necessity of taking courses in the philosophy of science as a means of improving understanding of the nature of science.

7. That there was no significant difference in understanding of the nature of science as expressed by graduate science teachers with long teaching experience and graduate science teachers with short teaching experience goes to confirm the finding by Kimball (1967-68:114) that experience may not be related to understanding of the nature of science. An important implication of this finding as noted also by Kimball in the study referenced above is

that the apparent lack of change in teachers' understanding of the nature of science with experience indicates that their concept of the nature of science is fairly well established by the time of graduation from the university. This is therefore another argument in favour of purposefully influencing students' understanding of the nature of science during their undergraduate training.

5.4 Limitations

The generalizations arising from the findings of this study have been limited to the populations studied. Some findings have been limited in scope, for example, it was not possible to say categorically whether or not the level of understanding of the nature of science as expressed by the various populations was adequate. This was mainly due to the lack of a norm or standard for the research instrument against which the scores of the various samples could be more specifically compared.

Considering possible limitations of the use of pure philosophical thought in the evaluation of a science model, efforts were made, while building up the model of the nature of science, to depend as much as possible on the expressed opinion of reputable scientists and science educators on the major issues. However, even the dependence upon opinion as authority has its own weaknesses, and this happens to be probably an unavoidable limitation of this

type of study.

5.5 Recommendations

Since the present study was limited in scope, there is the need for replicating it in other populations in the Nigerian educational system. One major advantage of such replication would be that national norms could be established for the research instrument (NOSS) on the basis of the results of such studies. With such norms it would be possible to evaluate more precisely the adequacy of the level of understanding of the nature of science expressed by other populations in future studies.

Many of the findings reported in this study pointed to possible advantages in developing understanding of the nature of science through instructions in the philosophy of science. Other researchers have also come to similar conclusions on this issue (Kimball, 1967-68:119). On the basis of these, it is being recommended here that the Faculty of Education of Ahmadu Bello University increase the level of understanding of the nature of science of the science education undergraduates by intensifying instructions in the philosophy of science. The Faculty of Science of Ahmadu Bello University, on the other hand, may need to introduce instruction in the philosophy of science as part of its training program for science undergraduates

so as to upgrade students' understanding of the nature of science.

As for the population of graduate science teachers studied, their understanding of the nature of science may be improved by relevant private reading or by organised in-service training programs which have the development of a better understanding of the nature of science as a special area of interest. For those graduate science teachers without professional teaching qualification it may be reasonable to suggest that in-service training toward professional teaching qualification may be a way to improve their understanding of the nature of science, since the findings of this research have shown that graduate science teachers with professional teaching qualification expressed a better understanding of the nature of science than graduate science teachers without professional teaching qualification. The authorities in charge of such teachers would do well to encourage them to go for such training programs as a way of improving their overall efficiency as science teachers.

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APPENDIX A.

Table A.1

NOSS Scores of S.B.S. Science Students

9	9	9	5
7	8	9	9
9	9	8	7
14	13	11	9
3	8	9	10
8	7	5	11
6	9	8	10
7	14	14	7
8	7	7	10
8	8	11	11
10	9	7	
9	11	11	
9	8	7	
7	8	7	
14	9	9	

Sum of Scores = 486

N = 55

Table A. 2

NCSS Scores of S.B.S. Science Teachers.

12	7
17	15
12	8
11	7
11	16
10	9
13	11
7	13
12	15
13	14
11	

Sum of Scores = 244

N = 21

Table A.3

NCSS Scores of
Science Education Undergraduates

8	11	13
8	11	13
8	11	13
8	11	13
9	12	13
9	12	14
9	12	15
10	13	
11	13	

Sum of Scores = 304

N = 27

Table A.4

NCCS Scores of Science
Undergraduates (Biol. Sciences)

4	10	11
4	10	12
6	10	13
6	10	13
7	10	13
9	11	13
9	11	
10	11	
10	11	

Sum of Scores = 267

N = 27

Table A.5

NOSS Scores of Science
Undergraduates (Chemical Sciences)

6	9
6	10
7	10
9	10
9	10
9	10
9	11
9	12
9	13
9	15

Sum of Scores = 192

N = 20

Table A.6

NOSS Scores of Graduate Science Teachers with Professional Teaching Qualification

12	12	11
17	12	14
10	17	10
11	16	13
11	8	9
10	12	8
9	13	8
13	7	13
11	15	
7	11	

Sum of Scores = 320

N = 28

Table A.7

NOSS Scores of Graduate Science Teachers
without Professional Teaching Qualification

6	9	8
12	13	11
11	7	11
11	11	6
10	15	11
10	8	11
8	7	7
12	16	9
11	9	13
8	9	11
9	9	15
10	9	14
13	9	6
10	11	10
11	14	
9	6	

Sum of Scores = 466

N = 46

Table A

Percentage of Subject
gave Correct Response

Item No.	Sc. Education Undergrad.	Sc. Undergrad. (Bio.Sciences)	Sc. Und (Chem.S
1	26	0	1
2	44	41	2
3	0	4	1
4	22	26	1
5	37	7	3
6	56	56	6
7	0	11	1
8	0	0	
9	63	63	7
10	15	33	4
11	41	63	5
12	33	59	3
13	22	15	
14	70	59	
15	44	33	
16	78	56	
17	41	22	
18	74	44	
19	52	59	
20	7	22	
21	22	7	
22	85	67	
23	33	33	
24	19	19	
25	56	59	
26	59	44	
27	52	30	
28	74	52	
29	0	4	

Table A.9

NOSS Items to which only Less than 40
Percent of all Samples Gave Correct Responses

Item	Model Response
1. The most important scientific ideas have been the result of a systematic process of logical thought.	Disagree
3. Thanks to the discovery of the scientific method, new discoveries in science have begun to come faster.	Disagree
4. The primary objective of the working scientist is to improve human welfare.	Disagree
5. While a scientific hypothesis may have to be altered on the basis of newly discovered data, a physical law is permanent.	Disagree
7. Science is constantly working toward more detailed and complex knowledge.	Disagree
8. A fundamental principle of science is that discoveries and research should have some practical applications.	Disagree
13. Any scientific research broader than a single specialty can only be carried out through the use of a team of researchers from various relevant fields.	Disagree
20. When a large number of observations have shown results consistent with a general rule, this generalization is considered to be a universal law of nature.	Disagree

Table A.9 (Cont'd)

Item	Model Response
21. The scientific method follows the five regular steps of defining the problem, gathering data, forming a hypothesis, testing it, and drawing conclusions from it.	Disagree
23. The steam engine was one of the earliest and most important developments of modern science.	Disagree
24. Scientific research should be given credit for producing such things as modern refrigerators, television, and home air-conditioning.	Disagree
29. An important characteristic of the scientific enterprise is its emphasis on the practical.	Disagree

Table A.10

NOSS Scores of Graduate Science Teachers with Long Teaching Experience

10	13	13
11	11	8
13	7	11
7	8	11
12	7	8
9	9	11
17	9	9
10	9	11
13	15	15
16	9	14
11	11	8
8	11	6
9	14	13
13	10	14
7	9	
12	11	

Sum of Scores = 493

N = 46

Table A.11

NOSS Scores of Graduate Science Teachers
with Short Teaching Experience

12	12	16
17	10	6
6	11	9
12	9	6
11	11	11
11	8	7
10	12	13
10	10	10
8	9	
11	15	

Sum of Scores = 293

N = 28

APPENDIX B

THE NOSS AS USED IN THIS STUDY

Please indicate whether you agree or disagree with each of the following statements about the nature of Science by ticking (✓) the response of your choice.

1. The most important scientific ideas have been the result of a systematic process of logical thought. (Agree; Disagree)

2. Classification Schemes are imposed upon nature by the scientists: they are not inherent in the materials classified. (Agree; Disagree).

3. Thanks to the discovery of the scientific method, new discoveries in science have begun to come faster. (Agree; Disagree)

4. The primary objective of the working scientist is to improve human welfare. (Agree; Disagree)

5. While a scientific hypothesis may have to be altered on the basis of newly discovered data, a physical law is permanent. (Agree; Disagree)

6. The scientific investigation of human behaviour is useless because it is subject to unconscious bias of the investigator. (Agree; Disagree)

7. Science is constantly working toward more detailed and complex knowledge. (Agree; Disagree)

8. A fundamental principle of science is that discoveries and research should have some practical applications. (Agree; Disagree)

9. While biologists use the deductive approach to a problem, physicists always work inductively. (Agree; Disagree)

10. The ultimate goal of all science is to reduce observations and phenomena to a collection of mathematical relationships. (Agree; Disagree)

11. The best definition of science would be "an organized body of knowledge". (Agree; Disagree)

12. Science tries mainly to develop new machines and processes for the betterment of mankind. (Agree; Disagree)

13. Any scientific research broader than a single specialty can only be carried out through the use of a team of researchers from various relevant fields. (Agree; Disagree)

14. Investigation of the possibilities of creating life in the laboratory is an invasion of science into areas where it does not belong. (Agree; Disagree)

15. Team research is more productive than individual research. (Agree; Disagree)

16. Many scientific models are man-made and do not pretend to represent reality. (Agree; Disagree)

17. Scientific investigations follow definite approved procedures. (Agree; Disagree)

18. Most scientists are reluctant to share their findings with foreigners, being mindful of the problem of national security. (Agree; Disagree)

19. The essential test of a scientific theory is its ability to correctly predict future events. (Agree; Disagree)

20. When a large number of observations have shown results consistent with a general rule, this generalization is considered to be a universal law of nature. (Agree; Disagree)

21. The scientific method follows the five regular steps of defining the problem, gathering data, forming a hypothesis, testing it, and drawing conclusions from it. (Agree; Disagree)

22. One of the distinguishing traits of science is that it recognizes its own limitations (Agree; Disagree)

23. The steam engine was one of the earliest and most important developments of modern science. (Agree; Disagree)

24. Scientific research should be given credit for producing such things as modern refrigerators, television, and home air-conditioning. (Agree; Disagree)

25. If at some future date it is found that electricity does not consist of electrons, today's practices in designing electrical apparatus will have to be discarded. (Agree; Disagree)

26. By application of the scientific method, step by step, man can solve almost any problem or answer almost any questions in the realm of nature. (Agree; Disagree)

27. Scientific method is a myth which is usually read into the story after it has been completed. (Agree; Disagree)

28. Scientific work requires a dedication that excludes many aspects of the lives of people in other fields of work. (Agree; Disagree)

29. An important characteristic of the scientific enterprise is its emphasis on the practical. (Agree; Disagree).

QUESTIONNAIRE OF PERSONAL INFORMATION FOR GRADUATE SCIENCE TEACHERS

BRIEF PERSONAL INFORMATION: (please note that all information will be treated with strict confidence)

Name (optional) ----------

First degree: B.A., B.Sc., B.Ed., B.Sc. Ed., (or any others, please specify)----------

Major subject for first degree: Chem. Physics, Biol., Bot., Zoo. (or any others, please specify) ----------

University awarding first degree ----------

Masters degree (if any): M.A., M.Sc., M.Ed., (or any others, please specify) ----------

University awarding Masters degree ----------

Doctoral degree (if any): Ph.D., Ed.D., (or any others, please specify) ----------

University awarding doctoral degree ----------

Dip. Ed. (or Equivalent) ----------

For how long have you been teaching science? ----------

Which science subject or subjects are you teaching now (e.g. Biology, Chemistry, Physics) ----------

In which school are you teaching now? ----------
