"A STUDY IN CONCEPT GROWTH AND ATTAINMENT IN SCHOOL SCIENCE"

BY

ABDUL RAHMAN N. MUGHOL

B.Sc.(Hons.),M.Sc.,M.Ed.

A thesis submitted in part-fulfilment of the requirement for the degree of Doctor of Philosophy of the University of Glasgow, Faculty of Science.

June, 1977.

I dedicate this humble piece of work to my worthy father, the late Hazrat Fakir Mian Noor Mohammad Mughol, who in spite of limited sources, always encouraged me to seek for knowledge and higher education. What I am is due to his untiring efforts.

C O N T E N T S

ACKNOWLEDGEMENT

I am deeply indebted to my supervisors, Professor D.W.A. Sharp, Professor S.D. Nisbet and Dr. A.H. Johnstone, for their encouragement and advice during my research period. In particular, I am sincerely grateful for the rewarding and agreeable association with Dr. Johnstone who, characteristically, extended his services on my behalf beyond the prescribed duties of supervisor, and whose energetic approach and patient understanding undoubtedly was my source of motivation.

Within the University of Glasgow, I should also like to thank Mr. Norman Reid for his help, guidance, enthusiasm and encouragement. My thanks also go to Mr. I. Bryson who helped me with computing, Mrs. M.J. Carter, Miss F.E. Wilson, and Mrs. J. Shed for their secretarial help and advice.

My thanks are also to all the Directors of Education, Science Advisers, Head Masters, Principal Teachers and pupils who co-operated in the experimental work embodied in this thesis.

I wish also to record my gratitude to all members of my family, specially to my younger brother, Mr. Khalil-ur-Rahman Mughol, Planning and Development Officer, University of Sind, who in my absence looked after the family and discharged his duties to the best of his ability. He also did much for me by encouraging, helping and showing his enthusiasm, which greatly supported my work and my peace of mind.

Finally, I am grateful to the Government of Pakistan for their award of a scholarship and to the University of Sind for granting leave for study with pay during my stay abroad.

S U M M A R Y

A STUDY IN CONCEPT GROWTH AND ATTAINMENT IN SCHOOL SCIENCE

The decades of the fifties and the sixties witnessed an unparalleled growth in the development of new curricula. Because of this, syllabuses in physics contained not only too much content but also some of it was conceptually difficult for the stage of the development of the children being taught. Difficulty in understanding physics was reported by many authorities. One of them was Scottish Certificate of Education Examination Board. This agency, from 1972 till now, in its annual reports, has been mentioning this factor of difficulty, encountered by the pupils in physics and has pointed out certain topics and concepts which were proving troublesome and were not properly understood by many pupils even at the higher levels of study. Many science educationists drew attention to another important factor which was creating difficulty and that was 'age' at which the topics and concepts were being taught. These views and reports indicated the need to study the difficulty and growth of topics and concepts in physics. Up to this time, nothing was reported regarding the pupils' views about this study. It was thought that the views and information given by the pupils would be useful and as important as the views given by various authorities and agencies.

The study followed here is empirical in nature and was planned to find out about:(i)difficult topics and concepts in the course, (ii) the age level at which these become clear to the pupils, (iii) the growth of some of the concepts and (iv) the most appropriate order for the presentation of some topics.

The survey of the literature was made at the beginning of the investigation. In this it was found that not such work of this nature had been done in this field in Britain before or after implementation of new syllabuses in physics which came into force in the late sixties.

To fulfil the first three objectives of the research, the work was carried out for a period of more than two years and in different educational institutions and various classes.

The beginning of the study was made with the general survey of difficult topics and concepts at various levels. This unit of work was applied in two consecutive years with the objectives to find out the topics and concepts which were: (i) understood first time or with a little effort, (ii) difficult but were mastered after considerable efforts, (iii) not clear, never understood and so needed to be taught again and, (iv) not covered by pupils in their course.

For achieving these objectives, the work in first year consisted of a questionnaire having 41 items. This was applied to first year university students and pupils of 'H' and 'O' grades in five schools. In second year, a modified questionnaire having 23 items and a test were prepared for subjective and objective assessments. This material was also applied in the same way.

To find out about (i) the age level at which some of the concepts become clear and (ii) the growth of these concepts, three concepts - density, heat and temperature and, electrical resistance were selected, one from each of the main areas of the study, mentioned above. Density was selected to study the 'natural' development of the concept; heat and temperature for confusion in normal everyday language usage and electrical resistance for it does not come often into normal use or conversation. The experimental techniques for investigating these concepts were similar although they differed considerably in detail. For each concept, the material prepared consisted of (i) a working net called a 'path diagram', (ii) an interview schedule and (iii) a diagnostic test. This material was also applied over two years in four schools. For the concept of density, the interview was conducted in SI to SIII classes and the test was applied to SI to SV classes. For the concepts of heat and temperature, and resistance, the interviews were conducted in SII to SIV classes and the tests were applied to SII to SV classes.

There are two main features of the experimental technique, (i) The tests were prepared on the basis of the interview information and were validated against the interview results and (ii) new types of diagnostic tests were prepared and novel ideas were introduced in the test construction.

The general survey of the syllabus revealed that there were certain topics and concepts which were difficult and were proving troublesome and, the troubles were carried by the pupils into their undergraduate careers. The study of the selected concepts revealed that the concept of density became clear to the pupils at the age of about 15 years and, in third year classes, there was fast growth of the concept. At the age of about 16 years, the concepts of heat and temperature were becoming clear to the pupils and the concepts were growing fast in fourth year classes. The concept of resistance became clear to half of the pupils at the age of about 17 years and the growth rate started improving in fifth year classes.

The work embodied in this entire investigation is now actively being considered by the Consultative Committee on the Curriculum in its planning of the syllabuses for the 1980s.

CHAPTER 1

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1. INTRODUCTION

In the world today, more people are reading about science, talking about science and speculating about the future of scientific developments than at any time in the history of mankind. There are many reasons why science has played an important role in our lives. The first one is that the people working at it have given us many goods and services which add greatly to the comfort and joy of living and, sometimes, even the possibility of living. The other reason for its importance lies in the vast amount of knowledge that has been accumulated from scientific discoveries made over the past several hundred years. The third reason for its importance is its method of solving problems.

The word science is derived from the Latin word "scientia", which means 'knowledge'. It is in the very nature of the meaning of this word that its growth points are unpredictable. There has been no time in the past when one might have foreseen the key developments which have had such an enormous effect on the direction, magnitude, and influences of resulting developments. The goals for the future of science are therefore necessary. It has provided a great many tested methods and techniques which man used with confidence and efficiency in solving problems. Modern advances in science have changed the life of man and given him a new civilization. They have placed in his hand tremendous powers, enabling him to control the forces of nature and change his environment to suit his needs.[1]

Scientific discoveries and their applications in industry, communication, agriculture, medicine and war have caused great changes in the lives and habits of mankind. Our mode of life has made us entirely dependent on the scientific discoveries. The future can only be secure in the hands of a race of people who grasp the significance of the changes which these discoveries have wrought, and are fully alive to the responsibilities which have to be assumed for the heritage of the past.

Science gives an intelligible picture of what we perceive by our senses in so far as it can be expressed in terms of numbers, ratios, sizes, shapes, weights and motions and all the qualities and units derived from these.[(2)] A.B. Arons (1965) supports this statement by saying that science has freed us from ancient tyrannies and fears, it has revealed to us a rational physical universe characterized by symmetry and mathematical order, it has given us deep insight into the regularities to be discovered in that range of physical phenomena directly perceivable by our senses... It has given us equally deep insight into an amazing range of phenomena not directly perceivable.[(3)]

Basically, science is one of the distinctive ways of knowing about and understanding the world.[(4)] Science is an area of knowledge which is largely responsible for shaping the age in which we live. What is important in science is that it grows by the progressive building of what J.B. Conant has called grand conceptual schemes. These are the great patterns of science within which there fit together the smaller patterns. As for these patterns, these are mental constructs of our own, and their ultimate sanction is that they do fit together.[5]

Science is not only a series of concepts and conceptual schemes but, it is also a method for the description, creation, and understanding of human experience. Thus science calls upon a child to take a stand to make decisions, and then to expose his belief to the test of what is happening in the world around him.[6]

Indeed, accepting science also means accepting nature as it is. The value of knowing nature is now recognized by educators. Science has now established its claim to a place in the school curriculum. Practically every school, whether secondary or elementary, attempts to give its pupils some instruction in the subject, and science is taught in secondary schools today because of the recognized need for general scientific literacy, our dependence upon scientists and engineers and the value that we place upon critical thought.[7]

1.1. Importance and Aims of Science Education

A. Science education has been the subject of much attention in the past twenty years. In the many countries of the world, project teams have been established to determine afresh the nature of science or the separate sciences in order that science may be taught and learned at all three levels of education. The outcomes from these projects have been a vast variety of materials for use in schools and institutions of higher learning.[8] Today's unprecedented impetus for teaching science derives from these sources. Scientific literacy is needed, first of all, by each member of a culture. The momentum of technological development is itself a source of pressure for teaching science. Maintenance of present standards of production, as well as advances in quantity and kind, depends upon a broad base of trained personnel in laboratories and on assembly lines and at the many way-stations between. To educate those in our schools for these tasks is thus the second important responsibility of today's science. Perhaps the greatest need, however, is the need in our society for leadership inculcated with the habits of critical thinking that are characteristic of the method used by scientists in solving problems.(7) In a similar way, R.G. Bridgham (1969) says that the spirit underlying science... can enable entire people to use their minds with breadth and dignity and with striking benefit to their health... It can strengthen man's efforts on behalf of world community, peace and brotherhood. It develops a sense of one's power-tempered awareness of the minute and tenuous nature of one's contributions. In so far as an individual learns to live by the spirit of science, he shares in the liberation of mankind's intelligence and achieves an invigorating sense of participation in the spirit of the modern world." He further quotes Shamos who says that a knowledge of science is important because of the "sense of order it provides over environment." He also quotes Karplus who in this context asserts that effective science teaching will permit students "to have some understanding of science work carried out by others even though they themselves do not become scientists."(9) B.S. Bloom (1971) summarizes all this in these words, "the principal purpose of science education is to develop the student's scientific literacy", a purpose that the traditional curriculum has failed to fulfil effectively.[10]

B. Every discipline has certain aims and objectives, so has science education. Curriculum Paper 7 has defined the term "aim" in these words: "By aim we mean a broad statement of intent."[11] The same paper has given the following aims of science education. In science education, pupils should acquire:

(a) some knowledge of the empirical world around him;

(b) a little of the vocabulary and grammar of science, i.e. communication skills;

(c) an ability to observe objectively;

(d) an ability to solve problem situations and think scientifically;

(e) an awareness of the culture which is science.[11]

The Nuffield Foundation has given the following aims of science education. Science education should provide:

(a) an essential ingredient in a human's education;

(b) an indispensable foundation for adult life and work in an increasingly scientific and technological age;

(c) a well-grounded understanding of science (or branch of science); not a knowledge of disconnected facts;

(d) encouragement of children to think freely and courageously about science in a way that practising scientists do;

(e) experimental and practical inquiry for children as a means of awakening original thought."[12]

Regarding the importance of aims, the book "The

Teaching of Science in Secondary Schools" says, "Aims are clearly more than objectives towards which teaching is directed; they are also objectives that provide a detailed specification for the science examiner in the construction of his examination paper."(13) This statement emphasizes objectives also. According to Curriculum Paper 7, "Objective is a technical term in educational theory specifying the outcome of learning activities in behavioural terms. These should be observable and measurable." There are two types of objectives: (a) summative, (b) formative. The same paper about these two types says summative or general are attainable after frequent experiences of a given kind. Formative or specific delineates the outcomes of working with a particular piece of syllabus content.(11)

J.S. Richardson (1957) has given the following list of objectives of science teaching.

(a) Develop the ability to think critically, to use the method of science effectively;

(b) Acquire the principles, concepts, facts and appreciations through which they can better understand and appreciate the nature of the earth, its inhabitants and the universe;

(c) Use wisely and effectively the natural sources of our earth as well as products of science and technology;

(d) Understanding the social functions of science and think and act in relation to the implications of science and technology for society;

(e) Acquire information, understanding and appreciations that will contribute to their educational and vocational guidance."[7]

At another place he remarks "Those facts, concepts and principles that are functional, and attitudes, appreciations and interests having implications for functional learning should contribute the objectives of science teaching."[7]

The teaching of science should be meaningful as a human activity. In this context the book "The Teaching of Science in Secondary Schools" says "Science should be recognized and taught as a major human activity which by exploring the realm of human experience methodically and imaginatively, by disciplined speculation, produces a coherent system of knowledge. In the past science has been taught in such a way that any mention of training in scientific habits of thought would be quite meaningless."[13] It further mentions that "science teaching in schools has several functions to perform: it must give pupils a lasting understanding of what it means to approach a problem scientifically, pupils must be given opportunities to observe and explore so that they develop critical and imaginative thinking, and pupils should be aware of what scientists can and cannot do."[13]

Saunders (1955) has given the following aims of science teaching:

1. The first and obvious reason for teaching science is to give information about the world in which we live;
2. Probably the most important purpose of science teaching is to make pupils aware of methods and attitudes of scientists;
3. There should be built up in him an uncompromising

regard for facts as distinct from opinions, a readiness to revise theories in the light of a problem;

4. Practical work is essential to the main purpose of science teaching;
5. In the course of his study a pupil should learn something of the history of man's conquest of nature.(14)

Regarding the objectives of science teaching, L.D. Mackay (1971) says: "Science courses in different countries and in different school systems differ in many ways ... but there is a good agreement on the objectives of teaching science. This agreement is reflected in the three-fold aims for science teaching listed by the National Society for the Study of Education in its 59th Yearbook: "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 methods; and third to develop understanding and appreciation of science and scientist."(15) R.W. West (1976) has given the following aims of science education. He says: "The aims of science education in our schools have traditionally focused on producing a small but ever increasing number of able boys and girls who would read for degrees in science and technology as a step towards professional careers in pure or applied science. School science has thus by tradition been tightly interlocked with university science, with one seen essentially as a preparation for the other."(16) By way of conclusion let us turn to the remarks of Jean Piaget who says: "The principal goal of education is to create men who are capable of doing new things, not simply repeating what other generations have done - men who are creators, inventors and discoverers. The second goal of education is to form minds which can be critical, can verify and do not accept anything they are offered."(17)

1.2. Historical Background of Science Education

Historically speaking, science education started when the Royal Society was established. This Society was founded in 1663. It aimed at the mutual enlightenment of its members by discourse and discussion. There was no experimental work done by this Society at that time. Formal instruction in science was provided by Gresham College, which was founded in 1597 and worked up to 1768.

It will be proper to observe that the greatest impetus to science education was given by repressive measures forced by Elizabeth I upon the Jesuits, who established schools in their own jurisdictions. It was in these "dissenting academies" that the seeds of science education were planted and flourished. The Napoleonic War produced a climate of opinion and inquiry favourable to science education. The Lunar Society was founded in Birmingham in 1731. The Literary and Philosophical Society was established in 1781 and the Royal Institution was founded in 1799. But before these two institutions came into being, John Anderson, in 1760 founded the first Mechanics Institute in Glasgow.

The Great Exhibition of 1851 proved to be a milestone in science education in the nineteenth century. The public schools showed the initiative earlier in the century.

Stonyhurst in 1794 moved from Belgium to Britain, bringing with it a lively tradition of interest in science. In 1882, physics teaching was started in University College, London. Science was in the syllabus of University College School in 1833. At Rugby, natural philosophy was started in 1849. At the City of London School, science lectures were started in 1847. Late in the century, in 1884, at an International Conference in education held in London, Armstrong first outlined his method of teaching chemistry. It was the development of an heuristic approach to science education. Thus the study of science in schools began to develop in this country along its present lines, about one hundred and twenty-five years ago. Before the middle of the nineteenth century, the study of any branch of natural science hardly existed in any school or even in the universities.

The Higher School Certificate, the fore-runner of the present A/H level examinations, was established in 1918. This led to a considerable expansion of science teaching. However, between 1918 and 1932 no document concerned with the teaching of science was issued by the Board or Ministry of Education. The Spens Report of 1938 paid scant and disappointing attention to science education, but the Norwood Report produced in 1943, emphasized the imperative need for science as an essential factor in school education. The Education Act of 1944 extended the emphasis on science education into higher age groups in secondary and technical fields. The situation remained unsatisfactory up to 1955. In this year a group of far-sighted industrialists decided to give a lead to the government and set up "The Industrial

Fund for the Advancement of Science Education in Schools."

For a long time the response from local authorities was very limited, so in 1959 a great surge forward came from the science teachers themselves. In 1957 the two associations (Science Masters' Association and the Association of Women Science Teachers, which were separate at that time) began a comprehensive overhaul of the science teaching syllabus. A preliminary policy statement was issued. In 1961 it became possible to publish a revised policy statement, together with a great deal of detailed proposals as to how the new syllabuses might be designed and handled in schools.

In 1962 the Nuffield Science Project came into being.

In Scotland, the movement for changes in the syllabuses began in the late 1950's and is still continuing. In 1962 the alternative courses in physics and chemistry for the S.C.E. were provided and the trial of the Nuffield biology text as a basis for a new certificate course in that subject constituted the first stage of this change. In 1966 a working party was set up. This party reviewed the science teaching for non-certificate courses, and also the curriculum in science at that time. The revised edition of the syllabus, introduced in 1962, was published in 1964. In 1968 a second revision of syllabuses was issued by the Board. Since that time all schools presenting for the Board's examinations have adopted these syllabuses which with the disappearance of the traditional syllabuses are now the only syllabus on which examinations in science subjects on the ordinary and higher grades are set up by the Board. This is, in a nut shell, the historical background of science education in Great Britain.

1.3. Physics, its Importance and Aims in Science Education.

Science consists of so many branches: physics, chemistry, biology, etc., but we will confine ourselves to physics.

When people began to study scientific phenomena such as fire, air and water by examining, weighing, measuring and making other kinds of observation, they called their studies "Natural Philosophy". The name remained until fairly recently, when it became 'physics'. In certain universities physics is still named as "Natural Philosophy". Glasgow University is one of them. The word 'physics' is of Greek origin, which means 'nature'. Physics may be defined broadly as the investigation of the properties of matter and energy. The definition is generally restricted to exclude these laws involving the presence of life (biology) and also these laws which take into consideration the molecular change in matter.[18] Nelson's encyclopedia defines physics as "that department of science which is concerned with the fundamental laws of the material universe". The broader distinction between chemistry and physics is that the former science considers more practically molecular change of matter, but the two branches of science overlap, so that it is not possible to draw a clear line of division between them".[19] Ashhurst says, "physics is a study of non-living things."[20] J.B. Jenkins (1958) says: "The subject of physics embraces the study of certain aspects and phenomena of the natural world around us, especially those properties of material bodies which do not depend on a knowledge of their composition."[21] R.K. Adair (1969) says, "the relations between the observations of the physical universe are the subject matter of physics."[22]

Science has become highly specialized. Natural philosophy has developed into a constellation of disciplines which span the alphabet from aerodynamics to zoology.[23] But Sir Frederick Dainton recognizes physics as essentially atomic science and chemistry as molecular science and the study of molecules is impossible without an understanding of atoms, either in isolation or in assemblies. He further says: "of all subjects, perhaps physics offers the greatest opportunity for discoveries of fundamental philosophical importance... physics lies at the heart of science."[24]

Teaching of physics is essential for mankind because it is an essential part of man's nature. To seek to know more of nature and so to learn about himself gives him greater power over his own destiny. So physics encourages certain attitudes and carries a specific content. Regarding the importance of physics teaching, Gerald Holten (1973) says: "during the past two decades, the importance of general education's approach to science has been widely recognized; many colleges and universities have initiated courses in physics for the non-science major." He further says, "science is dynamic interaction with the total intellectual activity of an age. In a deep sense, science is part of the study of history and philosophy... If we therefore tried to think away the achievements of physics, the course of modern history would be almost incomprehensible... Eliminating physics would, of course, make nonsense of the history of industrial development."[25]

In every area physics is characterized not so much by its subject matter content as by the precision and depth of understanding which it seeks. The aim of physics is the construction of a unified theoretical scheme in mathematical terms whose structure and behaviour duplicates that of the whole nature world in the most comprehensive manner possible. Where other sciences are content to describe and relate phenomena in terms of restricted concepts peculiar to their own disciplines, physics always seeks to understand the same phenomena as a special manifestation of the underlying uniform structure of nature as a whole. In line with this objective, physics is characterized by accurate instrumentation, precision of measurement and the expression of its results in mathematical terms.[26] From these views, one comes to the conclusion that in physics, people study carefully and enthusiastically. This careful study reveals the facts. Physics is responsible for standardization of the units of quantities employed in various aspects of life.

The inclusion of the teaching of physics in the school curriculum is based upon certain reasons. Some of the important reasons are:

1. Children find interest in science.
2. It helps to make pupils think.
3. It is an attitude to life.
4. It is a need for a scientifically educated democracy.

At secondary school level, the aim of O-level physics is 'physics for all' and teaching physics as modern science, to give pupils a lasting sense of understanding, physics is a structure of knowledge.[27] J.G. Houston (1970) in this context says: "The broad aims for a physics course in a secondary school for pupils aged 11-18 years, might be stated as:

(a) To explain what physics is about and nourish an understanding of the principles and concepts of physics;

(b) To enable the pupils to 'do' physics in a laboratory as a practical human activity;

(c) To inculcate in the pupils an awareness of the significance of physics in modern life;

(d) To stimulate an interest in physics as an attractive and satisfying intellectual discipline."[28]

There are also objectives of teaching of physics in secondary schools. A few of these in common use are that students should develop skills in:-

1. the proper use of books;
2. manipulation of apparatus;
3. clear expression;
4. knowledge;
5. exploration.

They should also develop:

1. good attitudes to the subject;
2. good work habits;
3. interest in the subject.

1.4. Definitions and Types of Concepts.

Nature acts in simple and regular ways. When we study these acts of nature we are studying science. "Science", according to R.W. Tylor (1967)"is a structured discipline rather than a miscellaneous collection of facts and generalizations".[(29)] But J.B. Conant (1951) defines science in terms of concepts. He says: "Science is an inter-connected series of concepts and conceptual schemes that have developed as the result of experimentation and observation and are fruitful for further experimentation and observations."[(30)]

A. Physics is the fundamental science, dealing with basic features of the natural world, such as space, time, matter and radiation.[(31)] It gives us power to predict, design, understand and adventure into the unknown.[(32)] It attempts to describe the universe of phenomena in terms of few concepts employed in hypotheses, principles, theories and laws.[(33)] From these quotations it becomes clear that the universe of phenomena in science in general and in physics in particular can well be explained if one knows about concepts, their types and their importance. With concepts, always one more term is used and that is 'generalization'. In psychology, education and science education, it has been observed that there is no line drawn in between these two terms but Lawrence Frank warns us to distinguish between concept and generalization. "We derive", he insists, "our generalizations inductively from an analysis and synthesis of data; analysis and synthesis of generalizations build concepts which again become the primer upon which further inquiry is based."[(34)] J.D. Novak (1965), D.J. Wilkinson (1973) and K. Lovell (1975) support these

ideas. Novak says: "the structure of a science may be viewed as the system of major generalizations or concepts together with the process by which these concepts are obtained and enlarged." He further shows a connection among generalization, concept and facts. He says, "concepts in science are broad generalizations regarding some aspects of the physical or biological world; they are a composite of individual facts and emotional experiences."(35)
K. Lovell also has the same view but he says: "In generalization, the concept stands for, as a hypothesis (e.g. circle or insect) which the observer proceeds to test by trying out on fresh specimens of the class."(36) In the view of D.J. Wilkinson, generalization and concepts are two different terms and that concepts depend upon generalizations. He says " The generalization upon which concepts are built derives from an active research by the mind for all the points of similarity between ideas and the data."(37)

B. The word 'concept' is defined in so many ways. Before actual definitions are given let us look at "what is a concept". A concept can be viewed as having three parts. First, there is the extensive array of instances grouped together and those excluded; secondly, there is the rule or law or common property by which the elements in the array are put together; finally, this is the arbitrary name given to the concept. In the physical and biological sciences, workers are mainly concerned with extending generalization. ... The arbitrary naming of concept gives trouble in all school subjects. Once the name has been acquired, the whole tendency of learning, particularly through reading text, is for the rule which the name identifies to be forgotten or distorted. This difficulty is less apparent in science subjects than, say, in history, because in science an early, precise definition is found and tends to be better held through the precision of science as a whole.[27]

As this work is concerned with teaching of science, let us look at what is meant by "a scientific concept". The answer is supplied by Strevens and Kothari. They say "Here we find multiple ambiguity. The term is used both loosely and with apparent precision... The various usages of the term (other than the conversational) relate to five distinct ideas: first, to certain linguistic skills common to all advanced academic or scholastic study; second, to certain characteristics of the habits of thought of the individual scientist; third, to a number of concepts pre-requisite to science, but not unique to it; fourth, to one special pre-requisite, that of practical numeracy; and fifth, to those concepts which are unique and proper to science or which if they are not unique to it, are at least inseparable from it."[24A]

In every discipline there are concepts. It is important that they may be defined. Peter Fensham (1975), M.O. Peela (1965) and Gerald Holten (1973) support this view. Peter Fensham says: "concepts are defined because they are useful."[38] M.O. Peela refers this need to science. He says: "There is need for definitions of science concepts, inquiry, scientific enterprise..."[39] Gerald Holten emphasizes the need by saying that "Ideally, each of the concepts used in physical science can be made clear in terms of some such operational definitions." He further says: "The secrets of this successful harmony and continuity in physical science ... lies to a large degree in the nature of concepts and their definitions."[25] Looking at literature, it is observed that the term 'concept' is defined in so many ways. Each person has defined it in its own way. In this context, M.C. Serra (1952) says, "The attempts to define the word "concept" have been many but as yet there has been little agreement on an adequate definition." Dewey defines it as a meaning sufficiently individualized to be directly grasped and readily used and thus fixed by a word.[40] Brandwein (1962) considers a concept as the simplest pattern which helps us to order the events around us.[34] K. Lovell (1961) says, "A concept may be defined as generalization about data which are related".[41] J.G. Wallace (1965) in his book, "Concept Growth and the Education of the Child", has quoted many definitions of concept. He says "Ribot defined a concept as a habit, an organized memory. To Price, it is a recognitional capacity. Vinacke defined concept as a cognitive organization system which brings pertinent past experience to bear on a present object or situation ... To Russel, concepts are one type of the materials of thought as distinct from the processes, and he himself defines concept as a 'thing', a piece of mental furniture, a product of reification.[42] D.J. Wilkinson (1973) says "a concept refers to the contingency in which a common response is evolved by a class of stimuli."[37] In the view of J.E. Garone (1960), concepts are integrations and organizations of percepts and interpretations.[43]

E.J. Archer (1966) defines the concept as "the label of a set of things that have something common."[44] R.M. Gagne (1966) in his article "The Learning of Principles", has quoted the definition given by Carroll. He defined a concept as"an abstraction from a series of experiences which defines a class of objects or events".[45] R. Beard (1971) looks at the concept as an idea of class of objects or relations normally expressed by words.[46] K.D. Urquhart (1975) says "a concept is defined to be an inferred mental process".[47] R.M. Gagne (1970) defines the concept as a class of observable objects or object qualities.[48] Peter Fensham (1975) remarks about a concept in the sense in which this term is used in education means generalization of one sort or another.[38] B.S. Bloom et al (1971) support the views of M.C. Seera (1952)[40] by saying that though there is no general agreement on what constitutes a "concept" in science, here the term "concept" of science is taken to mean those abstractions of observed phenomena or relationships which scientists have found to be continually useful in investigating the natural world and for which they have agreed upon exact definitions. In this sense, concepts of science include both fairly limited scientific ideas (such as density, chemical element ...) and larger scientific ideas (such as cycle system, force ...)[10] E.M. Rogers (1960) says "in ordinary discussion, a 'concept' is a highbrow word for an idea or general notion. In discussing science, we shall give it several meanings."[49]

After going through all these definitions, it comes to mind that there are certain common characteristics of a concept. E.J. Archer (1966) has given the psychological characteristics and Gerald Holten (1973) has mentioned the general characteristics of scientific concepts. E.J. Archer says "the first, and probably most obvious characteristic of a concept is that it is identifiable (identifiability)... After a concept has been identified, it must be learned by a subject (learnability)... Another obvious psychological characteristic of concepts is that they can be labelled or named (labelability)... Another obvious psychological characteristic of concepts is that of transferability... It seems safe to assume that concepts that are identified, learned, named and generalized, or transferred can also be forgotten (forgettability)."(44) According to Gerald Holten, "there are two general characteristics which are shared by those concepts that have contributed most to the growth of science. First, each of the guiding concepts of physical science has a core which is clear and unambiguous or, at any rate, which through continual application to experimental situations has attained an operational meaning that is tacitly understood and communicable. Second, by the same token, the great majority of physical concepts are quantitative, that is to say, they can be associated with numbers and measurements and therefore with manual or mathematical operations... These two characteristics of concepts are joined by a third, without which science would degenerate into meaningless conglomerate of data... What makes certain concepts important, therefore, is their recurrence in a great many descriptions and laws, often in areas very far removed from the context of their initial formulation."(25)

As there are various definitions of concept, there are different names and types of concepts. The distinction between different types of concepts will be either logical or psychological, as P.E. Johnson et al (1971) say, "the distinction between types of concepts can be made on purely logical grounds... the distinction may be useful for the purpose of psychological analysis." According to them, there are two main types of concepts: (a) relational, (b) operational. The distinction between relational and operational concepts is partly arbitrary. A relational concept (e.g. force) can be given an operational definition by the use of an application term such as 'push' or 'pull', which in turn is indexed by a device such as the spring balance. Similarly, an operational concept, such as mass, can be given a relational definition in the sense that within the theory of physics, $m = f/a$ is as approximate as $f = m \times a$.[50] P.E. Johnson (1967)[51], Strevens and Kothari[24A] and E.M. Rogers (1960)[49] and School Council Curriculum Bulletin - 3 (1974)[27] support these ideas but with slight changes. School Council Curriculum Bulletin - 3 says that "science concepts in the main do not consist of the conjunction of simple attributes. They are 'relational concepts' which consist of common relationships between the features of different experiences."[27] In the view of E.M. Rogers, there are two main types of concepts in science. He has named them as: (a) Minor concepts, (b) Major concepts. He has divided minor concepts into three categories: (i) Mathematical concepts, (ii) Name concepts, and (iii) Definition concepts. Major concepts are also categorized by him as: (i) scientific concepts, (ii) conceptual schemes, and (iii) grand conceptual schemes. Mathematical concepts are useful tool ideas such as the idea of direct proportionality or variation... Name concepts are the ideas in some descriptive names that help us to classify and discuss. We may name a group of materials (e.g. metals)... Definition concepts are the ideas that we invent and define for our own laboratory use. They may be manufactured from simple measurement (e.g. pressure)... Scientific concepts are useful ideas developed from experiments... conceptual schemes are more general scientific ideas that act as cores of thinking... Grand conceptual schemes are the examples such as conservation of energy, conservation of momentum."[49] P.E. Johnson says, "Many of the concepts in a subject matter are defined by means of their relation with other concepts in that subject matter... this is specially true in physics, where much of the logical structure consists of interrelation among concepts." He further says, "physics consists of operational concepts also. There is a class of concepts (defined in terms of environmental data) in physics which are operationally defined."[51] He is supported by Strevens and Kothari that in physics, we deal with concepts which are precisely defined.[24A]

In the view of Richard Mascolo (1969) there are two main types of concepts: (a) key concepts, (b) process concepts. Key concepts that make up the structure of the discipline and process concepts by which the individual learns how to learn.[52] R.M. Gagne (1970) has given different names to relational and operational concepts given by P.E. Johnson (1967)[51] According to him, these types are: (a) concrete (b) abstract. Things which can be observed are called concrete concepts. Since they can be denoted by pointing to them, so they depend upon direct observation... Concepts that are abstract in the sense that they involve relations, these are concepts by definitions.[48]

Kegan et al (1970) have given three formal conceptual classes. These are: (i) analytic - descriptive, (ii) relational, (iii) inferential - categorical.. Analytic descriptive category includes concepts that are based on similarity in objective elements within a stimulus complex that were part of the total stimulus. Inferential categorical concepts include concepts that are not directly based on a partial objective attribute of the stimuli but involve an inference about the stimuli grouped together. Relational category includes concepts that are based on a functional relationship between or among the stimuli grouped together.[53] E.B. Hunt and C.I. Hovland (1960) have given three types of concepts. They are (i) conjunctive, (ii) disjunctive, (iii) relational. In the conjunctive type, all of the instances have features in common, so the concept is one where each instance possesses characteristic A and B or A and B and C. In the case of disjunctive concepts all instances have one or another feature ... in relational concepts, the common properties are sets of relationships rather than common specific stimulus elements.[54] M. Glanzer et al (1963) have supported Hunt and Hovland[54] by giving the above mentioned types of concepts. They have given two more categories of concepts: (a) positive concepts, (b) negative concepts. An example that meets the requirements for membership in a specified category is called a positive instance of the category or concept. An example that does not meet these requirements is called a negative instance.[55]

Having read all these authorities, the researcher defines the concept "as a unifying idea which makes relational sense of a variety of observations."

1.5. Importance of Concepts in Science Education

In the civilized world of today, much importance has been given to the new discoveries in science. These new inventions have changed people. Now the future of every country is bound up with the advancements of science. But science cannot advance without having useful concepts. Gerald Holten (1973)[25] quotes J.B. Conant, who says: "science advances not by the accumulation of facts... but by the continuous development of new and fruitful concepts."[25] M.W. Wartofsky (1968) is also of the same opinion. He says: "Science did not spring into being full grown. It grew by accretion, modification, radical reformulation side by side with tradition and with vestigial concepts." In his view, "there are two main approaches to the understanding of science. One is the study of science itself... study beyond that of the sciences themselves is undertaken. Such a study is the study of the conceptual frameworks of the sciences... the concepts of science are the working tools of scientific thought. They are the ways in which the scientist has learned to understand complex phenomena, to realize their relations to each and, to represent these in communicable form. Among the most wonderful of those things we consider inventions of science are the concepts of science. They are, in fact, the sophisticated instrumentation, the high technology of scientific thought and discourse."[56] According to D.E. Billing and B.S. Furniss (1973), there are various aims of a teaching course. One of the broad aims of a course might be to enable students to appreciate the patterns and interrelationships within scientific concepts.[57] T. D. Minter (1972) is also of the same opinion. He says: "concepts, being intellectual patterns based on facts, may last longer. The highest goal of teaching is achieved when the facts and concepts that are listed in the course syllabus have become so much the possession of the learner that his view of the world is affected."[24B] J.D. Bernard (1963) supports him by saying that it would seem there is still general agreement that a good science programme should result in the understanding of certain basic concepts of science, and the processes of science or methods of critical thinking. On the other hand, furthermore, that concepts and processes are inextricably related in scientific enterprise.[33A]

Many pupils think of science as a unity. If a science is perceived by pupils as a unity, key concepts which provide the foundation of many scientific disciplines need to be emphasized in its teaching.[58] L.E. Klopfer (1969) in support of the above statement remarks in a slightly different way. He says, "one component of scientific literacy is the understanding of key concepts and principles of science. Even though an individual is not personally engaged in a scientific or science-related occupation, he needs to have some functional understanding of scientific ideas to be able to comprehend the phenomena and the changes in the natural world in which he lives... By applying his understanding of key concepts and principles, the scientifically literate person is able to choose courses of action that will help him to live in safety and health.[59] Gerald Holten (1973) supports these statements by saying that without our almost axiomatic key concepts, we should be largely deprived of intelligence and communication.[25]

Peter Fensham (1975) quotes Strong of the C.B.A. Project, who in support of concepts advocates an emphasis on concepts with a wide ranging role.[38] One of the important roles of concept is its motivation. R.G.E. Mitias (1970) quotes Comb in this connection. According to Comb: "concepts and perception of objects and events are universally considered as fundamental motives for human behaviour and conducts."[60] K. Lovell shows the importance of concepts in the following words: "Concepts enable words to stand for a whole class of objects, qualities or events and are of enormous help to us in thinking."[41]

Basic and key concepts are important in every discipline. D.G. Osborne (1972) says, "Basic concepts common to physics taught everywhere, are essential."[24C] Gerald Holten (1973) has elaborated this statement by saying that the most spectacular case of such generally useful ideas is we saw, that of the so-called "fundamental" concepts of physics (e.g. length, time, mass). They are only a small handful of them, yet they are the building blocks from which all other concepts are constructed or derived." He further quotes Einstein who says, "The only justification for our concepts... is that they serve to represent the complex of our experience."[25]

E.M. Rogers (1960)[49] while defining the scientific concepts and giving their types, speaks about "conceptual schemes". These conceptual schemes are very important in science. Brandwein (1962) in this context says, "These conceptual schemes relate what we call the body of scientific knowledge... without an ordering in conceptual schemes, the science curriculum becomes a pot-pourri." He further says, "for our purposes, it is sufficient to consider a concept as the simplest pattern which helps us to order the events around us. A concept then is a reduction of events to a recognizable configuration, and a conceptual scheme is a relation among a number of concepts."(34) Gerald Holten (1973) by supporting the above statement says: "It is a conceptual scheme which we invent or postulate in order to explain ourselves, and to others, observed phenomena and the relationships between them, thereby bringing together into our structure the concepts, laws, principles, hypotheses, and observations from often very widely different fields."(25)

All these show the importance of concepts in science education. In this context Bill Ritchie (1971) says: "It is therefore important to allow pupils to see the need to introduce concepts, because of their usefulness in interpreting events."(31) In interpreting the events, problems may rise. So, an understanding of basic concepts is essential for it is these that are supplied again and again to a new problem.(13)

From all these quotations, it is obvious that concepts play an important role in science and so in teaching of physics.

CHAPTER 2

PSYCHOLOGICAL BASIS AND THEORIES OF CONCEPT LEARNING

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Psychology is one of the oldest subjects in which mankind has taken keen interest. This study of 'the soul', which started as philosophy has taken the shape of an experimental science nowadays. Because of its vast applications in human and animal nature, psychology has been divided into many branches. Some of its branches are briefly stated below:

(i) Normal psychology is study of the activities of normal individuals.

(ii) Abnormal psychology deals with the activities of abnormal individuals.

(iii) Child psychology studies the development of young children.

(iv) Animal psychology describes the behaviour of animals.

(v) Social psychology is concerned with the way in which the thought and behaviour of the individual are influenced by the structure, customs, and institutions of the group or society of which he forms a part.

(vi) Applied psychology is the application of the findings of psychology to the practical situations of life.[36]

As the researcher is interested in the studies of the growth of concepts among children so the views of some psychologists regarding the child's intellectual development, concept formation, concept attainment, learning and concept learning are given in this chapter.

2.1. Jean Piaget and his Work.

Jean Piaget is one of the psychologists who have studied child development in the first half of this century. He has worked in this field for more than fifty years. His work is of interest from two different points of view. From that of the psychologist, a knowledge of the process of concept formation in the individual is likely to be of help in understanding the abnormal adult in whom that process has either not been completed or undergone a devolution. From the point of view of the philosopher of science, the origin of concepts which have been so widely used in science is clearly important.[61] In the view of Johanna Turner (1975)"Jean Piaget is the major exponent of the 'cognitive developmental' approach. He is concerned with the qualitative changes which take place in a person's mental make-up between birth and maturity."[62]

Piaget started his work in 1921. The extent of Piaget's investigations vastly exceeds that of any previous inquiries into children's thinking. By means of observations and experiments with his own three children, he followed the cognitive development of infants; two books cover these investigations (Piaget, 1953, a & b). A further book describes the origin of play and imitation in children as symbolic ways of representing the world are learned (Piaget, 1960). With children of school age, sometimes with the aid of collaborators, he studied the development of language and thought in children (Piaget, (1926), their judgement and reasoning (Piaget, 1928), their understanding of physical casuality (Piaget, 1930) and origins of phenomena in the world (Piaget, 1929). The last four books, with a fifth concerning the development of moral concepts (Piaget, 1932), were his earliest books dating from the 1920's ... a very valuable series of investigations showed an increase in number of experiments to be discussed or tasks to be performed by the children. It includes investigations into the development of concepts of numbers (Piaget and Szeminska, 1952), time (Piaget, 1946), speed and movement (Piaget, 1946 a), quantity (Piaget, 1941), space (Piaget, 1956), geometry (Piaget, 1960), and classification (Piaget, 1959). In 1950, the psychology of intelligence was published in English. This gives an account of Piaget's theory of the origins of intelligence in children and the stages as they pass through cognitive development. Recently, Piaget and Inhelder have given more attention to adolescent thinking (Inhelder and Piaget, 1959) and, in the untranslated volume, they have summarized the periods of cognitive development and their characteristics (Piaget, 1956). Again more recently, Piaget with some of his students has made more than thirty studies of perception which are listed by Flavell.[46] C.M. Lomax (1973) summarizes the work of Piaget in these words: "Piaget's work on children's thinking falls into three main phases. His early work used the verbal clinical method ... His second series of researches carried out in the 1920's and 30's, was based on observations of his own three children... His later and most influential research is ...

concerned with logical and mathematical concepts such as number, space, and time".[63] Lomax's views are supported by Ruth Beard[64] and David Elkind,[65] who have given the details of these three phases of Piaget's investigations.

From the views mentioned above, it becomes clear that Piaget has done a lot of work in child psychology. Because of its enormous quantity, it was thought necessary to test his views and theories. Many American and British psychologists and educationists followed his studies. Here follow-up studies done in Britain are reported. T.D. Davies (1970) says: "In the field of scientific concepts, one of the first follow-up studies in Britain is reported by Lunzer (1956). His study was an extension of the work done by Carpenter (1955), who repeated Piaget's experiment on the conservation of volume which involved pouring liquids from one vessel to another ... In a series of studies, Elkind replicated Piaget's investigations and confirmed his assertion that conservation of global quantity precedes conservation of weight which in turn precedes conservation of volume. However, conservation of volume did not occur for 75% of his subjects until the age of about fifteen ... E.A. Peel (1959) reports a number of experimental examinations of some of Piaget's schemata concerning children's perception and thinking, carried out in Birmingham, and in particular discusses an experiment on logical judgement which was carried out by A.R. Lodwick ... Case and Collinson (1962) followed up Lodwick's work. They concluded that "from our own experience we know that well defined stages do not really exist ... Neither mental age nor chronological age was more important than the other in the development of thought structure ... One of the first follow-up studies in logical thinking was done by S. Jackson (1965) who compared the growth of logical thinking in normal and subnormal children ... R.M. Beard (1962) reports on the experiments about the pendulum and the projection of shadows described in "The growth of logical thinking". She concluded that "there was no evidence of clear stages corresponding either with age or intelligence and that young children may reach the higher stages of logical thinking ... proportionality was used only by children over the age of twelve and predominantly by the boys." K. Lovell (1961), with a team of assistants, made a large scale follow-up of ten experiments described by Inhelder and Piaget in "The growth of logical thinking".(66) K. Lovell (1974) supports Davies by saying that "follow-up studies of various kinds using the same general types of experiments have been carried out by Lovell, Jackson, Hughes and Davies.(67)

In going through the books of child psychology two terms are used throughout. They are: (1) development, and (2) learning. The nature of the problems of development is different from the nature of the problems of learning. Piaget is also of the same opinion. He says, "I would like to make clear the difference between two problems: the problems of development in general and the problems of learning." He adds "development is a process which concerns the totality of the structure of knowledge ... learning is provoked by situations ... it is limited process-limited to a single problem or to a single structure." He further says, "development is the essential process and each element of the learning occurs as a function of total development."(68) These views of Piaget reflect that he is interested in development. This is confirmed by the remarks of Turner (1975) about Piaget which are mentioned earlier in these pages.

There are three views regarding the development of a child. According to Turner (1975) these views are: "Firstly, the child can be viewed as an organism which grows almost like a plant, with the implication that it contains within it the seeds of adulthood... Alternatively the child can be thought to bring nothing with him beyond a set of reflexes so that what he becomes is a reflection of what has happened to him. A third view is the 'cognitive developmental' which is essentially interactionist in that the child is here thought to be affected by the environment and yet to be able to determine to an extent those aspects of the environment to which he will respond." She further defines the term cognitive development as "the development of a set of fundamental processes not the acquisition of any specific piece of knowledge or information."(62) In the view of Farnham-Diggory (1972) "the term cognitive development refers generally to changes in thinking abilities."(69) According to Piaget, cognitive development is neither the result of the maturation of the organism, nor of the influence of the environment alone, but of the interaction of the two.(62)

From these definitions of cognitive development it becomes clear that this is the development of the process or processes by means of which an individual is able to acquire knowledge. According to Piaget, this developmental process is marked by a series of stages, the order of which is invariant although the age of onset and termination may vary.[62] W.F. Archenhold (1975) defines the term stage as "a period when a particular way of tackling a problem or situation seems to be characteristic."[5] Regarding the period of these stages Turner (1975) remarks: "He (Piaget) is not saying that a person functions exclusively at one stage. Indeed a child or adult may operate at one level for one concept and at a higher or lower level for another. But generally speaking, each stage represents a different way of dealing with a particular aspect of the environment and hence one would expect that most of a child's thinking would be characteristic of the stage he has reached." She further remarks "Piaget distinguishes four main stages: sensori-motor (0-2 years), pre-operational (2-7 years), concrete operational (7-11 years), and formal operational (11 - adulthood)."[62] Ruth Beard (1960),[64] E.A. Peel (1960),[70] K. Lovell (1974)[67] are some of the educationists and psychologists who have mentioned the same stages of the development given by Piaget. K.D. Urquhart (1975) has quoted K. Lovell, who has given some detail of Piaget's stages. Lovell says: "(1) up to the age of 6, the child interacts with persons and objects and experiences and varied situations, i.e. his knowledge of the world is abstracted directly from objects, persons or events; (2) at 7 or 8, the child's thinking becomes more systematised and logical, i.e. he can classify and seriate and is entering the period of concrete operational thought; (3) at 8-12 the child's thinking is more flexible but he still makes exact relations between mental actions which bear directly on things. He forms first order relations which are inadequate for concepts required by science; (4) at 14-15, the child develops deductive ability in his thinking. He can form second order relations, i.e. can set up a hypothesis and deduce what would happen if it was held true. He is entering the stage of formal operational thought."[47] A book "Cognitive Development in Children", published by the Society for Research in Child Development (1970)[53] and E.A. Peel (1960)[70] have given the same description of the stages. The advantage of using the term 'stage' or 'level' in the cognitive development is shown by J.G. Wallace (1972). He says, "the term such as 'stage' or 'level' is employed to aid in the division of behaviour into units, which are suitable for precise description and to facilitate understanding of the speed and fluidity of change in children."[42A]

Piaget's developmental stages and his work have been widely criticized. The first follow-up study of Piaget was done by T.E. Carpenter in 1955. She, in the conclusion to her study says... "the correlation with mental age (of child) is considerably higher than that with chronological age."[71] She is supported by E.A. Lunzer (1956) and M. Shayer (1972). Lunzer says, "It is noteworthy, though perhaps not surprising that total scores on Piaget-type tests should have been more closely related to mental age than to chronological age."[72] Shayer in his article quotes R.J. Mealings, who says "Piaget's developmental stages are found to correlate quite well with mental ages rather than chronological ages."[73] These educationists have accepted Piaget's theory of definite stages but there are educationists who do not accept this theory. King is one of them. M.M. Hughes (1965) says "King does not accept the theory of definite stages in development ... He repeats Oaks' statement that there is no evidence to corroborate Piaget's interpretation of definite stages characteristic of a given age." He adds, "The fact that factor analysis studies have given no support to the stage theory, is frequently quoted in literature." He further says, "In discussing the merits of Piaget's theory of cognitive development, Peel also shows that the picture is not quite as clear as Piaget suggests. There are variations among children of the same age in respect of I.Q. and experience and, furthermore, the inherent difficulty of the experiments is not constant." Hughes continues: "Research at Birmingham University has shown that Piaget's stages can be applied to history, literature and science so that his views have wide application, but nevertheless Peel cautions 'we must however be on our guard against claiming too much for propositional logic'."'74) Hughes also mentions views of Case and Collinson and Lodwick. These views have been referred to already.

Because of the wide application of Piaget's theory of development, the curricula in science and mathematics have been influenced. The results of this have been given by D.G. Phillips (1971) who mentions: "Curriculum development especially in science and mathematics has also reflected the impact of Piaget's work, but often the results have been disappointing. At first glance it may appear that a well defined science or mathematics curriculum can be derived directly from Piaget's stages and sub-stages of intellectual development but such is not the case. The levels of development as outlined by Piaget are extremely broad and lack the prerequisite sequencing necessary for curriculum development."(75) K. Lovell (1974) and D.P. Ausubel (1964) have criticized Piaget's concrete and formal stages of development. K. Lovell says: "The broad trends indicated by the Genevan work have certainly been found, but the age of onset of formal thought varies according to the task and with the familiarity of the pupil with the first order relations which underpin the task."(67) Ausubel has supported K. Lovell. His views are mentioned in section 2.5.

E.A. Lunzer (1956) has viewed the experimental work of Piaget. He says, "The experimental work of Piaget differs from mental measurement in a number of important respects. First, it may be said that, in general, test psychology is concerned with the success or failure of an individual to solve a test at a given level. It does not go on to inquire how success is achieved or what may be the reason for failure. By contrast, Piaget is interested in the process by which the individual solves the problems with which he is confronted. He is not satisfied to say merely that a given situation... is mystifying to certain children or to most children at a certain age." He adds: "Piaget is not primarily interested in the classification of individuals, his interest is to understand the working of their intellect at different stages. Hence the work of Piaget has a bearing more on educational methods than on educational selection... Second, an intelligence test, an attainment test or an aptitude test must be such that no one for whom it is designed is capable of a perfect solution. This requirement is achieved by increasing the length of the test while limiting the time allowed for its completion, or by its progressive difficulty or by a combination of these... Piaget's situations make no demand for speedy solution. Moreover it may be said that all the concrete situations he creates are solved by all normal children sooner or later... Third, the demand that tests of intelligence should be impartial as between subjects who have had more or less favourable educational backgrounds has resulted in the attempt to make them as different as possible from the problems that may be met with in daily life or the tasks in the schools... By contrast, Piaget's situations have been deliberately taken from the problems with whose solutions we are constantly confronted in daily life or in scientific research." Lunzer concludes: "Thus the work of Piaget differs from that of test psychologists in aim, in content and in purport... Piaget himself has not studied the relation between the achievements of his subjects in his situations and their rating in intelligence tests."(72) W. Mays (1955) points out a frequent objection to Piaget's work. He says, "A frequent objection to Piaget's work is the absence from it of statistics."(61) Ruth Beard (1960) supports Mays and mentions more weak points of Piaget's work. She remarks: "Piaget believes that all individuals pass through the same stage of development in achieving concepts and, in his writings, he assigns an approximate age to each stage, implying that development depends more on chronological age than intelligence. But he drew his conclusions without the aid of statistical data. So far as is known, he did not test the same children in different kinds of concepts so it can not be concluded from his work that any individual is at the same stage with respect to concepts in different fields, e.g. number and spatial concepts. Since there is no information concerning the number of individuals in each age group it is impossible to check the ages given for achievement of a stage and, if the spread of ages was in fact very wide for achievement of a stage, the concept of stage would be practically meaningless. Further, there is no attempt to relate the achievement of concepts to innate differences in children or to their environments."[76] T.D. Davies (1970) has summarized the criticism of Piaget's work in these words: "The main criticism of Piaget's work has been: (1) That many of his observations were made on small unrepresentative samples of children; (2) that his procedures were not standardized; (3) that he failed to use even the simple statistical procedures in analysing his data; (4) that he failed to give a full account of what he actually did in many experiments and failed to give even the most rudimentary quantitative information; (5) that he seemed to make profound theoretical proposals on the basis of rather meagre experimental evidence."[66]

After going through these authorities, the researcher arrives at the following conclusions:

1. The child or adult may operate at one level for one concept and at a higher or lower level for another;
2. Each stage represents a different way of dealing with a particular aspect of the environment;
3. Not all, but most of a child's thinking might be characteristic of the stage;

4. Piaget's developmental stages are more closely related to the mental age of the child than to the chronological age;
5. For each stage the period of chronological age given by Piaget varies from individual to individual. Even if his stages correlate with mental age, the period of mental age for each stage varies;
6. For fixing the period of the stage, the same group of children should be tested in different kinds of concepts;
7. The number of individuals in each age group may be stated for the achievement of the stage;
8. The period of stage also depends upon the innate differences in children and their environment.

2.2. R.M. Gagne and his work.

Up to now we have dealt with a psychologist who started work in the first half of this century. Now we will look at a man who is one of the psychologists of the second half of this century and has worked in the field of learning. He is Robert M. Gagne.

Gagne is basically a 'behaviourist'. The main difference between Piaget and Gagne is that "Piaget has placed more emphasis on trying to define the structure of a child's mental apparatus which allows him to perceive his surroundings in certain ways."(5) On the other hand, "Gagne's emphasis is on what is to be learned."(38); i.e. Piaget is interested in development of thechild and Gagne in learning. D. Soulsby (1975) supports Peter Fensham(38) by saying that "Gagne is concerned not with the process of learning but with the (measurable) states of having learned."(77)

The idea of learning hierarchies is given by Gagne. These are one of the elaborations of task analysis. According to Gagne (1974) task analysis is a technique which could be brought to bear upon the problem of how to get from known human tasks to designed optimal conditions of instructions which would yield competence in these tasks." He adds, "Task analysis was proposed as a method of identifying and classifying the behavioural contributions to task competence for which differential instructional design was possible and desirable." He further says, "Task analysis, however, is not a theory nor is it based upon any conceptualizing that deserves to be called a theory."(78)

Historically, the learning hierarchy research began with a small preliminary study by Gagne in 1962, in which he attempted to teach seven children how to find formulas for sums of terms in number series... Gagne derived a network of elements which he called a hierarchy of knowledge.(79) R.T. White (1973) has outlined three major investigations done by Gagne. According to him "In the first of three major investigations by Gagne and his co-workers, Gagne and Paradise (1961) used a programmed book to teach 118 Ss a hierarchy of twenty-two elements, known then as 'learning sets', which led to the element solving linear equations." In Gagne's second major investigation, White adds, "Gagne, Mayor, Garstens and Paradise (1962) wrote another hierarchy for mathematical subject matter. It had fourteen elements and a double peak." For Gagne's third major investigation, he says, "In the third major study (Gagne and staff, 1965) another mathematics hierarchy was written and investigated."(79)

Like Piaget, many psychologists and educationists have done follow-up studies of Gagne's learning hierarchical approach. In his three different articles: "Research into learning hierarchies",(79) "A limit to the application of learning hierarchies",(80) and, "Past and future research on learning hierarchies",(81) Richard White has given the details of follow-up studies on Gagne's model and theory. He identifies the following areas of research on learning hierarchies:

"1. Investigations of the validity of learning hierarchies;
2. use of hierarchies in mediating vertical transfer;
3. generalizability of a valid hierarchy;
4. presence of hierarchies in many subject areas;
5. mastery of learning of intellectual skills;
6. retention and transfer of intellectual skills;
7. development and evaluation of instructional materials."(81)

The theories used by the research workers investigating the formation and development of concepts in children have tended to fall into two categories: (a) the behaviourists; (b) the cognitive theorists. Gagne belongs to the first category as has been mentioned above. About the theories of behaviourists, Soulsby (1975) says: "the theories of behaviourists are not strictly theories of learning at all, but rather theories about changes in performance, or about the modification of behaviour."[77] Gagne (1974)[78] indirectly supports the views of Soulsby, which are mentioned above. From these statements it becomes clear that learning hierarchies are not strictly theories of learning but are just as techniques.

In order to know about the learning hierarchies, it will be appropriate to know about Gagne's model and hypotheses. Regarding the model, W. Capie and H.L. Jones (1971) say, "Gagne who views behavioural development as resulting from accumulated learning effects claims that a child progresses ... because he learns an ordered set of capabilities which build on each other in progressive fashion through processes of differentiation, recall and, transfer of learning. According to Gagne's model, children acquire behaviour in a common sequence where each child passes through the chain in orderly fashion. A child who fails to master a step can not skip it and go on, for he is effectively limited in that chain."[82] These views give birth to the idea of 'prerequisites' of intellectual skill learning.

There are two forms of the prerequisite hypothesis: (a) weak, (b) strong. According to Gagne (1975) "... both of which are useful, but need to be distinguished." He defines each form by saying that, "the 'weak' form states that the recall of a prerequisite (subordinate) skill will make the learning of a given (super ordinate) skill more probable... the 'strong' hypothesis states that if a given (super ordinate) skill is learned, the learner must be able to recall the subordinate skill."[83] White (1973) adds more by giving their uses. He says, "The weak form is very close to the classic idea of transfer... the strong form should be more useful in educational practice, so long as it is tenable."(80) These forms of hypothesis give a clear cut idea of learning hierarchies.

Before learning hierarchies are defined, let us see their importance. B.S. Deming (1975) says: "It may be, however, that learning hierarchies would provide a more efficient and effective means for selecting, ordering and teaching curriculum than any other approach presently used." He further says: "Through the use of learning hierarchies, we can trace the step by step incrementation of learning by requiring the student to exhibit the performance specified in each succeeding objective."(84) The importance of this approach is established by the follow-up studies and areas of research which are mentioned above. Soulsby (1975) supports these ideas by saying that "A growing volume of studies testify to the increasing popularity of this type of learning and, in particular, of the notion of learning hierarchies."(77)

From the above statements, it is revealed that learning hierarchies have wide applications in the learning process. Let us see now, what they are. Gagne (1968) refers the term "to a set of specified intellectual capabilities having, according to theoretical considerations, an ordered relationship to each other."(85) At another place, he describes them "as patterns of learning tasks that led up to a terminal skill: each subordinate task would be a prerequisite for the task above it, and would mediate transfer for that task."(81) This means that learning hierarchies are based on the assumption that the ability to profit from teaching can only be exhibited by those pupils who have already acquired the relevant subordinate skills prerequisites.[77] In the words of Gagne himself: "learning hierarchy results from an analysis of some target learning outcome... it identifies the prerequisite skills for this target task, and then proceeds to analyse and identify the prerequisite skills for those prerequisite skills."[78] These views indirectly point towards the characteristics of learning hierarchies.

Gagne (1968) has given three characteristics in interrogative form. He says, "First, the question by means of which the analysis is begun namely, 'what would the individual have to know how to do'... second 'how does one know if the order assigned to the skill in the hierarchy is correct?... A third characteristic of hierarchies seems to be of considerable interest. Do they represent a sole learning route to the learning of the final task, or perhaps even a most efficient learning route?"[86] This means that a learning hierarchy should have subordinate skills which should be in chains or multiple discrimination. In the words of Capie and Jones (1971) "A properly constructed hierarchy considers the order, position and directionality of sub concepts."[82] These views help in validating the hierarchies, for which Gagne (1975) says, "the validation of any particular learning hierarchy depends upon the demonstration of ordered relationships among the skills it contains."[83] White (1974) by elaborating the above statement has described stages to be followed for the validation of learning hierarchies. First of all, he has identified five weaknesses made in the previous work done during the investigations of the validity of learning hierarchies. He says:

"1. The elements that comprised the hierarchy were often loosely defined, so that it was possible for someone to possess one attribute of the element but not another.

2. Often only one question was used for each element to test whether Ss had learned it or not.

3. The students lacked a proper index that could be used to decide whether connections between pairs of elements could be accepted as hierarchical or not.

4. In some studies the elements of the hierarchy were taught to a group of Ss, who were tested on all the elements together after the teaching was completed. In other studies there was no teaching and the Ss were only tested on their possession of the elements.

5. In a few studies a small number of Ss was used, which meant that quite a substantial proportion of people in the population from which the Ss were drawn could behave in ways contrary to that required by valid hierarchy and yet remain undiscovered through not being drawn in sample."(86)

He, considering these weaknesses, suggests nine stages for the validation of hierarchy. The stages given by him are:

"Stage 1. Define in behavioural terms the element that is to be the pinnacle of the hierarchy.

Stage 2. Derive the hierarchy by asking Gagne's question:

"What must the learner be able to do in order to learn this new element, given only instructions of each element in turn, from the pinnacle element downwards?"

Stage 3. Check the reasonableness of the postulated hierarchy with experienced teachers and subject matter experts.

Stage 4. Invent possible divisions of the element of the hierarchy, so that very precise definitions are obtained.

Stage 5. Carry out an investigation of whether the invented divisions do in fact represent different skills.

Stage 6. Write a learning programme for the elements, embedding in its test questions for the elements.

Stage 7. Have at least 150 Ss, suitably chosen, work through the programme answering the questions as they come to them.

Stage 8. Analyse the results to see whether any of the postulated connections between elements should be rejected.

Stage 9. Remove all rejected connections from the hierarchy."(86)

After going through these stages a question arises: whether hierarchy can be used in every subject or it can be useful for some subjects? Gagne (1968) in this respect says, "A learning hierarchy does not represent everything that can be learned, nor even everything that is learned within the domain it attempts to describe. In particular, a diagram of hierarchy does not present what is perhaps the most important result of the learning."(85) At another place he says, "... learning of hierarchies do not identify the external conditions of learning. In and of themselves, learning hierarchies tell us nothing about the content of instructional situations."(78)

White (1973) and Deming (1975) talk about the effective uses of the hierarchy. Deming says, "... the hierarchy approach has been demonstrated most successfully within relatively short components of curricula such as a single lesson."(84) White supports him by saying: "...the strong form of Gagne's hypothesis of learning hierarchies is supported for intellectual skills. Much of the subject matter of mathematics and the physical sciences is of this type, so learning hierarchies should be particularly valuable in those subjects. Intellectual skills appear to be more difficult to identify and define in other subjects, and so at present, the theory is of little use outside mathematics and physical science."(80)

Gagne's learning hierarchies are widely criticised. Soulsby (1975) says "The most general objection which can be made to Gagne's theory is that ... particular examples of learning were generalized to become prototypes representing (or rather misrepresenting) the domain of learning as a whole." He adds, "... his description does not cover the affective domain at all, nor can it adequately explain the highest and most complex varieties of human performances. Both of these are in themselves crippling defects in a theory of learning."(77) He is supported by White (1973),(79) White and Gagne (1974)(81) and Gagne (1968)(85) himself.

After reading these views regarding the learning hierarchies, the researcher draws the following conclusions:

1. Learning hierarchy is one of the elaborations of task analysis.
2. It is not a theory of learning but is a technique or it is just a network.
3. Learning hierarchies are concerned with intellectual skills.
4. In a learning hierarchy the ordered relationship is important. The position and directionality are also factors to be considered as important.
5. A learning hierarchy identifies prerequisite skills.
6. For each element in a hierarchy more than one question is required.
7. Procedure of validating learning hierarchies is long, time consuming and difficult.
8. A learning hierarchy does not represent everything that can be learned, not even everything that is learned.
9. A diagram of hierarchy does not present what is perhaps the most important result of the learning.
10. A learning hierarchy does not identify the external conditions. They are concerned with the internal conditions of learning.
11. A learning hierarchy does not tell about the content of the instructional situation.
12. In curricula, they are useful for a single lesson.

2.3. Concept formation and concept attainment.

A human being is called a social animal. He is distinct from other animals in respect of learning. Human learning differs fundamentally from the learning of other animals in its extensive use of concepts.(87) It is quoted above that in the field of research investigating the formation and development of concepts in children, there are two types of psychologists who have worked: (1) Behaviourists, (2) Cognitive theorists. Up till now, we have read about one psychologist from each category. The common feature between Piaget and Gagne is that, in general their work contributes towards concept development. Piaget describes the intellectual development in terms of stages. Each stage involves a period of formation and a period of attainment.(66) Here we find two terms: 'formation' and 'attainment'. These terms are also used in the learning of concepts. These are: 'concept formation' and 'concept attainment'. Some authors have given these two terms as 'concept development' and 'concept attainment'. In a broad sense, concept development and concept formation are just the same. According to Turner (1975), "Studies of concept development are loosely of two kinds. Firstly, those which describe the stages a child passes through whilst he is in the process of acquiring a concept, and secondly, more detailed studies of the strategies a person employs."(63) In section 2.1, the first kind of studies have been touched. The second kind of studies which are in fact studies of concept formation, are touched in the following paragraphs.

According to Peter Fensham (1975), 'concept development and 'concept attainment' are two different terms. He says, "In considering the learning or formation of concepts a distinction is often made between concept development and concept attainment. The first term relates to what concepts it is possible for children and adults, to learn and, the second is more concerned with how the learning actually occurs."[38] J.G. Wallace (1965) has quoted Vinacke who supports Peter Fensham. Wallace says: "Vinacke made the distinction between concept formation and concept attainment - on the one hand, a study of the origins of concepts in the learning of the infant and child and, on the other hand, an analysis of how the adult reorganizes his conceptual repertory and uses it in dealing with the external world - the key to the organization of his survey."[42] A.R. Jenson (1966) supports Vinacke by saying: "One basic distinction would seem to be that between concept formation and concept attainment... In the former case, the subject learns the concept almost from scratch, since at the beginning the relevant dimensions of the concepts are not yet salient, the subject has not yet learned to discriminate the dimensions of the stimuli and has no readily available labels for whatever components of the stimuli he may be able to discern... In concept attainment, on the other hand, the subject comes to the task having already learned to distinguish and label all the stimulus elements; he simply has to discover in the concept attainment task which dimensions the experimenter has selected to be relevant for the attainment of the concept."[88]

After seeing the distinction made between the concept formation and concept attainment, let us see the importance of concept development and concept formation. In this context, J.E. Garone (1960) says, "concept development is essential to effective thinking and learning. Because concept development is so intricately related to children's total development, teachers and parents need to know and understand more about it."[43] If concept development is of such importance, two questions arise: (1) What factor usually initiates concept development? (2) What is the fundamental factor in concept development? Again Garone (1960) has answered both the questions. He says, "percepts provide the materials for concept development... perception usually initiates concept development." Regarding the second question, he replies: "Interpretation is fundamental to concept development... Interpretations enable children to make generalizations concerning percepts. Reliable, consistent, and coherent interpretations contribute to reliable, consistent and coherent concept development."[43] E. Stones (1966) supports Garone. He says, "... one of the most important elements in concept formation is the process of perception. Until one perceives an object as a thing in itself it is impossible to develop a concept of a class of such things."[87] There are three stages in the process of concept formation. K.D. Urquhart (1975) has briefly described those stages. She says:

1. 'Play' stage, where activity is purposeless and undirected.
2. 'Direction' stage, where objects are grouped into classes, compared and perhaps counted.
3. 'Insight' stage, where constituents of a concept click into place explicitly, constructively or

analytically."[47]

There are certain basic issues in the study of the process of concept formation. D.J. Wilkinson (1973) has touched these issues by quoting Vinacke. He says: "Vinacke distinguishes three basic issues in studying the process of concept formation. The ways in which a particular person attains a concept and the conditions under which the process occurs, form the first. The concepts characterize the stages in the development, the second. And finally, the organization of the relationship between concepts."[37]

2.4. Concept Learning.

In child psychology, when one studies the development of the child, he also studies learning. Learning is not only important in psychology, it has equal importance in education also. Those who profess to study and improve education through methods of research, are inevitably, concerned with the human activity of learning.[89] Learning can be defined in two ways. According to Gagne (1972): "Definition one is the process of acquiring modifications in existing knowledge, skills, habits, or action tendencies." The second definition is "knowledge or skill that is acquired by instruction or study."[89] According to Ausubel and Robinson (1971): "Learning refers to the process of acquiring meanings from the potential meanings presented in the learning material."[90]

There are many varieties of learning. Ausubel and Robinson (1971) have given four basic kinds of learning. They say, "(1) meaningful-reception; (2) rote-reception;

(3) meaningful discovery; (4) rote-discovery."(90) Gagne has also given different kinds of learning. He says "... varieties of learning that are distinguishable from each other in terms of the conditions required to bring them about." He further says, "... description of eight sets of conditions that distinguish eight types of learning, called signal learning, stimulus-response learning, chaining, verbal association, discrimination learning, concept learning, rule learning and problem solving."(48)

In this list of kinds of learning, concept learning occupies sixth place, according to Gagne. Ausubel and Robinson (1971) have mentioned concept learning as one of the four kinds of meaningful learning. According to them, these four kinds are: "(a) representational learning; (b) concept learning; (c) proposition learning; (d) discovery learning."(90)

In section 2.3, much has been said about concept formation. It seems that, what we have mentioned there, is just the same as we have said about concept learning. This is, because, concept formation is one of the aspects of concept learning. Let us see what it is. According to Gagne (1970) "Concept learning refers to the acquisition of a classification of object properties, objects, and events... Beginning in the early grades and throughout his school career, the student will be asked to classify many things and events... This type of learning is obviously a most pervasive one." At another place, he defines the concept learning as "... learning, which makes it possible for the individual to respond to things or events as a class, is called concept learning."(48) Archer (1966) has quoted

E. Hunt, who has defined concept learning. Hunt says: "... concept learning is defined as a term which applies to any situation in which a subject learns to make an identifying response to members of a set of not completely identical stimuli..."(44) M.B. Rowe (1965) has quoted another definition of Hunt. He says, "Hunt defines concept learning as the process of acquisition or utilization, or both of a common identifying response to dissimilar stimuli."(91) Gagne (1966) has quoted Kendler, who has defined concept learning. He says, "Kendler defined concept learning as the acquisition of a common response to dissimilar stimuli."(45)

There is an important factor on which concept learning depends. Gagne (1970) has pointed out that factor. He says: "... a kind of learning that appears to be critically dependent on internal neural processes of representation for its very existence."(48) Gagne has also mentioned conditions of concept learning, and has shown its effect on an individual. He says: "The effect of concept learning is to free the individual from control by specific stimuli."(48) There are certain restrictions on concept learning. Archer (1966) has quoted Hunt, who has given these restrictions. Archer says: "Hunt has also added the following restrictions, although the first seems excessively constraining:

"1. The subject must conceivably, be able to instruct a human to apply the classification rule. The subject is not allowed to use examples during the course of this instruction.

2. The rule to be learned must be one that can be applied to any appropriate stimulus regardless of the context in which the stimulus appears.

3. The rule must be deterministic, once a given stimulus is completely described it must be uniquely classifiable."(44)

The second rule of Hunt gives some idea about another type of learning. This is 'context learning'. M.B. Rowe (1965) has defined context and context learning in the following words: "A context is defined as a set of entities related in such a way that the meaning of any one of the entities is partly or wholly determined by defining the meaning of the set containing the entity... context learning is the process of forming such sets, and assigning numbers to them." Rowe has shown the difference between context learning and concept learning. He says: "Context learning differs from concept learning... concept learning ... involves you in the process of taking cues from an entity and using them to place that entity inequivocally in a given class... concept learning then is considered as an all or none proposition." He adds, "context learning on the other hand, constitutes another different but essential mode of learning... In context learning, an object may sometimes be assigned to one class... and sometimes to another class. Unlike concept learning which possesses an 'all or none' characteristic, context learning is equivocal."(91) B.J. Underwood (1966) has shown contrast between concept learning and rote learning. He says: "The study of concept learning is the abstraction - selection - of a common feature, characteristic, or property which is present in a number of stimuli which differ on other characteristics. Indeed, if we were to contrast rote learning and concept learning at the point where a contrast is most meaningful, we would say that stimulus selection is an interesting by-product of rote learning but a necessity in concept learning."(92)

2.5. D.P. Ausubel and his work.

In psychology, the factor related to learning is the learning process. The psychologist who has worked extensively on 'learning process' is D.P. Ausubel. This psychologist started working in this field in the 1940's. The learning process is very important. It is often concerned with teachers and so Ausubel has relevance to them. This is confirmed by L.H.T. West and P.J. Fensham (1974) who say: "Because Ausubel is concerned with the cognitive process of learning complex verbal material, his theories have considerable relevance to the teachers."(8)

Like Piaget, Ausubel has also worked on the stages of intellectual development. He is inspired by Piaget's work. He says: "Piaget's delineation of qualitatively distinct stages of intellectual development has been a powerful stimulus to research in this area, as well as a perennial source of theoretical controversy."(93) Though Piaget's idea of stages has been appreciated by him, he has also criticized this idea. He says: "Despite the general cogency and heuristic promise of his formulations, however, the issue of stages remains unresolved for a number of reasons: some of these reasons, unfortunately, inhere in Piaget's unsystematic and faulty methods of conducting his research and reporting his finds." He adds: "In the first place, he is almost totally indifferent to problems of sampling, reliability and statistical significance... Second, he tends to ignore such obvious and crucial considerations as extent of intersituational generality and relative degree of intra and inter-stage variability in delineating stages of development. Third, the cross-sectional observation he uses to measure developmental change (observation on different groups of children) are particularly ill-adapted for his purposes. The transitional stages and qualitative discontinuities he purports to find can be convincingly extended to studies of the same children. Logic inference is not an adequate substitute for empirical data in naturalistic investigation. Finally, he refines, elaborates, and rationalizes sub-divisions of his stages to a degree that goes far beyond his data." Ausubel further says: "Hence, the psychological plausibility and freshness of the general outlines of his theory tend to become engulfed by a welter of logical gymnastics and abstruse, disorganized speculation."(93)

From this criticism it seems that Ausubel himself is interested in the stages of development. Regarding these stages, he says, "stages of development are always referable to a given range of difficulty and familiarity of the problem area. Beyond this range, individuals commonly revert (regress) to a former stage of development."(94) There is a transition between two stages. It depends upon certain factors. In his view "... transition from one stage of development to another presupposes the attainment of a critical threshold level of capacity that is reflective, in part, of extended and cumulative experience."(94)

In developmental stages, Ausubel is more interested in concrete and formal stages. He has criticized these stages of Piaget in detail by quoting other psychologists. He says: "Many American psychologists and educators, for example, have been sharply critical of Piaget's designation of stages for the concrete abstract dimensions of cognitive development." He adds: "They argue that transition between these stages occurs gradually rather than abruptly, that variability exists both between different cultures and within a given culture with respect to the age at which the transition takes place; that fluctuations occur over time in the level of cognitive functioning manifested by a given child; that the transition to the formal stage occurs at different ages, both for different subject matter fields and for component sub-areas within a particular field; and that environmental as well as endogenous factors have demonstrable influence on the rate of cognitive development. For all these reasons, therefore, they deny the validity of Piaget's designated stages."(94)

Following the criticism of the American psychologists, Ausubel himself is of the opinion that "... Since the transition to new stages do not occur instantaneously but over a period of time, fluctuations between stages are common until the newly emerged stage is consolidated. In addition, because of intrinsic differences in level of subject-matter difficulty, and because of intra and inter-individual differences in ability profiles and experimental backgrounds, it is hardly surprising that transition from one stage to another does not occur simultaneously in all subject-matter areas and sub-areas."(94) Ausubel also gives his opinion about the transition between concrete and abstract stages. He says: "... the transition from concrete to abstract cognitive functioning takes place specifically in each separate subject-matter area, and invariably presupposes a certain necessary amount of sophistication in each of the areas involved."(94)

While going through these comments by Ausubel on transition between stages, it is revealed that, like Gagne, he believes in a theory of 'prior knowledge'. In fact Gagne and Ausubel both have proposed theories of 'prior knowledge'. According to West and Fensham (1974)"Gagne has proposed a theory which is concerned with the first of those roles (prior knowledge is a determinant of what further learning can occur). The basis of his theory is that any piece of knowledge can only be acquired by people who possess certain prerequisite pieces of knowledge, which have their own prerequisite in turn." Regarding the theory of Ausubel, he says, "Ausubel's theory as a model of the second role (prior knowledge influences the process whereby this learning occurs) concerning the influence of prior knowledge on how learning occurs."(8) West and Fensham have also shown the difference between these two theories. About Gagne's theory, they say: "It leads to the creation of a sequence which is significant to one who has already mastered the learning, and so will be closely related to the logical structure inherent in the content of the material. Because of this, the task of deciding what basic factual knowledge the learner needs to know for a particular piece of learning, and so the task of preparing a readiness test for that learning is relatively straight-forward, although all too rarely used by teachers." Regarding Ausubel's theory, they say, "Ausubel's theory refers to the part played by prior knowledge in organizing new learning and building it into the cognitive structure of the learner. This is a psychological issue which may present very different premises for the structure of the learning sequence compared with those of the mastery situation."(8) We summarize the difference in the words of Peter Fensham (1975) who says: "If Gagne's emphasis is on what is to be learned, Ausubel's concern is with the process of learning, and his theory of this process suggests how the concepts the learner has already formed interact with new ones."(38)

This comment of Fensham gives an idea about meaningful learning, which is one of the basic kinds of learning given by Ausubel. Ausubel has also mentioned another kind of learning. It is rote learning. Ausubel has shown the difference between meaningful learning and rote learning. According to West and Fensham (1974) "Ausubel distinguishes between 'rote learning' and 'meaningful learning' and postulates that meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Rote learning of the new knowledge occurs when no such interaction takes place. The distinction is not a simple dichotomy. Rote learning is the lower end of the meaningful learning continuum."(8) These two types of learning have other sub types. Two of them are called reception learning and discovery learning. Regarding these two Ausubel (1966) says: "... reception learning is invariably rote and discovery learning is invariably meaningful." Ausubel has also described these sub types of learning. He says, "In reception learning, the principal content of what is to be learned is presented in more or less final form. The learning does not involve any discovery on his part... The essential feature of discovery learning... is that the principal content of what is to be learned is not given but must be discovered by the learner before he internalizes it."(95) These descriptions of the learnings give birth to two new ideas: (a) concept formation and (b) concept assimilation. According to Ausubel (1966) "... concept formation as an example of meaningful discovery learning and concept assimilation as an example of meaningful reception learning."(95) Much has been said about concept formation in section 2.3. We will touch here concept assimilation and the difference between the two.

Concept assimilation is an idea given by Ausubel. This is another aspect of concept learning. Ausubel and Robinson (1971) have defined this term. They say: "... When the criterial attributes of a concept are presented to the learner by definition, rather than being discovered by him... the concept learning involved is referred to as concept assimilation."(90) Ausubel (1968) distinguishes between concept formation and concept assimilation. He says: "In most instances of concept attainment after early childhood, particularly in the school environment, the criterial attributes of concepts are not discovered inductively through a process of concept formation, but are either presented to learners as a matter of definition, or are implicit in the context in which they are used. Concept attainment, therefore, largely becomes a matter of concept assimilation."(93)

After going through these pages about the work of

Ausubel, the researcher arrives at the following conclusions:

1. During the study the developmental stages inter-situational generality and relative degree of intra and inter-stage variability must be considered.
2. For fixing the period of stage, the same group must be studied at every stage.
3. Stages of development are referable to a given range of difficulty and the familiarity of the problem area.
4. The transition between stages occurs gradually.
5. Variability exists between different cultures and within a given culture with respect to the age at which the transition takes place.
6. The transition to the formal stage occurs at different ages both for different subject-matter fields and for component sub-areas within a particular field.
7. Environmental as well as endogenous factors have demonstrable influence on the cognitive development.
8. Intrinsic differences in level of subject-matter difficulty and intra and inter individual differences in ability influence the stage of the development.
9. Prior knowledge influences the process of learning.

C H A P T E R 3

THE EXPERIMENTAL STUDY - GENERAL INTRODUCTION AND SURVEY OF THE DIFFICULT TOPICS AND CONCEPTS.

C H A P T E R 3

THE EXPERIMENTAL STUDY - GENERAL INTRODUCTION AND SURVEY OF THE DIFFICULT TOPICS AND CONCEPTS

A steady increase in the research dealing with the learning and teaching of science has been observed for more than a decade. This has been due to the curriculum reform movement in science over about the last fifteen years. Science education research is the systematic attempt to define and investigate the problems involved in learning and instruction in science.[96] There are four different types of science education research. According to W.J. Jacobson (1970), they are: "(1) empirical, (2) philosophical, (3) policy and (4) developmental or formative studies."[96] It is inevitable that researches closely connected with or arising from curriculum development projects are largely 'empirical' in nature.[97] Jacobson has defined empirical research as "Empirical studies usually involve the collection of data concerning the behaviour of students, teachers, or other subjects under study. Often, the data are used to accept or reject hypotheses."[96] The purpose of this research is to provide the curriculum developer with knowledge and information as may be used by him to improve the quality of products and to enhance the educational effectiveness of the instructional procedures advocated by him. The value of such researches is indisputable.[97]

3.1. Need and Purpose of the Study.

The decades of the fifties and the sixties witnessed an unparalleled growth in the development of new curricula, particularly in the natural sciences. Scientific knowledge has an ever increasing growth rate with the consequence that science courses have an over full content. It is very easy to introduce new material but so difficult to reduce a syllabus.[57] These views are supported by Curriculum Paper 7. It says, "... It had already recognised that the original examination syllabuses in modern physics and chemistry contained not only too much content but also that some of it was conceptually too difficult for the stage of development of the children being taught."[11] These remarks point towards another important factor in the learning of science, namely conceptual difficulty. Many science educationists have shown their concern over this factor. As in this study we are concerned with teaching of physics, the views will be limited to physics only.

The difficulty in understanding physics is reported by many authorities. Let us go through the remarks given by the reports of the Scottish Certificate of Education Examination Board regarding physics. In the report for 1972, it is said, "Some concern must be expressed about the lack of understanding of some of the fundamental physics of the Ordinary and Higher Grade courses among the weaker candidates; examples on the Ordinary Grade are the basic concept of acceleration and, on the Higher Grade the dependence of kinetic energy on the square of velocity and the power converted in electrical circuits." For the Certificate of Sixth Year Studies, the report says, "... it was disturbing to note that there seemed to be real confusion between concepts of energy and momentum."[98]

In the report for 1973, it is remarked, "... one question at Ordinary Grade revealed that many candidates have little knowledge or no knowledge of the concept of acceleration, while another revealed only the vaguest idea of kinetic theory." For Sixth Year Studies, the report says, "... It is disturbing to find that many candidates were confused about basic ideas in the course. There was widespread confusion between angular and linear momentum and about the conservation of energy and momentum."(99) For 1974, the report says, "... Kinetic theory seems to discriminate sharply between the few for whom it is understandable, easy and satisfying, and the many for whom it is a major source of confusion." For Sixth Year Studies, the same report says, "... Many displayed an almost total lack of understanding of electromagnetism, Faraday's laws of electromagnetic induction being poorly understood even at a quite elementary level."(100) In the report for 1975, the remarks are, "... The question on optics, while proving to be popular, was badly done and many candidates show a lack of knowledge of the action of a prism... on the Higher Grade, many candidates showed great weakness with regard to the application of Newton's second law..." Regarding the Sixth Year Studies, the report says, "... Many were confused between angular and linear momentum and between translational and rotational kinetic energy; and there was confusion between electric field intensity and electric potential - all fundamental concepts."(101) These remarks reveal that there are many topics and concepts which are felt difficult by the pupils and even these are not properly understood by many pupils at higher levels of the study. Robinson et al (1975) quote D.C. Gaskel, who says, "Pupils find physics and chemistry 'hard' subjects, because, the syllabuses require teachers to teach many difficult concepts."[102] The term 'difficulty' is not easy to define. According to Bridgham and Welch (1969) "... To a student it may mean that conceptual demands are great, or that some of the demands are inappropriate to his own interest or simply that the student's work is evaluated against a relatively severe standard." They add, "If the 'difficulty' of physics is determined by curricular demands, then perhaps a redesign of the curriculum would make physics courses appealing to a wider range of students."[103]

Apart from the above mentioned factors, in the teaching of concepts, the age factor is important. This is one of the causes which creates difficulty in understanding concepts in physics. In schools, very basic concepts are being taught at an early age. In this context, Richard Barr et al (1967) say: "... the main difficulty lies in the understanding by the pupils at such an early age, of the abstract ideas and concepts. Apart from the obviously abstract nature of kinetic theory and atomic structure, such concepts - familiar to the teachers - as molecule, ion, electron, force, motion and, energy are only vague names to the pupils."[104]

All these views indicated the need to study the difficulty and growth of concepts and topics in physics. Another reason which encouraged the researcher to begin to study in this field was that the researcher was interested to know the views of the pupils who study the subject. Up to this time nothing was reported about the pupils' views about this study. To the researcher, their views and information is as important as the views mentioned above by the reports and science educationists. The 'difficulty' and growth of topics and concepts were the main factors which inspired the work in this field. R.W. Tyler (1967) supports these views of the researcher. He says, "The conceptions and the learning activities of students should also be studied in order to determine the extent to which courses as conceived and planned are actually being carried out."(29)

This study is an empirical study whose main purpose is stated in the above pages. Besides the main purpose, this research aims:

(i) to find out difficult topics and concepts in the course;

(ii) to find out the age level at which these concepts and topics become clear to the pupils;

(iii) to find out the growth of some of the concepts;

(iv) in the light of (i), (ii) and (iii) to place the concepts and topics in a more appropriate order in the cycles of the syllabus.

3.2. Survey of the Relevant Literature.

After going through the journals and periodicals of international repute, it was found that no such work had been done before in this field in Britain, before or after implementation of new syllabuses in physics which came into force in the late sixties.

3.3. Scope of the Study.

To fulfil the aims of the research, the work was carried out for a period of more than two years, and in different educational institutions and various classes. The results of this work have already been published.(105) The detail is as under:

A. 1974-1975.

In this year, the material was applied in the following institutions:

(i) University of Glasgow;

(ii) Bishopbriggs High School;

(iii) Victoria Drive School;

(iv) Kingsridge School;

(v) Williamwood High School.

The pupils and students who participated were belonging to the following classes:

(i) First year university;

(ii) 5th year (Post 'O' Grade);

(iii) 4th year (Pre 'O' Grade).

B. 1975-1976.

The material was applied in the following institutions:

(i) University of Glasgow;

(ii) Paisley Grammar School;

(iii) Greenock High School;

(iv) Greenock Academy;

(v) Port Glasgow High School;

(vi) Eastwood High School;

(vii) John Neilson High School;

(viii) Bishopbriggs High School;

(ix) Lanark Grammar School.

The pupils and students who participated were taken from the same classes as mentioned in A.

C. 1976-1977.

The material was applied in the following institutions:

(i) Hillhead High School;

(ii) Hyndland Secondary School;

(iii) Claremont High School;

(iv) St. Patrick's R.C. High School.

The pupils who participated were from first year to fifth year.

3.4. Preparation for the Study.

A. Syllabus:

The physics syllabus for 'O' and 'H' grades[106] was carefully studied to identify the areas of important topics and concepts at various levels. The following main areas were chosen:

(i) Motion;

(ii) Energy;

(iii) Electricity.

After choosing the areas, main topics and concepts were also chosen for the study.

B. Apart from mutual discussions, a number of science advisers and physics teachers in various schools were consulted:

(i) to see if they agreed or disagreed with chosen areas in general and topics and concepts in particular;

(ii) to check if there was any work done earlier in these topics and concepts by them for this purpose.

All of them agreed with the choice and also claimed that these areas (i.e. topics and concepts) were not already being used by them for this purpose.

C. To study pupils' existing conditions in physics and to be in contact with teachers and pupils in the schools and, to make sure that these areas were not used by the teachers, the researcher:

(i) visited all the schools which were selected for his research work;

(ii) attended many lessons in physics - two full days in every week for 15 months in two of the schools, i.e. Hillhead High School and Hyndland Secondary School.

In the light of A, B and C above, the following material was prepared:

(i) two pupils' questionnaires for the survey of difficult topics and concepts;

(ii) three sub-tests for checking objectively the subjective assessment of pupils and students;

(iii) three interview schedules for three different concepts (i.e. density, heat and temperature and, resistance). Each for one concept.

(iv) three diagnostic tests for the concepts mentioned in (iii). Each for one concept.

The details of the material prepared, will be given in the following pages and chapters.

3.5. Survey of the Difficult Topics and Concepts.

The beginning of the study was made by surveying the difficult topics and concepts. 'Survey' is one of the approaches to the problem. The term 'survey' is used... for the wide range of studies which involve observation of a situation as it is, without setting up experimental conditions or allocating groups to different treatments.[107] For this approach, Nisbet and Entwistle (1970) say, "Surveys are more than mere recording of information ... surveys may include the use of tests, examining the distribution of scores, or the application of sophisticated techniques of measurement to contrasting groups which already exist within the educational system." They add, "By the design of the survey, and in particular by the choice of samples, one introduces an element of the experimental into the survey."[107]

This unit of survey was applied in two consecutive years.

3.6. The Trial Edition of the Unit.

A. The design of the unit.

(i) Objectives of the unit were defined.

(ii) Material preparation: the material consisted of a questionnaire for students and pupils.

(iii) Material application: the material was applied in 1974-75 to pre 'O' grade, post 'O' grade pupils and first year university students.

More details of the above mentioned items are given below.

B. Objectives of the unit.

The unit prepared had the following objectives:

(i) to find out the topics and concepts which are understood first time or with a little effort;

(ii) to find out the topics and concepts which are difficult but were mastered after considerable effort;

(iii) to find out topics and concepts which are not clear, never understood and so need to be taught again;

(iv) to find out the topics and concepts which are not covered by the pupils in their courses.

C. Source of material.

The topics and concepts chosen were taken from the Scottish Certificate of Education Examination Board Syllabus for physics for Ordinary and Higher grades.[106]

D. The material structure.

After going through the syllabus and identifying the areas comprising important topics and concepts, a questionnaire was prepared. As it was the trial edition of the unit, a large number of topics and concepts was included in the draft out of which 41 items comprising various topics and concepts were selected. The items selected and the sections of the syllabus from which these were chosen are shown in Table 3.6.1 and, the questionnaire appears as Appendix 3.6.(a). The questionnaire was passed through all the stages given by Nisbet and Entwistle (1970).[107]

Table 3.6.1.

List of topics and concepts, and sections of the syllabus.

S. No.	Topic/Concept	Section of the Syllabus
1.	Evidence that matter exists as particles.	C.1
2.	Difference between solids, liquids and gases in terms of kinetic theory.	C.2
3.	Gas laws (e.g. Boyle's Law, Charles' Law).	K.6
4.	How to show that one set of units (e.g. ms^{-2}) is equivalent to another ($N\,Kg^{-1}$).	N.
5.	Difference between mass and weight.	J.
6.	Density	C.3
7.	The law of flotation.	N.3
8.	Difference between a vector (e.g. displacement) and a scalar (e.g. distance).	J.3
9.	Difference between force and pressure	N.3
10.	The lever as force multiplier.	G.1
11.	How a couple acts on a body.	G.
12.	Relation between action and reaction and conservation of momentum.	G.1.
13.	Idea of inertia.	G.1.
14.	Relation between impulse of force and momentum.	N.2.
15.	Difference between elastic and inelastic collisions.	N.2.
16.	Use of conservation laws (energy, momentum).	J.5.
17.	Resolution of forces.	J.3.
18.	Addition and subtraction of vectors.	J.3.

S.No.	Topic/Concept	Section of the Syllabus
19.	Equations of motion for free fall bodies.	N.1.
20.	Difference between energy and power.	B & H.2.
21.	Difference between heat and temperature.	K.
22.	Specific heat capacity, latent heat, heat calculations.	K.4 & K.5.
23.	Behaviour of a charged particle in an electric field.	L.1.
24.	The field vector ϵ , and the potential V in an electric field.	L.1.
25.	Conductors and insulators.	D.3 & H.3.
26.	Ohm's law in circuits.	L.2.
27.	E.M.F. and P.D. (Potential Difference).	O.1 & D.6.
28.	Use of potentiometer.	O.1.
29.	Thermionic emission (how diode and triode works).	L.5.
30.	Relation between frequency and pitch, wavelength and velocity.	F.2.
31.	Refraction and reflection in waves.	I.2.
32.	Interference and diffraction in waves.	I.2.
33.	Wave particle duality.	P.4.
34.	Why do different objects in white light have different colours.	P.4 & F.1.
35.	Electromagnetic induction.	L.4.
36.	A.C. circuits, capacitance, inductance.	L.3, O.3, & H.6.
37.	The idea of half-life.	M.1.
38.	α, β, γ , radiations.	M.1.

S.No.	Topic/Concept	Section of the Syllabus
39.	How a lens system (e.g. a telescope) forms a magnified image of a distant object.	F.1.
40.	Why a current carrying coil is deflected in a magnetic field.	L.3.
41.	How a commutator works.	L.3.

E. How the material was applied.

The questionnaire was first administered to 115 first year students in the university. It was then sent to five schools, where it was applied to 55 post 'O' grade and 211 pre 'O' grade pupils.

The ledger method[107] was used as data processing technique for this questionnaire.

F. Results.

The indices of difficulty as percentages were computed arithmetically for each year, i.e. first year university, post 'O' grade (fifth year) and pre 'O' grade (fourth year). The formula used for the computation is:

$$\text{Index of \% difficulty} = \frac{(B + C) \times 100}{\text{Total} - D}$$

where B, C and D are defined in questionnaire shown as Appendix 3.6.(a).

It was anticipated that if we presented this questionnaire to first year university students (those who had successfully passed the school system) we would get a number of topics in 'B' and 'C'. If we then presented the questionnaire to pupils at school (post 'O' grade) who were working for university entrance examinations, we would expect to see the same topics appearing in their subjective choice, but this time, more of them should report difficulty, because we are dealing with a probably less able sample of the age cohort. If this procedure was adopted with pupils yet one year younger preparing for 'O' grade examination, the difficulty effects should further intensify.

Figure 1 shows the results of plotting percentage

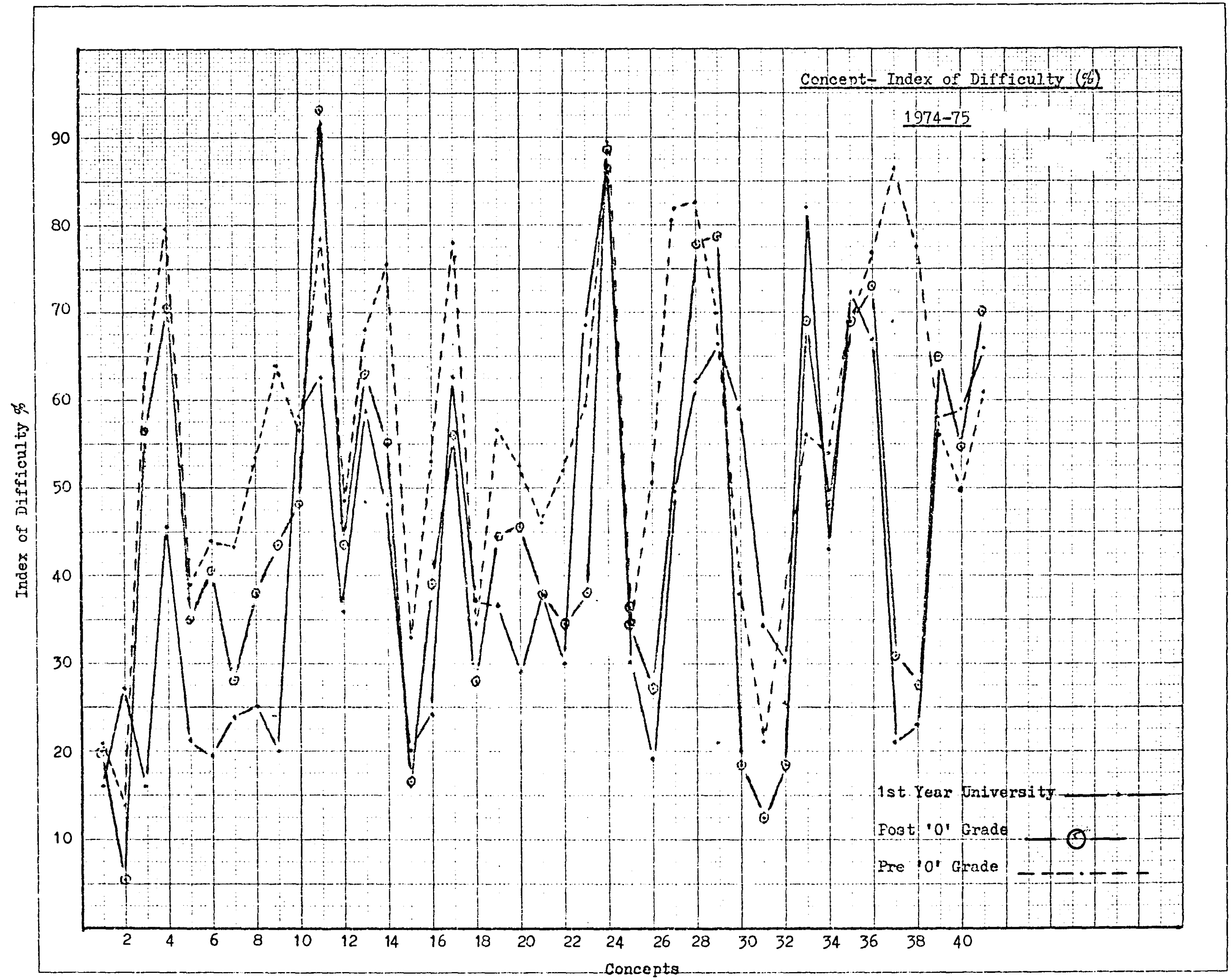

Concept- Index of Difficulty (%)
1974-75
1st Year University
Post 'O' Grade
Pre 'O' Grade
Index of Difficulty %
90 80 70 60 50 40 30 20 10
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Concepts

Figure 1.

Table 3.6.2.

List of topics and results for subjective assessment.

Concepts and Topics	Index of Difficulty %		
	1st Yr. University	Post 'O' Grade	Pre 'O' Grade
1. Evidence that matter exists as particles.	16.03	20.0	21.2
2. Difference between solids, liquids and gases in terms of kinetic theory.	26.95	5.5	14.2
3. Gas Laws (e.g. Boyle's Law, Charles' Law).	15.92	56.4	61.5
4. How to show that one set of units (e.g. ms^{-2}) is equivalent to another ($N\ Kg^{-1}$)	45.45	70.6	79.7
5. Difference between mass and weight.	21.05	35.2	39.3
6. Density.	19.46	40.7	44.3
7. The law of flotation.	23.75	27.9	43.7
8. Difference between a vector (e.g. displacement) and a scalar (e.g. distance).	25.21	38.2	53.5
9. Difference between force and pressure.	20.17	43.6	63.9
10. The lever as force multiplier.	58.16	48.3	56.5
11. How a couple acts on a body.	62.50	93.3	78.4
12. Relation between action and reaction and conservation of momentum.	35.71	43.4	48.5

Concepts and Topics	Index of Difficulty %		
	1st Yr. University	Post 'O' Grade	Pre 'O' Grade
13. Idea of Inertia.	58.71	63.0	68.2
14. Relation between impulse of force and momentum.	48.18	54.9	75.4
15. Difference between elastic and inelastic collisions.	20.00	16.4	33.1
16. Use of conservation laws (energy, momentum).	24.34	38.9	53.3
17. Resolution of forces.	62.61	56.3	78.2
18. Addition and subtraction of vectors.	36.84	27.8	34.4
19. Equations of motion for free fall bodies.	36.52	44.4	56.4
20. Difference between energy and power.	29.20	45.5	52.4
21. Difference between heat and temperature.	39.73	37.7	45.9
22. Specific heat capacity, latent heat, heat calculations.	30.08	34.5	52.0
23. Behaviour of a charged particle in an electric field.	68.51	38.1	59.4
24. The field vector $\mathcal{E}$, and the potential V in an electric field.	86.36	88.5	89.7
25. Conductors and insulators.	30.35	36.4	34.5
26. Ohm's law in circuits.	19.13	27.3	50.6
27. E.M.F. and P.D. (Potential difference.	49.56	71.7	81.8

Concepts and Topics	Index of Difficulty %		
	1st Yr. University	Post 'O' Grade	Pre 'O' Grade
28. Use of potentiometer.	62.16	77.8	82.4
29. Thermionic emission (how diode and triode works).	66.31	78.5	70.00
30. Relation between frequency and pitch, wavelength and velocity.	59.04	18.5	37.8
31. Refraction and reflection in waves.	34.51	12.7	21.3
32. Interference and diffraction in waves.	30.35	18.5	25.4
33. Wave particle duality.	82.14	69.0	56.1
34. Why do different objects in white light have different colours.	43.13	47.9	54.2
35. Electromagnetic induction.	72.32	69.2	68.9
36. A.C. circuits, capacitance, inductance.	66.96	73.1	76.9
37. The idea of half life.	20.90	30.8	86.5
38. α, β, γ radiations.	22.72	27.7	77.4
39. How a lens system (e.g. a telescope) forms a magnified image of a distant object.	57.87	65.1	56.3
40. Why a current carrying coil is deflected in a magnetic field.	59.25	54.7	50.0
41. How a commutator works.	65.85	70.0	61.00

difficulty index against topic numbers. The list of topics and their numbers are shown in Table 3.6.2. The three graphs show a similarity which suggests that the subjective pupil assessment of the topics and concepts is consistent and the general trend is that the 'university line' lies below the post 'O' grade (fifth year) line which in turn lies below the pre'O' grade (fourth year) line.

The summary of the results showing the mean peaks of difficulty is given here with their topic number: (4) How to show that one set of units (e.g. ms^{-2}) is equivalent to another ($N\ Kg^{-1}$), (6) Density, (8) Difference between a vector (e.g. displacement) and a scalar (e.g. distance), (9) Difference between force and pressure, (10) The lever as force multiplier, (11) How a couple acts on a body, (12) Relation between action and reaction and conservation of momentum, (13) Idea of inertia, (14) Relation between impulse of force and momentum, (16) Use of conservation laws (energy, momentum), (17) Resolution of forces, (18) Addition and subtraction of vectors, (19) Equation of motion for free fall bodies, (20) Difference between energy and power, (21) Difference between heat and temperature, (22) Specific heat capacity, latent heat, heat calculations, (23) Behaviour of a charged particle in an electric field, (24) The field vector E and the potential V in an electric field, (27) e.m.f. and p.d., (28) Use of potentiometer, (29) Thermionic emission, (30) Relation between frequency and pitch, wavelength and velocity, (33) Wave-particle duality, (36) A.C. circuits, capacitance, inductance, (37) The idea of half-life, (38) radiations, (39) How a lens system (e.g. a telescope) forms a magnified image of a distant object, (40) Why a current carrying coil is deflected in a magnetic field, (41) How a commutator works.

3.7. The Final Edition of the Unit.

A. The design of the unit.

(i) The objectives of the unit were defined.

(ii) Material preparation: as number of topics and concepts was reduced from 41 to 23, so a new questionnaire was prepared. To complement this, three objective sub-tests were also introduced.

(iii) Material application: the design of the application was modified. The material was applied in 1975-76 to first year university students, post 'O' grade and pre 'O' grade pupils.

B. The objectives remained the same as those mentioned in section 3.6.B.

C. Source of material.

The topics and concepts were chosen from the same Scottish Certificate of Education Examination Board Syllabus for physics for Ordinary and Higher grades.[106]

For preparing the items of the sub-tests, apart from the researcher's own ideas, some items were taken from national bank items,[108] Scottish Certificate of Education Examination Board papers,[109] Help was also found from the books of R.W. Adams (1973),[110] J.A.D. Lowrie (1971),[111] J. Marshall et al (1973)[112] and J.B.O. McNair (1970).[113]

D. Material structure.

By looking at the results of the trial edition of the unit, it was concluded that there were many topics and concepts taught in school physics which proved to be difficult and troublesome. At that time, it was thought necessary that a systematic investigation of each of them might be taken to establish the cause of the difficulty. It might be that the problem would be one of intellectual development, of method or of language. It was decided to approach this subjectively (as done in the trial edition) and objectively so that one could detect the perceived as well as the actual difficulties of the pupils. For this reason, again, a questionnaire was prepared for subjective assessment. This time, the number of topics and concepts was reduced from 41 to 23, because of the risk of fatigue factors in pupils and the time demand on schools.

To complement this an objective test was constructed having at least three items on each topic/concept; one item was at recall level and the others in higher Bloom categories.[114] This gave rise to a big test of 69 items. The use of three 23 item sub-tests was preferred to a larger single test of 69 items because of the main reasons mentioned in the above paragraph. In addition to 23 items in each sub-test, 5 common marker items in each sub-test were included to check that the randomization of the pupil samples had been effectively done. In all, three 28 item sub-tests were prepared.

The items selected for the questionnaire and the sections of the syllabus from which these were selected are shown in Table 3.7.1, and the questionnaire appears as Appendix 3.7.(a). The questionnaire was passed through all

Table 3.7.1.

List of topics and concepts, and sections of the syllabus.

S. No.	Topic/Concept	Section of the Syllabus
1.	Particulate nature of matter (everything is made up of particles).	C. & C.1.
2.	Difference between mass and weight.	J.
3.	Idea of density (equal volumes of different substances have different masses).	C.3.
4.	Difference between a vector (e.g. displacement) and a scalar (e.g. distance).	J.2 & J.3.
5.	Idea of uniform motion (body can maintain uniform motion without some unbalanced force to keep it moving).	G.1.& J.3.
6.	Idea of pressure.	N.3.
7.	Idea of conservation of momentum.	N.2.
8.	Difference between elastic and inelastic collisions.	N.2.
9.	Difference between energy and power.	G.
10.	Idea of kinetic energy and potential energy.	G.2.
11.	Difference between heat and temperature.	K.
12.	Idea of specific latent heat (specific latent heat of fusion and specific latent heat of vaporization).	K.4 & K.5.
13.	Idea of heat transfer (e.g. conduction, convection and radiation).	E.1.

S. No.	Topic/Concept	Section of the Syllabus
14.	Idea of absolute zero (0 Kelvin is absolute zero).	K.6.
15.	Idea of wave motion as applied to -	
	(a) water waves (e.g. waves in ripple tank).	I.5.
	(b) sound waves (e.g. sound travelling through air).	I.5.
	(c) electromagnetic waves (e.g. light, ion waves and radio waves).	I.4.
16.	Idea of frequency and wavelength as applied to wave motion.	F.2.
17.	Idea of magnification of an image of distant object (e.g. telescope).	F.
18.	Idea of electric current -	
	(a) direct current (d.c.).	D.3.
	(b) alternating current (a.c.).	H.6.
19.	Idea of resistance (here electrons are hindered in their movement).	D.4.
20.	Idea of induction -	
	(a) electric (e.g. charging an electroscope by induction).	L.1.
	(b) magnetic (production of temporary magnets).	L.1.
	(c) electromagnetic (production of a current in a circuit when change in magnetic flux).	L.4.

S. No.	Topic/Concept	Section of the Syllabus
21.	Idea of field -	
	(a) electric (the space in the neighbourhood of charged body).	L.1.
	(b) magnetic (space around the magnets where their effects are felt).	L.1.
22.	Difference between e.m.f. and p.d. (e.g. cell when in operation tends to have a p.d. less than e.m.f.).	D.6 & L.2.
23.	Idea of half-life (e.g. half-life of a radio isotope is constant, irrespective of its mass).	M.1.

the stages given by Nisbet and Entwistle (1970).[107]

The test specifications appear in Appendix 3.7.(b) and the item specifications and common marker items are shown in Appendix 3.7.(c). Sub-tests I, II and III appear as Appendix 3.7.(d), Appendix 3.7.(e) and Appendix 3.7.(f) respectively. The key for the three sub-tests jointly appear in Appendix 3.7.(g). All the stages in the construction of the objective test given by Macintosh and Morrison (1969)[115] were followed.

E. How the material was applied.

The material was first administered to 83 first year university students. Afterwards, it was applied to 414 post 'O' grade and 499 pre 'O' grade pupils in eight schools. Each student and pupil completed the subjective assessment for 23 topics/concepts (i.e. questionnaire) and each candidate attempted one of three objective sub-tests which together tested all of the topics/concepts at three Bloom levels.

As the design of the unit was changed, the technique of the data processing was also changed. At this time a 'computer mark sense' cards method[107] was used.

To reduce management problems, the letters containing instruction for application of the material were sent to the principal teachers of the schools. Separate sheets containing clear instruction to be given to pupils were prepared for subject teachers. The covering letter is shown in Appendix 3.7.(h) and the sheet of instructions prepared for teachers appears as Appendix 3.7.(i).

F. Results.

The results of the final edition of the unit consist of subjective assessment and objective assessment.

(i) Results: subjective.

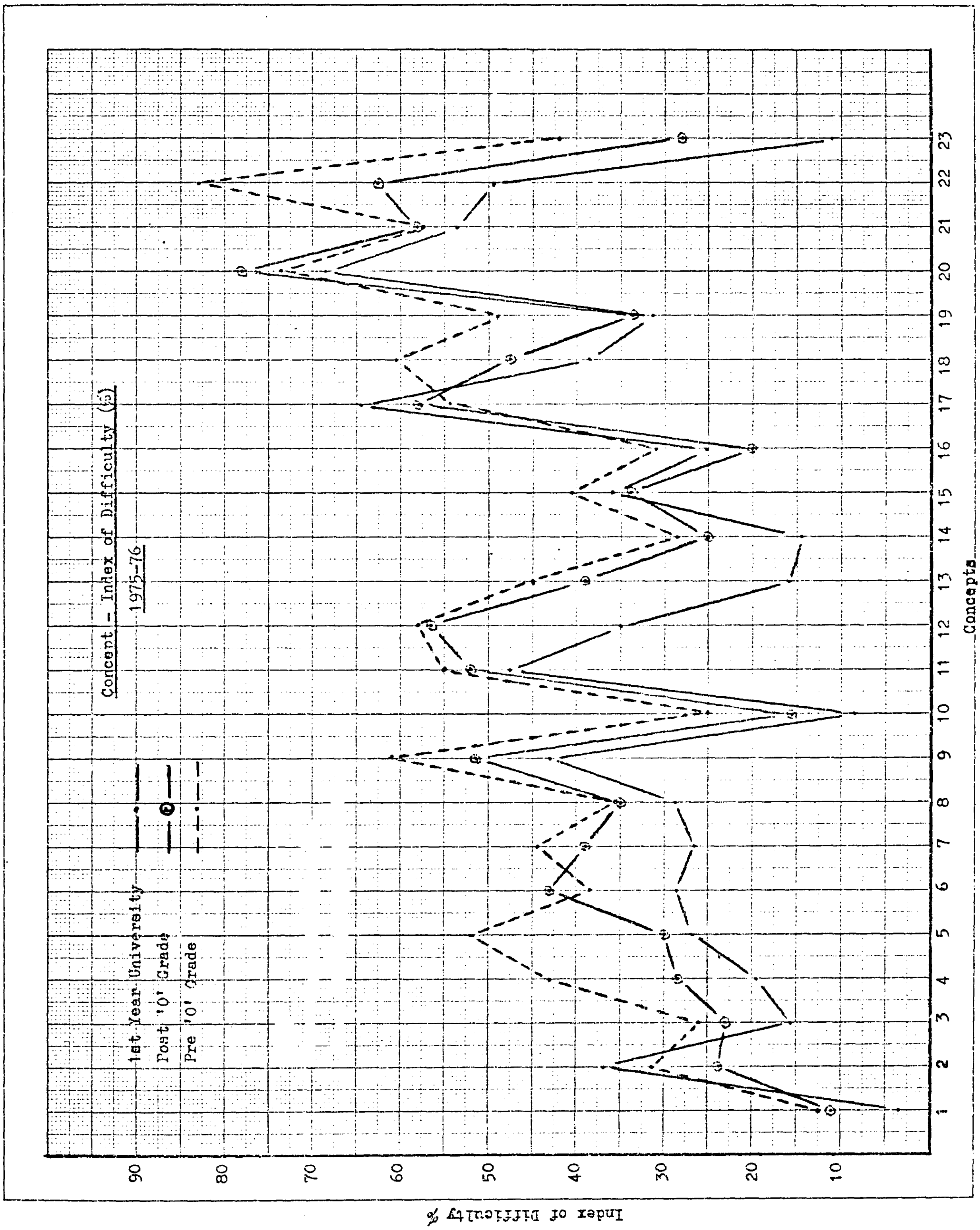
The index of difficulty for the subjective assessment was computed by the same formula i.e.

$$\frac{(B + C) \times 100}{\text{Total} - D}$$

where B, C and D are defined in the questionnaire in Appendix 3.7.(a). As anticipated in the trial edition, the list presented in this edition showed behaviour similar to that mentioned in section 3.6.F., i.e. when the list was presented to first year university students, a number of topics/concepts appeared in categories 'B' and 'C'. When we presented it to school pupils at post 'O' grade level we got the same topics appearing in their subjective choice, but at this time more of them reported difficulty. At pre 'O' grade level, the difficulty effects were further intensified.

Figure 2 shows the results of plotting percentage difficulty index against topic numbers. The list of topics and their number are shown in Table 3.7.2. The three graphs show a similarity as mentioned in section 3.6.F. The general trend is that the university line lies below the post 'O' grade (fifth year) line which in turn lies below the pre 'O' grade (fourth year) line. This gives added strength to the belief that we are seeing a true reflection of student and pupil reaction to these topics and concepts.

The summary of the results showing the main peaks of



Concepts
Figure 2.

Table 3.7.2.

List of topics and concepts and results for subjective assessment.

Topics and Concepts	Index of Difficulty %		
	1st Yr. University	Post 'O' Grade	Pre 'O' Grade
1. Particulate nature of matter (everything is made up of particles.	3.6	10.9	12.5
2. Difference between mass and weight.	37.3	23.7	31.5
3. Idea of density (equal volumes of different substances have different masses).	13.2	23.1	26.0
4. Difference between a vector (e.g. displacement) and a scalar (e.g. distance).	19.5	28.7	43.0
5. Idea of uniform motion (body can maintain uniform motion without some unbalanced force to keep it moving).	26.8	30.0	57.1
6. Idea of pressure.	28.9	43.0	38.7
7. Idea of conservation of momentum.	26.5	38.9	44.5
8. Difference between elastic and inelastic collision.	28.9	35.1	35.6
9. Difference between energy and power.	43.2	51.6	61.3

Topics and Concepts	Index of Difficulty %		
	1st Yr. University	Post 'O' Grade	Pre 'O' Grade
10. Idea of kinetic energy and potential energy.	8.4	15.7	25.3
11. Difference between heat and temperature.	47.5	52.2	55.0
12. Idea of specific latent heat (specific latent heat of fusion and specific latent heat of vaporization).	34.9	56.4	58.2
13. Idea of heat transfer (e.g. conduction, convection and radiation).	15.7	39.2	45.3
14. Idea of absolute zero (0 Kelvin is absolute zero).	14.5	25.1	28.5
15. Idea of wave motion as applied to - (a) water waves (e.g. waves in ripple tank). (b) sound waves (e.g. sound travelling through air). (c) electromagnetic waves (e.g. light, ion waves and radio waves).	36.1	34.3	40.4
16. Idea of frequency and wave-length as applied to wave motion.	25.3	20.0	31.3
17. Idea of magnification of an image of distant object (e.g. telescope).	64.6	57.9	54.4

Topics and Concepts	Index of Difficulty %		
	1st Yr. University	Post 'O' Grade	Pre 'O' Grade
18. Idea of electric current - (a) direct current (d.c.) (b) alternating current (a.c.)	38.5	47.5	60.5
19. Idea of resistance (here electrons are hindered in their movement).	31.3	33.6	49.2
20. Idea of induction:- (a) electric (e.g. charging an electroscope by induction) (b) magnetic (production of temporary magnets). (c) electromagnetic (production of a current in a circuit when change in magnetic flux).	68.6	77.8	73.4
21. Idea of field:- (a) electric (the space in the neighbourhood of charged body). (b) magnetic (space around the magnets where their effects are felt).	53.6	57.9	57.4
22. Difference between e.m.f. and p.d. (e.g. cell when in operation tends to have a p.d. less than e.m.f.).	49.4	62.6	83.0
23. Idea of half-life (e.g. half-life of a radio isotope is constant, irrespective of its mass.	10.9	28.3	42.0

difficulty (reported by > 30%) of the pupils is given here with their topic numbers, (2) The difference between mass and weight, (5) The idea of uniform motion, (6) Pressure, (7) Conservation of momentum, (8) Elastic and inelastic collisions, (9) Energy and power, (11) Heat and temperature, (12) Latent heat, (13) Heat transfer, (15) Ideas associated with wave motion, (17) Magnification, (18) Current (a.c. and d.c.), (19) Resistance, (20) Induction, (21) Field and (22) e.m.f. and p.d.

(ii) Results: objective.

The data of the sub-tests were processed by the computer. The facility value (F.V.), and the discriminatory factor (D.F.) were computed for each item in the sub-tests. For each topic/concept, there were three items, so the mean facility value (M.F.V.) was also computed for the items representing each topic/concept in the questionnaire. The description of F.V., M.F.V. and D.F. are shown for first year university students, post 'O' grade and pre 'O' grade pupils, in Appendix 3.7.(j), 3.7.(k) and 3.7.(l) respectively.

3.8. Discussion.

The results of subjective and objective assessments could give rise to at least four categories of response. They could be:

	Subjective	Objective
(a)	Easy (low score)	Easy (high score)
(b)	Easy (low score)	Difficult (low score)
(c)	Difficult (high score)	Easy (high score)
(d)	Difficult (high score)	Difficult (low score)

Categories (b) and (c) would suggest superficial learning or superficial testing. The details of the categories of response appear as Appendix 3.7.(m). However it was noted in passing that none of the topics came into category (b) and only about one-sixth of them came into category (c).

After going through the details of M.F.V. and percentage difficulty index in Appendices 3.7.(j), 3.7.(k) and 3.7.(l), it was observed that there was a clear relationship, although not a perfect one, between the pupils' subjective assessment and the mean scores of the objective items, set to test each of the topics. Table 3.7.3, given below shows the examples of such relationships.

Table 3.7.3.

Objective Assessment

Concepts	First year university		Post 'O' grade		Pre 'O' grade	
	% diff.	M.F.V.	% diff.	M.F.V.	% diff.	M.F.V.
10. Idea of kinetic and potential energy.	8.4	0.90	15.7	0.79	25.3	0.67
11. Difference between heat and temperature.	47.5	0.71	52.2	0.53	55.0	0.51
22. Difference between e.m.f. and p.d.	49.4	0.53	62.6	0.44	83.0	0.32

Scattergrams for first year, post 'O' grade, and pre 'O' grade assessment were constructed to test the inverse relationship between difficulty index (subjective) and test score (objective). They are shown in figure 3, figure 4 and figure 5 respectively. The co-relations were computed by the formula given below:

$$r = \frac{\Sigma XY - \Sigma X \Sigma Y/n}{\sqrt{\left[\Sigma X^2 - (\Sigma X)^2/n\right]\left[\Sigma Y^2 - (\Sigma Y)^2/n\right]}}$$

For constructing scattergrams, the values of 'slope' of the line (m) and Y intercept (c) were also computed. The formula used for 'm' is:

$$m = \frac{\Sigma XY - \Sigma X \Sigma Y/n}{\Sigma X^2 - (\Sigma X)^2/n}$$

and for c, the formula is

$$c = \frac{\Sigma Y - m\Sigma X}{n}$$

The values of 'r', 'm' and 'c' for three years are shown in Table 3.7.4 given below.

Table 3.7.4.

Showing values of r, m and c.

Year	'r'	'm'	'c'
1. First year	-0.45	-70.64	84.63
2. Post 'O' grade	-0.70	-90.45	99.96
3. Pre 'O' grade	-0.36	-57.29	82.34

It is mentioned in sections 3.6.F and 3.7.F that while presenting the list of topics/concepts to students

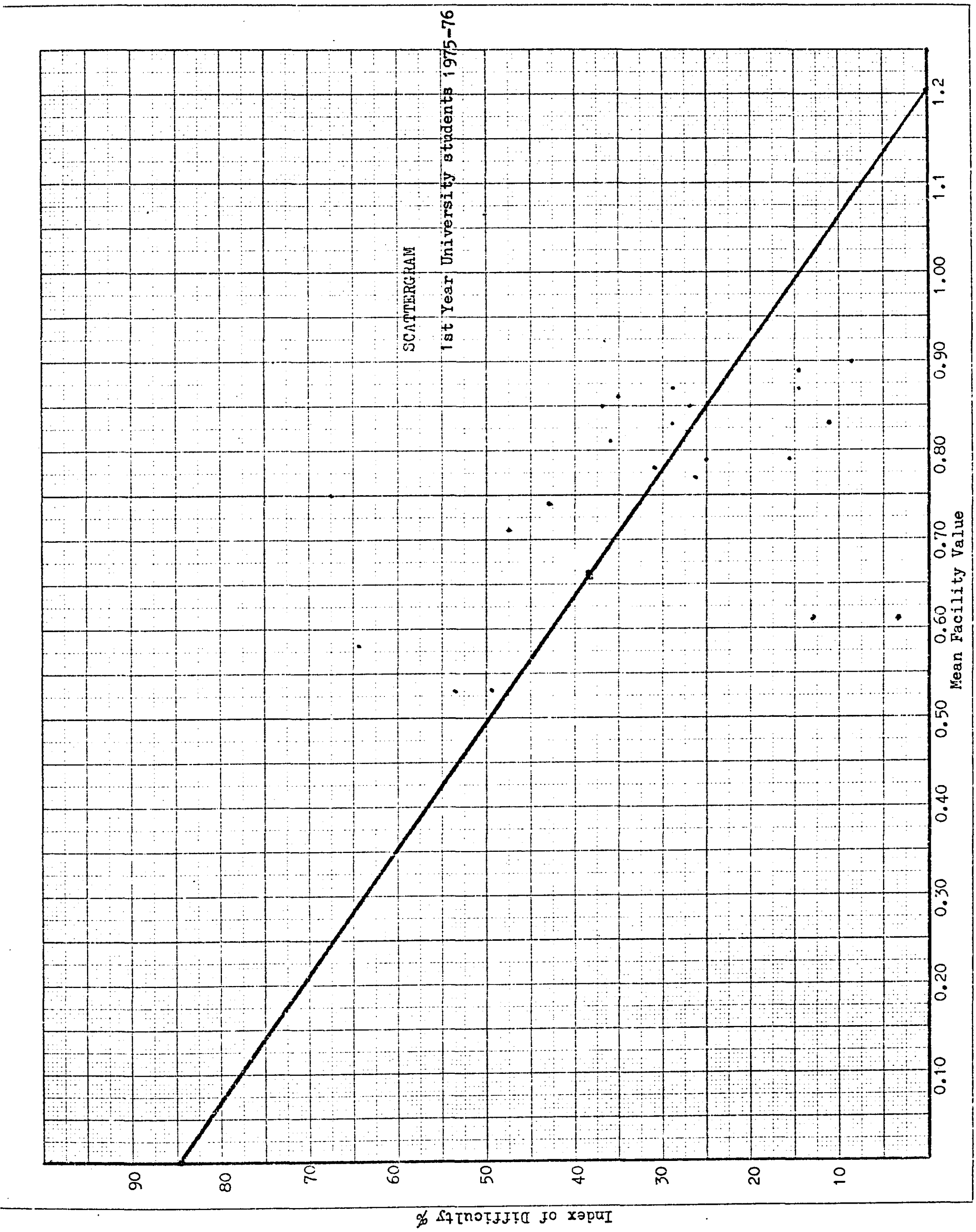

SCATTERGRAM
1st Year University students 1975-76
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.1
1.2
Mean Facility Value
90
80
70
60
50
40
30
20
10
Index of Difficulty %

Figure 3.

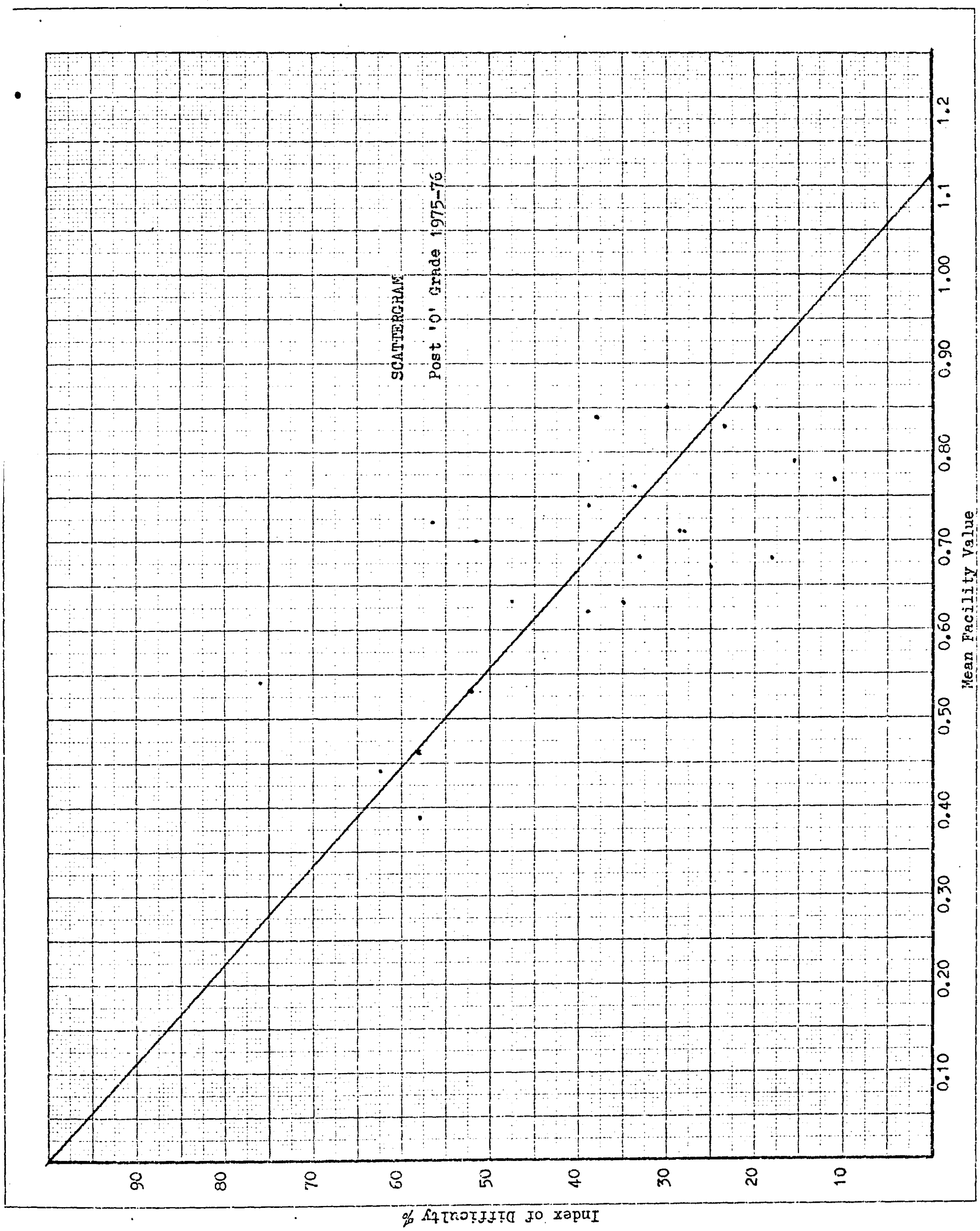

SCATTERGRAM
Post 'O' Grade 1975-76
Mean Facility Value
Index of Difficulty %
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.1
1.2
90
80
70
60
50
40
30
20
10

Figure 4.

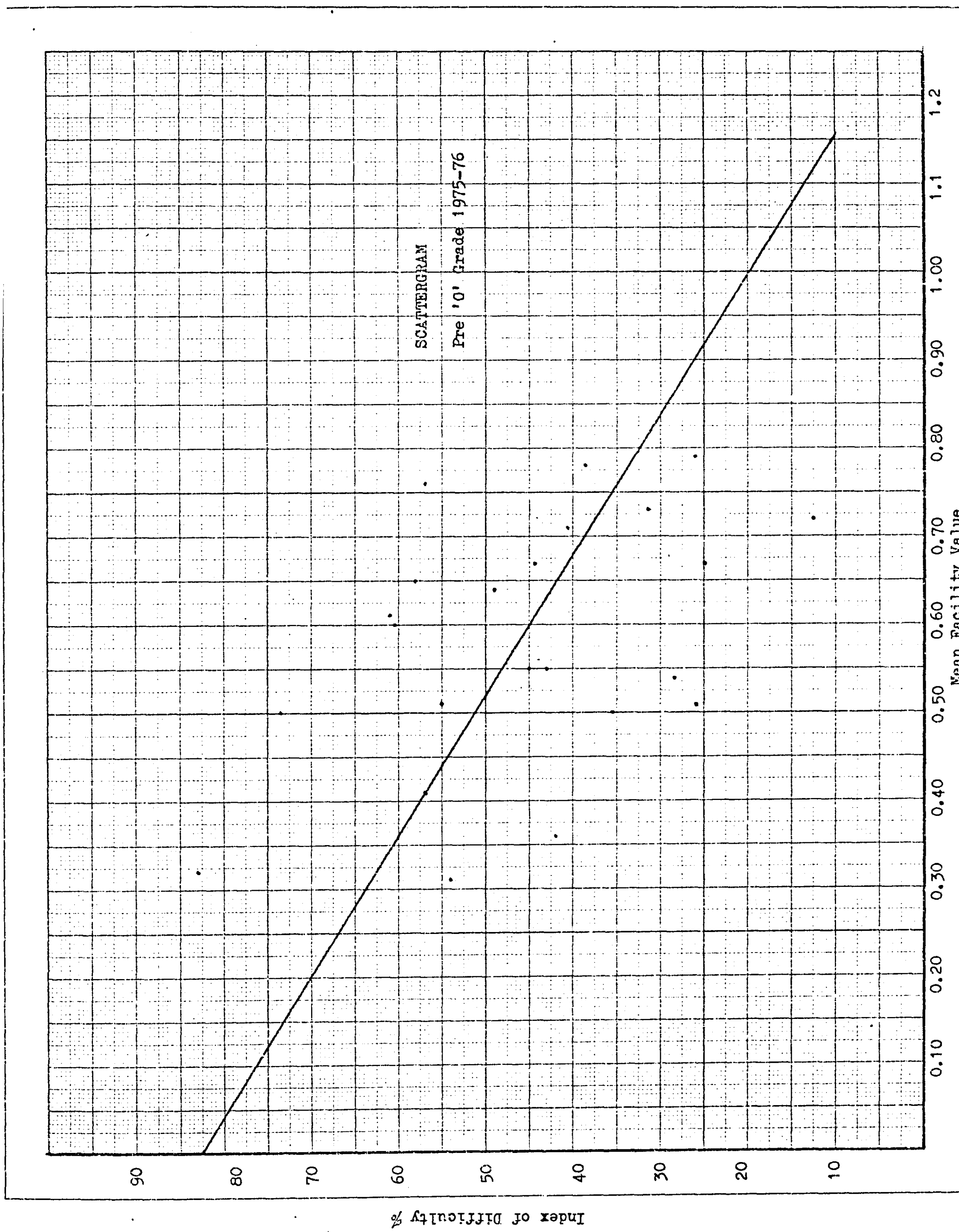

SCATTERGRAM
Pre 'O' Grade 1975-76
Mean Facility Value
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.1
1.2
Index of Difficulty %
90
80
70
60
50
40
30
20
10

Figure 5.

and pupils, it was expected that as we proceeded from first year university students to pre 'O' grade pupils, the difficulty index would increase. This happened to the majority of items in the lists. In both editions, few topics/concepts showed the reverse effect. In trial edition (1974-75) these are given by their topic numbers: (2) Difference between solids, liquids and gases in terms of kinetic theory, (10) The lever as force multiplier, (11) How a couple acts on a body, (15) Difference between elastic and inelastic collisions, (17) Resolution of forces, (18) Addition and subtraction of vectors, (23) Behaviour of charged particle in an electric field, (25) Conductors and insulators, (29) Thermionic emission, (30) Relation between frequency and pitch, wavelength and velocity, (31) Refraction and reflection in waves, (32) Interference and diffraction in waves, (33) Wave-particle duality, (35) Electromagnetic induction, (39) Magnification, (40) Why a current carrying coil is deflected in a magnetic field, (41) How a commutator works.

In final edition the topics/concepts which showed the reverse effect are: (2) Difference between mass and weight, (6) Idea of pressure, (15) Idea of wave motion, (16) Idea of frequency and wavelength as applied to wave motion, (17) Magnification, (20) Idea of induction, (21) Idea of fields.

The possible reasons for such behaviour could be:

(i) The language used in item may not be clear.

(ii) Individual differences (extrinsic and intrinsic) among the pupils.

(iii) The format of responses mentioned in the questionnaires.

(iv) Pupils underestimate their own difficulty

(v) Interesting learning with low understanding.

3.9. Conclusion.

The study of this unit helps in arriving at certain conclusions. This work confirms the views given by D.C. Gaskel.[102] There are certain topics and concepts which are felt difficult by the students and pupils. These topics/concepts are proving troublesome and the troubles are carried by pupils into their undergraduate careers. It has been shown in a similar chemistry study done by Garforth et al (1976)[116] that insecurity caused by the introduction of concepts too early can persist well into the later years at school and even into undergraduate life.

From the study, it is also revealed that the common troublesome areas in the course, according to syllabus, are sections F, G, J and L, which represent 'light and sound', 'work and energy', 'Newtonian mechanics', and 'electron physics'. This in turn confirms that the areas chosen were important and appropriate, and the difficulty lies in areas of 'motion', 'energy' and 'electricity'.

APPENDIX 3.6.(a)

Pupil's Questionnaire (1974-75)

Science Education Research Group

University of Glasgow

We are trying to establish the ease or difficulty encountered by pupils in learning basic physics. We should appreciate your help in filling in this grid. Results from this will not count against you in any way, and will further our research into the learning of physics.

Please indicate by a tick (✓) in the appropriate column how well you have understood the following ideas which you have met during your school course so far.

Definitions: (A) 'Easy to understand' - means that the ideas were understood first time or with little effort;

(B) 'Difficult to understand' - means that you understood the topic only after a lot of effort;

(C) 'Never understood' - means that you still are hazy about the idea and would need to be taught it again;

(D) 'Never studied' - means that this idea has not yet been covered in your course.

Please be completely frank and honest.

	Understanding			Never Studied
	Easy	Diffi-cult	Never	
1. Evidence that matter exists as particles.				
2. Difference between solids, liquids and gases in terms of the behaviour of molecules.				
3. Gas Laws (e.g. Boyle's Law, Charles' Law) in terms of kinetic theory.				
4. How to show that one set of units (e.g. ms^{-2}) is equivalent to another ($N\ Kg^{-1}$).				
5. Difference between mass and weight.				
6. Density.				
7. How steel ships float on water.				
8. Difference between a vector (e.g. displacement) and a scalar (e.g. distance).				
9. Difference between force and pressure.				
10. The lever as force multiplier.				
11. How a couple acts on a body.				
12. Relation between action and re-action.				
13. Idea of inertia.				
14. Relation between impulse of force and momentum.				
15. Difference between elastic and inelastic collisions.				
16. Use of conservation laws (energy, momentum).				
17. Resolution of forces.				
18. Addition and subtraction of vectors.				
19. Equations of motion for free-falling object.				

	Understanding			Never Studied
	Easy	Difficult	Never	
20. Difference between energy and power.				
21. Difference between heat and temperature.				
22. Specific heat capacity, latent heat, heat calculations.				
23. Behaviour of a charged particle in an electric field.				
24. The field vector $\mathcal{E}$, and the potential V in an electric field.				
25. Conductors and insulators.				
26. Ohm's law in circuits.				
27. Difference between E.M.F. and P.D. (Potential Difference).				
28. How a potentiometer works.				
29. Thermionic emission (how diode and triode works).				
30. Relation between frequency (pitch) wavelength and velocity.				
31. Refraction and reflection in waves.				
32. Interference and diffraction in waves.				
33. Light can behave sometimes as waves and sometimes as particles.				
34. Why do different objects in white light have different colours.				
35. Electromagnetic induction.				
36. A.C. circuits, capacitance, inductance.				
37. The idea of half life.				
38. α, β, γ radiations.				
39. How a lens system (e.g. a telescope) forms a magnified image of a distant object.				

	Understanding			Never Studied
	Easy	Difficult	Never	
40. How a current carrying coil behaves in a magnetic field.				
41. How a commutator (slip ring) works.				

APPENDIX 3.7.(a)

Pupil's Questionnaire

Science Education Research Group | University of Glasgow

We are trying to establish the ease or difficulty encountered by students in learning basic physics at school. We should appreciate your help in answering this questionnaire.

Please record your answers on the PINK computer card by shading in the appropriate oval using the pencil provided.

Use the following definitions to help you to fill in the card:-

(A) "Easy to understand" - means that the ideas were understood first time, or with little effort.

(B) "Difficult to understand" - means that you mastered the topic only after considerable effort.

(C) "Never understood" - means that you still are hazy about the idea and would need to be taught it again.

(D) "Never studied" - means that this idea was not covered in your course.

1. Particulate nature of matter (everything is made up of particles).
2. Difference between mass and weight.
3. Idea of density (equal volumes of different substances have different masses).
4. Difference between a vector (e.g. displacement) and a scalar (e.g. distance).

5. Idea of uniform motion (body can maintain uniform motion without some unbalanced force to keep it moving).
6. Idea of pressure.
7. Idea of conservation of momentum.
8. Difference between elastic and inelastic collisions.
9. Difference between energy and power.
10. Idea of kinetic energy and potential energy.
11. Difference between heat and temperature.
12. Idea of specific latent heat (specific latent heat of fusion and specific latent heat of vaporization).
13. Idea of heat transfer (e.g. conduction, convection and radiation).
14. Idea of absolute zero (O Kelvin is absolute zero).
15. Idea of wave motion as applied to -
    (a) water waves (e.g. waves in ripple tank).
    (b) sound waves (e.g. sound travelling through air).
    (c) electromagnetic waves (e.g. light, ion waves and radio waves).
16. Idea of frequency and wavelength as applied to wave motion.
17. Idea of magnification of an image of distant object (e.g. telescope).
18. Idea of electric current -
    (a) direct current (d.c.).
    (b) alternating current (a.c.).
19. Idea of resistance (here electrons are hindered in their movement).
20. Idea of induction:-
    (a) electric (e.g. charging an electroscope by induction.
    (b) magnetic (production of temporary magnets).
    (c) electromagnetic (production of a current in a circuit when change in magnetic flux).
21. Idea of field:-
    (a) electric (the space in the neighbourhood of charged body).
    (b) magnetic (space around the magnets where their effects are felt).

22. Difference between e.m.f. and p.d. (e.g. cell when in operation tends to have a p.d. less than e.m.f.).
23. Idea of half-life (e.g. half-life of a radio isotope is constant, irrespective of its mass).

APPENDIX 3.7.(b)

Test specifications: Bloom's levels and difficulty levels.

A.

Bloom's levels	Sub-test I		Sub-test II		Sub-test III	
	Items	% weighting	Items	% weighting	Items	% weighting
1. Knowledge (B1)	6	26.1%	7	30.4%	6	26.1%
2. Comprehension (B2)	8	34.8%	8	34.8%	8	34.8%
3. Application (B3)	9	39.1%	8	34.8%	9	39.1%
Total	23	100.0%	23	100.0%	23	100.0%

B.

Difficulty levels	Sub-test I		Sub-test II		Sub-test III	
	Items	% weighting	Items	% weighting	Items	% weighting
1. Easy (D1)	10	43.5%	5	21.7%	8	34.8%
2. Average (D2)	8	34.8%	12	52.2%	7	30.4%
3. Difficult (D3)	5	21.7%	6	26.1%	8	34.8%
Total	23	100.0%	23	100.0%	23	100.0%

APPENDIX 3.7.(c)

Item specifications in sub-tests, according to Bloom's levels and difficulty levels, and common marker items.

Item No.	Sub-test I	Sub-test II	Sub-test III
1.	B1 D1	B1 D1	B1 D1
2.	B1 D1	B1 D2	B1 D1
3.	B1 D1	B1 D3*	B1 D2
4.	B1 D1	B1 D1	B1 D3*
5.	B1 D1	B1 D2	B1 D1
6.	B1 D2	B1 D1	B1 D1
7.	B2 D1**	B1 D1	B1 D2
8.	B2 D1	B2 D1	B2 D2
9.	B2 D1	B2 D2	B2 D1**
10.	B2 D1	B2 D3	B2 D3
11.	B2 D2***	B2 D2	B2 D2
12.	B2 D1	B2 D1	B2 D2
13.	B2 D2	B2 D2	B2 D1
14.	B2 D3	B2 D1**	B2 D1
15.	B2 D2	B2 D2***	B2 D1
16.	B1 D3*	B2 D2	B2 D3
17.	B3 D2	B2 D2	B2 D1
18.	B3 D3	B3 D2	B3 D3****
19.	B3 D3	B3 D3	B3 D3
20.	B3 D2	B3 D2	B3 D3
21.	B3 D2	B3 D2	B1 D2
22.	B3 D3	B3 D2	B3 D2
23.	B3 D2	B3 D3	B2 D2***

Item No.	Sub-test I	Sub-test II	Sub-test III
24.	B3 D2	B3 D3	B3 D3*****
25.	B3 D3	B3 D3	B3 D3
26.	B3 D3****	B3 D3****	B3 D2
27.	B3 D3	B3 D3*****	B3 D2
28.	B3 D3*****	B3 D3	B3 D2

(Note: B and D are defined in Appendix 3.7.(b) and common number of asterisks represent the common marker items in the sub-tests.)

APPENDIX 3.7.(d)

Sub-Test 1

1. In a simple experiment a pupil carefully adds salt to a beaker which is already full of water to the brim. He observes that the water does not overflow after several additions of salt. What is the best conclusion he can draw from the experiment?

   (A) Spaces exist between water particles.
   (B) Spaces exist between salt particles.
   (C) Salt particles take up space.
   (D) Water particles take up space.

2. Which of these physical quantities is a scalar?

   (A) Momentum.
   (B) Acceleration.
   (C) Displacement.
   (D) Kinetic energy.

3. After falling some distance, a parachutist falls with a terminal velocity. This means that he -

   (A) has landed.
   (B) moves with uniform motion.
   (C) has increasing acceleration.
   (D) has decreasing acceleration.

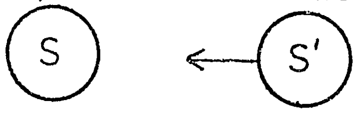
4. The higher the temperature of the gas in a closed container, the greater becomes its -

   (A) mass.
   (B) force.
   (C) weight.
   (D) pressure.

5. The momentum of a body is the product of its -

   (A) mass and velocity.
   (B) force and velocity.
   (C) mass and acceleration.
   (D) mass and velocity squared.

6. Suppose a 'frictionless' puck "S'" moves towards a fixed puck "S", as shown in the figure.



The upper faces of pucks have south magnetic poles and, therefore, repel each other. If an elastic collision has taken place, what has happened?

(A) Only energy has remained conserved.
(B) Only momentum has remained conserved.
(C) Energy and momentum, both have changed.
(D) Energy and momentum, both have remained conserved.

7. An astronaut on a space flight is moving away from earth at a constant speed. Which of the following describes the effect on his mass and his weight?

	His mass	His weight
(A)	decreases	remains constant
(B)	decreases	decreases
(C)	remains constant	decreases
(D)	remains constant	remains constant

8. It is easy to float on the very salty Dead Sea (temperature about 30°C) because the density of salty water is -

(A) less than the density of the human body.
(B) greater than the density of the human body.
(C) reduced due to the high temperature.
(D) increased due to the high temperature.

9. Hoist P can raise a load through a given height in 10 seconds. Hoist Q raises twice the load through the same height in 5 seconds. Hoist Q's rate of working is -

(A) half that of P.
(B) twice that of P.
(C) the same as that of P.
(D) four times that of P.

10. A temperature of $-20^{\circ}C$ is equivalent to -

(A) 353 K.
(B) 293 K.
(C) 253 K.
(D) -253 K.

11. Wave motion is a means of transferring -

(A) force.
(B) power.
(C) energy.
(D) matter.

12. When sea waves move up a beach, the water beneath them becomes shallow. As the waves approach the shore their -

(A) wave length increases.
(B) wave length decreases.
(C) frequency decreases.
(D) frequency increases.

13. If a telescope with a large magnifying power is to be built, it should have -

(A) an objective lens with short focal length.
(B) an eye piece lens with long focal length.
(C) an objective lens with long focal length and an eye piece lens with short focal length.
(D) an objective lens with short focal length and an eye piece lens with short focal length.

14. It is more dangerous to touch a live mains switch with a wet hand than with a dry one because -

(A) the voltage of the body is reduced.
(B) the resistance of the body is increased.
(C) the resistance of the body is reduced.
(D) the resistance of the body is the same as that of the main circuit.

15. The mass of a gas that can be packed into a given volume depends very much upon its -

(A) force and pressure.
(B) matter and energy.
(C) force and temperature.
(D) temperature and pressure.

16. A range of 1 degree on Kelvins (absolute) scale of temperature is equivalent on the Celsius scale to a range of -

(A) 1 degree.
(B) 5/9 degree.
(C) 1/273 degree.
(D) 273 degree.

17. A boy and a girl of equal mass go to the third floor of a building. The boy climbs the stairs and the girl goes straight up in a lift. At the third floor, the potential energy gained by the boy is -

(A) less than the potential energy gained by the girl.
(B) the same as that gained by the girl.
(C) greater than the potential energy gained by the girl.
(D) zero, all having been converted to kinetic energy.

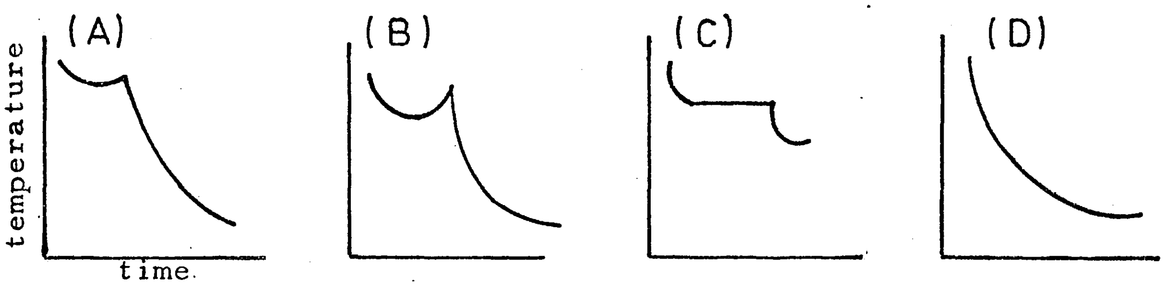
18. Four containers all having the same mass are made from copper, tin, glass and perspex. The specific heat capacity of these materials is the following -

(i) copper = 385 J Kg^{-1} K^{-1}
(ii) tin = 226 " "
(iii) glass = 670 " "
(iv) perspex = 1450 " "

Each container is filled with the same mass of water at room temperature. The iron spheres of 10Kg each, heated to the same temperature, are dropped into each container. The greatest rise in water temperature occurs in a container made up of -

(A) tin.
(B) glass.
(C) copper.
(D) perspex.

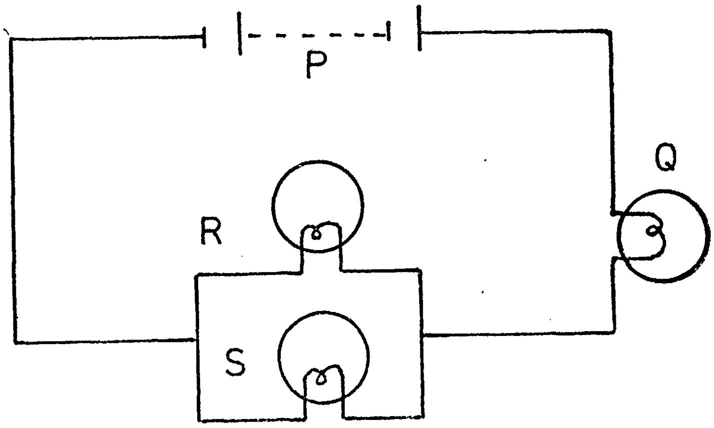
19. The graphs below show how the temperature of four different liquids of equal mass vary with time, when left to cool under the same conditions in a laboratory. Which of the graphs shows the liquid with greatest specific latent heat of fusion?



20. A book and a silver spoon are at room temperature. The spoon feels colder to the touch because -

(A) the book has the greater mass.
(B) silver is almost pure material.
(C) silver is a very good heat conductor.
(D) the spoon is made up of a denser material.

21. The circuit shows three lamps connected to a number of cells.



If the current values at various places are given by

P, Q, R and S, which one of the following statements is true?

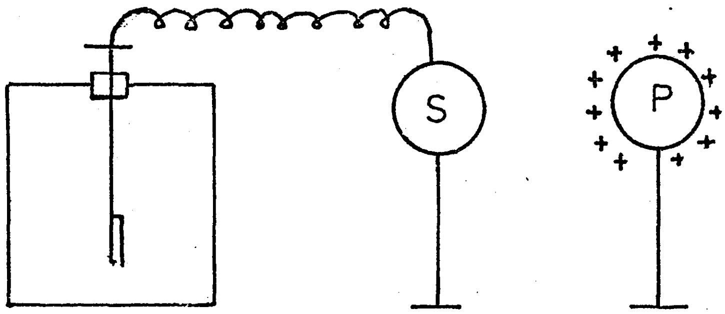
(A) P > Q.

(B) Q > R.

(C) R > S.

(D) S > P.

22. The plate of gold leaf electroscope is connected to an insulated uncharged metal sphere 'S'. A similar but positively charged sphere 'P' is moved from a distance point towards the sphere 'S'.



What is the effect of moving the sphere 'P' ?

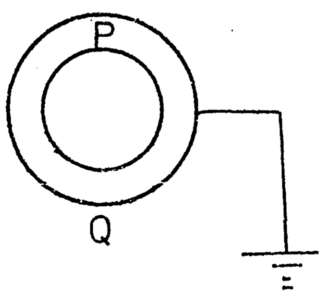
(A) 'S' remains uncharged, the gold leaf does not rise.

(B) 'S' becomes negatively charged, the gold leaf rises.

(C) 'S' becomes positively charged, the gold leaf does not rise.

(D) 'S' becomes positively charged, the gold leaf rises.

23. 'P' and 'Q' are two concentric metal spheres. P is charged positively and Q is earthed. Which statement is true?



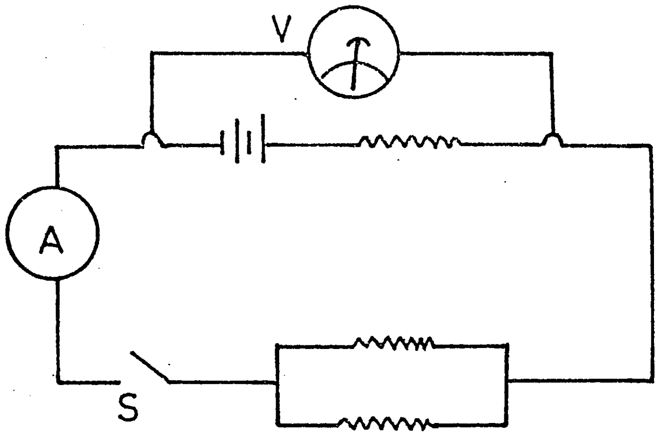
(A) There is no electric field inside P.

(B) There is strong electric field inside P.

(C) There is no field inside Q.

(D) There is no field between P and Q.

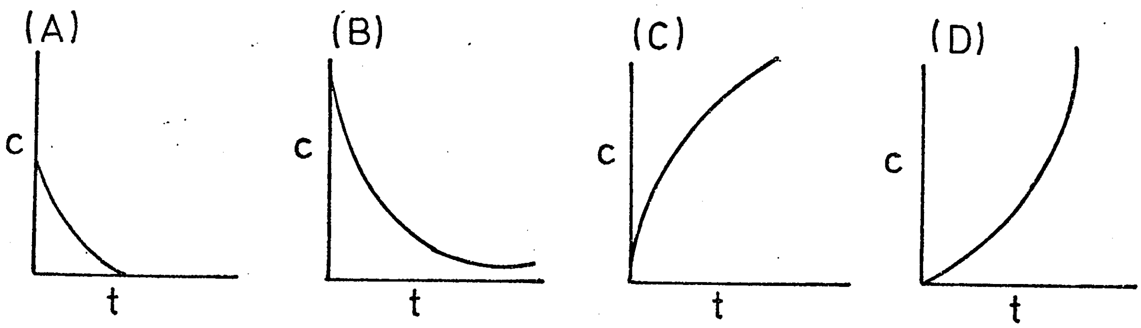
24. The switch 'S' in the circuit given below is open.



Before closing the switch, the reading in voltmeter 'V' is 2.0 volts. The battery has a small but significant internal resistance. If the switch is closed, the meter reading is likely to become -

(A) 2.2v.
(B) 2.0v.
(C) 1.8v.
(D) 0.0v.

25. A radioactive source (polonium) has a short half-life. It is placed near a detector and the count rate is noted at various times. Which of the following graphs of count rate 'C' against time 't' would be obtained?



26. If a man 70 Kg stands on spring scales in a lift, and if the lift is accelerated upwards, the scales will read -

(A) zero.
(B) less than 70 Kg.
(C) greater than 70 Kg.
(D) equal to 70 Kg.

27. In which of the following pairs is the second temperature double the first?

(A) $20^\circ C$ $40^\circ C$
(B) $25^\circ F$ $50^\circ C$
(C) 25 K 50 K
(D) $35^\circ C$ $70^\circ F$

28. The magnifying power of a simple two-lens astronomical telescope in normal adjustment is 36, and the diameter of the objective lens is 72 mm. The minimum diameter of the eye piece lens required to collect all the light entering the objective from a distant point source on the axis of instrument is -

(A) 36 mm only.
(B) 72 mm only.
(C) 72 x 36 mm.
(D) 72 ÷ 36 mm.

APPENDIX 3.7.(e)

Sub-Test 2

1. Which of the following pairs of quantities are both vectors?

   (A) Mass and acceleration.
   (B) Mass and kinetic energy.
   (C) Momentum and acceleration.
   (D) Momentum and kinetic energy.

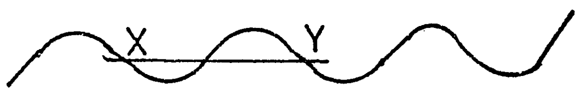
2. The specific latent of evaporation of water is the energy required to change 1 Kg of -

   (A) water at $0^{o}C$ into steam at $100^{o}C$.
   (B) water at $100^{o}C$ into steam at $100^{o}C$.
   (C) water at $99^{o}C$ into steam at $101^{o}C$.
   (D) steam at $100^{o}C$ into ice at $0^{o}C$.

3. A range of 1 degree on Kelvins (absolute) scale of temperature is equivalent on the Celsius scale, to a range of -

   (A) 1 degree.
   (B) 5/9 degree.
   (C) 1/273 degree.
   (D) 273 degree.

4. The sketch given below shows part of a transverse wave.



   The distance XY is called -

   (A) frequency.
   (B) wavelength.
   (C) amplitude.
   (D) displacement.

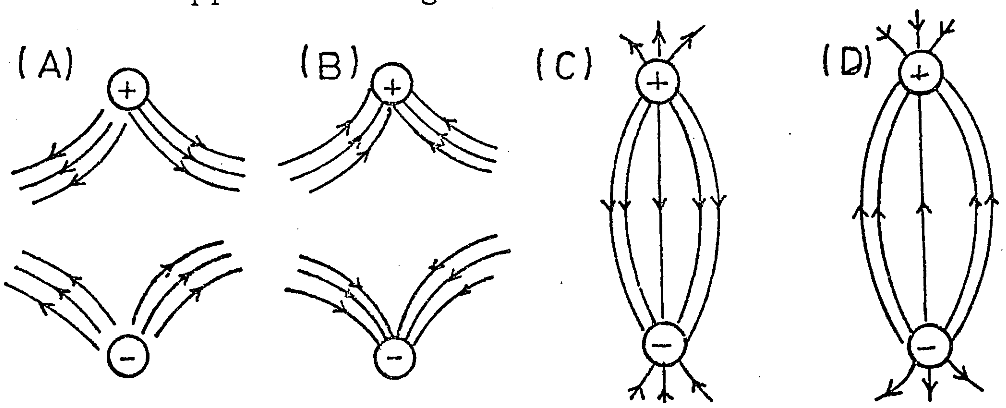
5. The astronomical telescope is focused on infinity (normal adjustment). The image formed by the objective lens acts as an object for the eye piece lens. The final image formed will be -

(A) erect, magnified and virtual.
(B) erect, magnified and real.
(C) inverted, magnified and virtual.
(D) inverted, magnified and real.

6. When an electric field is applied to the metallic conductor, there is regular drift superimposed on the random motion of electrons. This electric drift is known as electric -

(A) force.
(B) power.
(C) current.
(D) potential.

7. Which of the following shows the shape and direction of the electric field between a pair of small, equal but opposite charges?



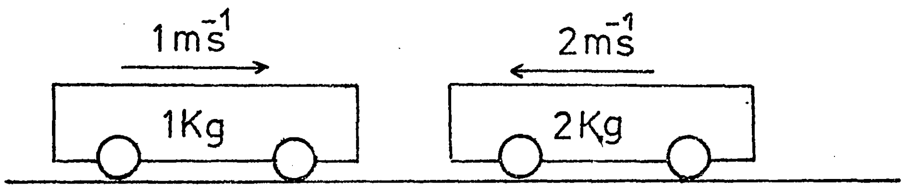
8. The particles of different kinds of substances at the same temperatures are in motion. They -

(A) have the same mass.
(B) are of the same size.
(C) move at different speeds.
(D) move at the same speeds.

9. The mass of a gas that can be packed into a given volume depends very much upon its -

(A) force and pressure.
(B) matter and energy.
(C) force and temperature.
(D) temperature and pressure.

10. A trolley of mass 1 Kg moving at $1ms^{-1}$ collides head on with a trolley of mass 2 Kg moving at $2ms^{-1}$ as shown.



After the collision the 1 Kg trolley rebounds at $1ms^{-1}$. The 2 Kg trolley will move to the -

(A) right at $2ms^{-1}$.
(B) right at $1ms^{-1}$.
(C) left at $1ms^{-1}$.
(D) left at $2ms^{-1}$.

11. How much energy (excluding heat) is transferred to a 15 Kg suitcase, which someone is holding for 5 minutes waiting for a bus?

(A) 0 J.
(B) 3 J.
(C) 15 J.
(D) 75 J.

12. When an object doubles its speed, its kinetic energy is -

(A) halved.
(B) doubled.
(C) quartered.
(D) increased four times.

13. According to the kinetic theory, the temperature of a material is related to the molecule's -

(A) total energy.
(B) average kinetic energy.
(C) average potential energy.
(D) average kinetic energy plus average potential energy.

14. An astronaut on a space flight is moving away from earth at a constant speed. Which of the following describes the effect on his mass and his weight?

	His mass	His weight
(A)	decreases	remains constant
(B)	decreases	decreases
(C)	remains constant	decreases
(D)	remains constant	remains constant

15. Wave motion is a means of transferring -

(A) force.
(B) power.
(C) energy.
(D) matter.

16. If one end of a soft-iron rod is held close to the 'S' pole of a strong magnet -

(A) the rod will spring away as soon as it is released.
(B) the far end of the rod will not attract iron-filings.
(C) there will temporarily be an 'S' pole near the other end of the rod.
(D) the rod becomes strongly magnetic after the bar magnet is removed.

17. The half-life of one gram of Uranium is 4.5×10^9 years. What is the half-life of half a gram of Uranium?

(A) 2.25×10^9 years.
(B) 4.50×10^9 years.
(C) 9.00×10^9 years.
(D) 18.00×10^9 years.

18. When a brick is taken from the earth to the moon, what happens to its mass and to its weight?

(A) The mass and the weight remain constant.
(B) The mass becomes more and weight becomes less.
(C) The mass becomes less and the weight becomes more.
(D) The mass remains the same and the weight reduces.

19. A hollow metal sphere of volume $0.01m^3$ and mass 2 Kg has to be completely filled with some material such that the filled sphere has a mass of 25 Kg. Which material should be used?

(A) Sand (density = $2.3 \times 10^3 Kg\ m^{-3}$)

(B) Salt (density = $2.2 \times 10^3 Kg\ m^{-3}$)

(C) Cement (density = $2.7 \times 10^3 Kg\ m^{-3}$)

(D) Lead shot (density = $1.13 \times 10^4 Kg\ m^{-3}$)

20. A car moving at 50m.p.h. starts to travel down a hill with the engine turned off. The car continues to travel at the same speed. The reason why it does not move faster as it travels down the hill is that -

(A) the forces acting on the car are balanced.
(B) there are no forces acting on the vehicle.
(C) the car is not heavy enough to gain the gravitational acceleration.
(D) frictional deceleration is greater than the gravitational acceleration.

21. A puck slides along a 'frictionless' surface and collides and sticks to a second puck. After collision -

(A) both the total momentum and kinetic energy have increased.
(B) both the total momentum and kinetic energy have decreased.
(C) the momentum will be the same but the kinetic energy will increase.
(D) the momentum will be the same but the kinetic energy will decrease.

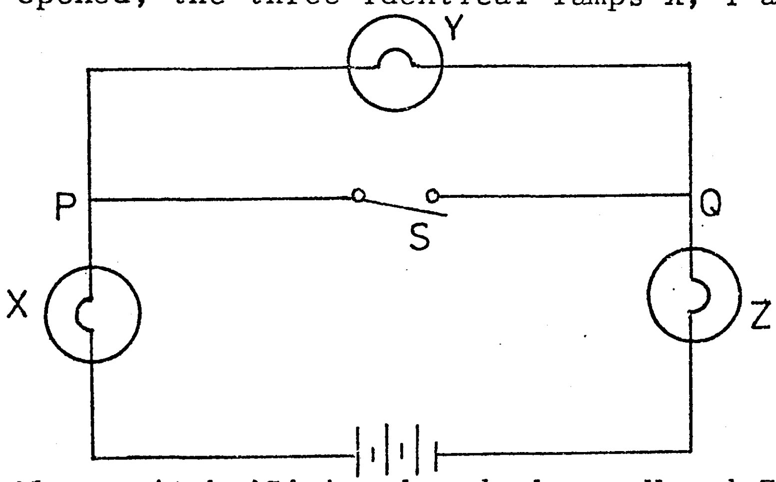
22. In which of the following is the second temperature double the first?

(A) 20°C 40°C
(B) 25°F 50°C
(C) 25°K 50°K
(D) 35°C 70°F

23. Which of the following shows the effect on the velocity, frequency and wavelength of water waves when they are moving from deep water into shallow water?

	velocity	frequency	wavelength
(A)	the same	the same	changes
(B)	the same	changes	changes
(C)	changes	the same	changes
(D)	changes	changes	the same

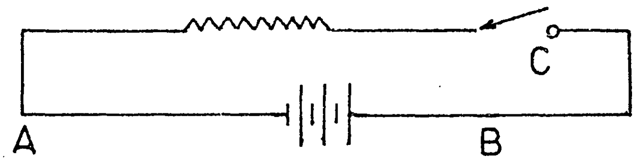
24. In the circuit shown below, when switch 'S' is opened, the three identical lamps X, Y and Z are lit.



When switch 'S' is closed, lamps X and Z become brighter. This is because -

(A) the current has a shorter distance to travel.
(B) the cells are more powerful with two lamps.
(C) closing the switch increases the voltage between P and Q.
(D) there is less resistance in the circuit so larger current flows through X and Z.

25. In the circuit, when the switch is opened, the potential difference



between AB is -

(A) zero.
(B) less than e.m.f. between AB.
(C) equal to e.m.f. between AB.
(D) greater than e.m.f. between AB.

26. If a man 70 Kg stands on spring scales in a lift and if the lift is accelerated upwards, the scales will read -

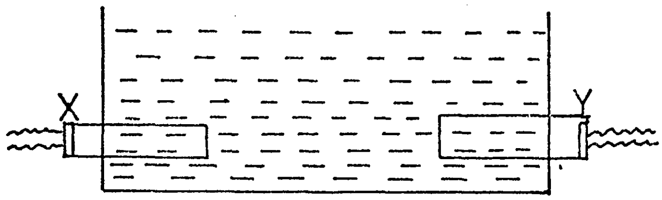
(A) zero.
(B) less than 70 Kg.
(C) greater than 70 Kg.
(D) equal to 70 Kg.

27. The magnifying power of a simple two-lens astronomical telescope in normal adjustment is 36, and the diameter of the objective lens is 72mm. The minimum diameter of the eye piece lens required to collect all the light entering the objective from a distant point source on the axis of the instrument is -

(A) 36 mm only.
(B) 72 mm only.
(C) 72 x 36 mm.
(D) 72 ÷ 36 mm.

28. Water is heated in a wide tank by 1 Kw immersion heater near the bottom of side X, and by a 2 Kw

heater near the bottom of the opposite side Y.



The circulation of the water will be -

(A) upwards at X and downwards at Y.

(B) upwards at Y and downwards at X.

(C) upwards near the middle and downwards at sides X and Y.

(D) upwards at sides X and Y, and downwards near the middle.

APPENDIX 3.7.(f)

Sub-Test 3

1. Energy is needed to carry electricity from one city to another. The energy carried each second is called -
   (A) work.
   (B) force.
   (C) power.
   (D) current.

2. Potential energy depends upon -
   (A) time.
   (B) route.
   (C) velocity.
   (D) position.

3. When a gas in a refrigerator is compressed, it changes into liquid. In doing so, it gives out its -
   (A) latent heat.
   (B) mechanical energy.
   (C) internal energy.
   (D) specific heat capacity.

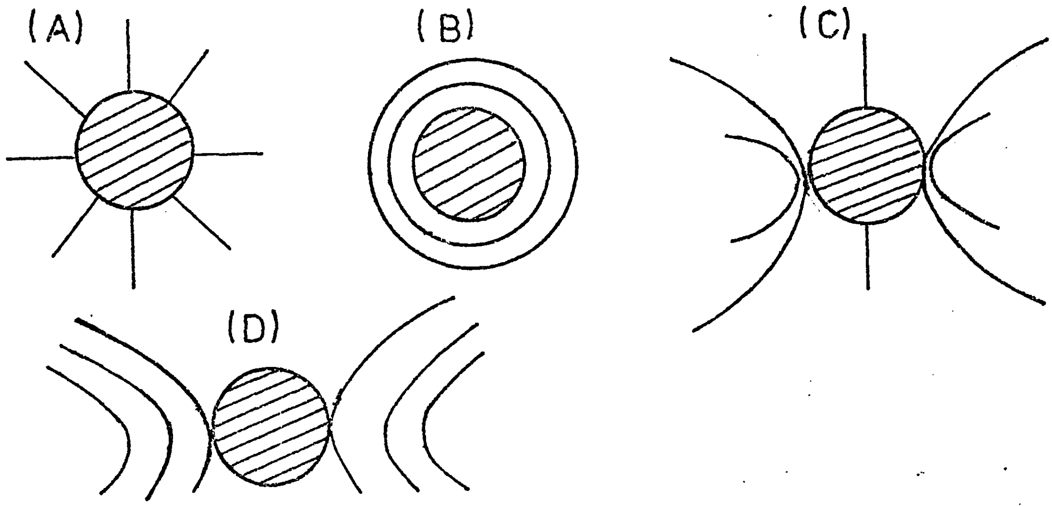
4. A range of 1 degree on Kelvins (absolute) scale of temperature is equivalent on the Celsius scale to a range of -
   (A) 1 degree.
   (B) 5/9 degree.
   (C) 1/273 degree.
   (D) 273 degree.

5. The best evidence that light is a wave motion is that it -
   (A) shows interference.
   (B) can be reflected.
   (C) can be refracted.
   (D) travels in a straight line.

6. When a magnet rotates near a conductor, alternating current is produced. This is due to -

(A) self induction.
(B) electric induction.
(C) magnetic induction.
(D) electromagnetic induction.

7. Which of the following shows the shape of the magnetic field around a straight current carrying conductor, if the conductor is perpendicular to the plane of the page?



8. Smoke laden air in a small container is viewed through a microscope. Little particles are seen which move in a random zig-zag fashion. Pupils make the following comments -

(1) "I can see the air particles moving in a zig-zag fashion".
(2) "I can see smoke particles moving in a zig-zag fashion".
(3) "The small invisible air particles are bumping into the layer of visible smoke particles".

Choose -

(A) if (2) only is correct.
(B) if (1) and (2) only are correct.
(C) if (2) and (3) only are correct.
(D) if (3) only is correct.

9. An astronaut on a space flight is moving away from earth at a constant speed. Which of the following describes the effect on his mass and his weight?

	His mass	His weight
(A)	decreases	remains constant
(B)	decreases	decreases
(C)	remains constant	decreases
(D)	remains constant	remains constant

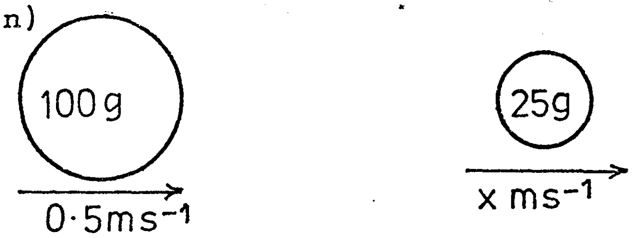
10. A man of mass 65 Kg stands on an ice-skate, the blade of which is 0.005 m wide and 0.25 m long. The pressure (in N m^{-2}) exerted on the ice will be -

(A) (65 x 10) ÷ (0.005 x 0.025)
(B) 65 x 10 x 0.005 x 0.025
(C) (0.005 x 0.025) ÷ (65 x 10)
(D) 65 ÷ (10 x 0.005 x 0.025)

11. A 100g marble travelling at $1ms^{-1}$ strikes a 25g marble at rest as shown.

(Before collision)

(After collision)

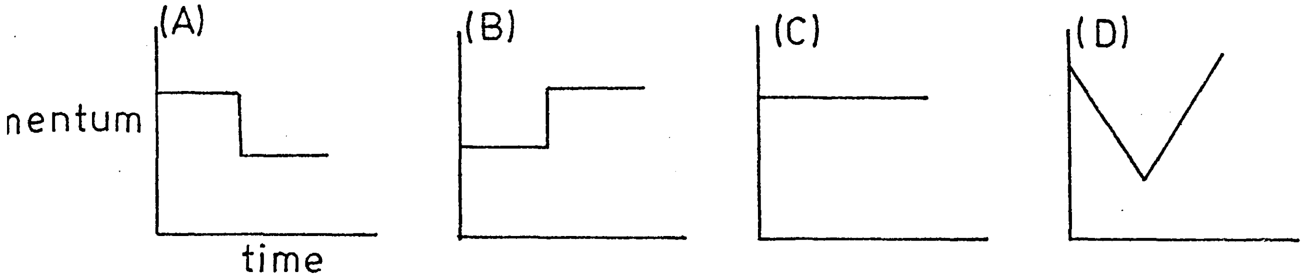


After the impact the larger marble is slowed down to $0.5ms^{-1}$ and the smaller one shoots off at xms^{-1}.

What is the value of x ?

(A) 0.5
(B) 1.0
(C) 2.0
(D) 4.0

12. Two ice pucks travelling along a "frictionless" surface collide head on. Which of the following graphs shows how the total momentum of the pucks varies with time before and after collision?



13. Coming out of the sea on a sunny summer day you feel cold. This is because -

(A) sea water is cold.
(B) the sea is warmer than air.
(C) the evaporating water keeps out the sun.
(D) the evaporating water takes heat out of your body.

14. The window of a room is double-glazed and the air space between the panes is evacuated. Heat loss through the window to the outside still takes place. The main reason is the -

(A) convection currents between the panes.
(B) convection currents inside the room.
(C) radiation of heat energy through the panes.
(D) conduction of heat energy through the panes.

15. A temperature of -20°C is equivalent to -

(A) 353 K.
(B) 293 K.
(C) 253 K.
(D) -253 K.

16. If the velocity of a source is constant, the relationship between frequency and wavelength, when the

source vibrates more rapidly, will be -

	frequency	wavelength
(A)	greater	greater
(B)	greater	smaller
(C)	smaller	greater
(D)	smaller	smaller

17. The activity of a radioactive source falls to one eighth of its original value in 24 minutes. The half-life of this decay process is -
(A) 3 minutes.
(B) 6 minutes.
(C) 8 minutes.
(D) 72 minutes.

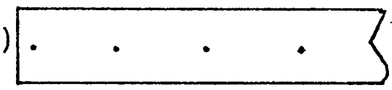
18. If a man 70 Kg stands on spring scales in a lift, and if the lift is accelerated upwards, the scales will read -
(A) zero.
(B) less than 70 Kg.
(C) greater than 70 Kg.
(D) equal to 70 Kg.

19. A coin contains 40% of copper by mass, the rest being zinc. It has a mass of 25g. What is its volume?
(density of copper = 9.0g cm^{-3})
(density of zinc = 7.0g cm^{-3})
(A) 1.11 cm^3
(B) 2.14 cm^3
(C) 3.10 cm^3
(D) 3.25 cm^3

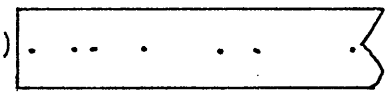
20. A path around a rose-bed is in the shape of a regular hexagon, each side being 10ft. long. What is the gardener's displacement when he has walked around the rose-bed once?
(A) zero.
(B) 40 ft.
(C) 60 ft.
(D) 80 ft.

21. A small trolley is moving down a slope at a constant velocity, drawing a length of tape through a ticker timer which produces 50 dots per second. Which of the following pieces of tape would be obtained?

(A) 

(B) 

(C) 

(D) 

22. In which of the following is the second temperature double the first?

(A) $20^{\circ}C$ $40^{\circ}C$
(B) $25^{\circ}F$ $50^{\circ}C$
(C) 25 K 50 K
(D) $35^{\circ}C$ $70^{\circ}F$

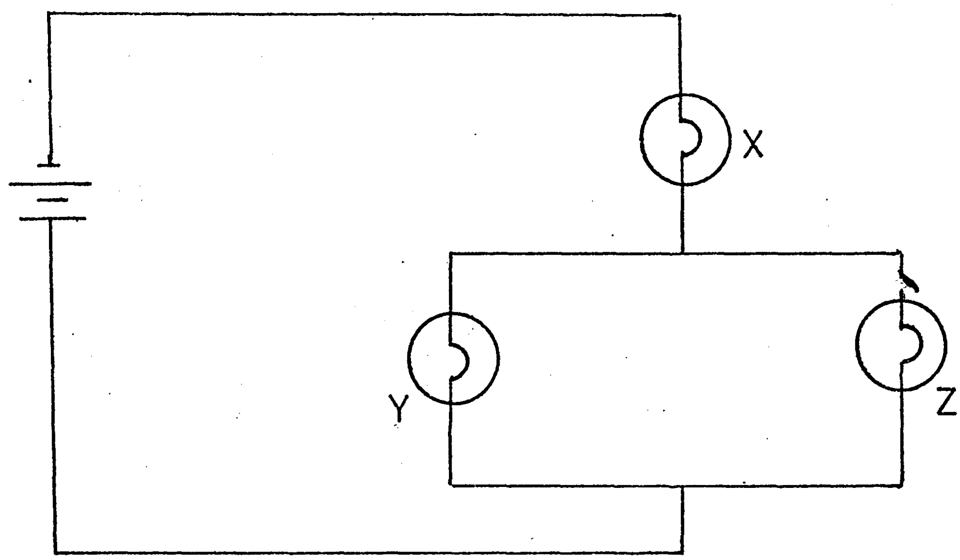
23. Wave motion is a means of transferring -

(A) force.
(B) power.
(C) energy.
(D) matter.

24. The magnifying power of a simple two-lens astronomical telescope in normal adjustment is 36, and the diameter of the objective lens is 72 mm. The minimum diameter of the eye piece lens required to collect all the light entering the objective from a distant point source on the axis of instrument is -

(A) 36 mm only.
(B) 72 mm only.
(C) 72 x 36 mm.
(D) 72 ÷ 36 mm.

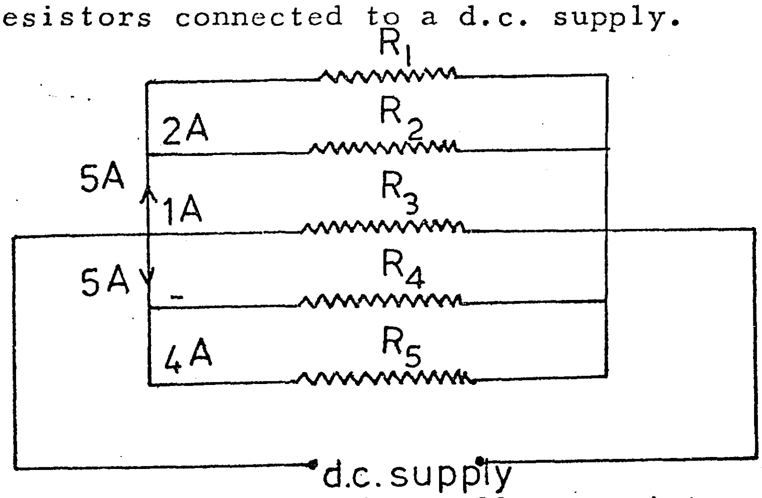
25. Three 2.5V 0.3A bulbs are connected as shown in the circuit.



How will the current in X and Y be affected when the switch is closed? The current in X will -

(A) increase and in Y will decrease.
(B) decrease and in Y will decrease.
(C) be the same as in Y.
(D) be zero and in Y maximum.

26. The circuit below shows the current in a network of resistors connected to a d.c. supply.



Which resistor has the smallest resistance?

(A) R_1
(B) R_3
(C) R_4
(D) R_5

27. A pupil examines a large leclanche cell and compares it to a small leclanche cell. Which of the following statements is true?

(A) The e.m.f. of the large cell is more than the e.m.f. of the small cell.
(B) The e.m.f. of the small cell is more than the e.m.f. of the large cell.
(C) The e.m.f. of the large cell is the same as that of the small cell.
(D) The e.m.f. of the small cell is negligible and the e.m.f. of the large cell is high.

28. When a brick is taken from the earth to the moon, what happens to its mass and its weight?

(A) The mass and weight remain the same.
(B) The mass remains the same and the weight reduces.
(C) The mass becomes less and the weight becomes more.
(D) The mass becomes more and the weight becomes less.

APPENDIX 3.7.(g)

Key to Sub-tests I, II and III

Item No.	Sub-test I	Sub-test II	Sub-test III
1.	A	C	C
2.	D	B	D
3.	B	A	A
4.	D	B	A
5.	A	C	A
6.	D	C	D
7.	C	C	B
8.	B	C	C
9.	D	D	C
10.	C	C	A
11.	C	A	C
12.	B	D	C
13.	C	B	D
14.	C	C	C
15.	D	C	C
16.	A	C	B
17.	B	B	C
18.	A	D	C
19.	C	A	D
20.	C	A	A
21.	B	D	B
22.	B	C	C
23.	A	C	C
24.	C	D	D
25.	B	C	A
26.	C	C	D
27.	C	D	C
28.	D	D	B

APPENDIX 3.7.(h)

Letter to Principal Teachers

Science Education
Research Group

The University,
Glasgow, G12 8QQ.

March 1976

Dear

Thank you very much for the help you have extended to me. I am sending herewith copies of the test along with the list of concepts. The answers for the list of concepts will be recorded on PINK computer cards and for the Sub-test on YELLOW computer cards. The Sub-tests should please be distributed equally throughout any class, so that all Sub-tests will be attempted by a random sample of pupils. No pupil will sit more than one Sub-test. The instructions for pupils are given on a separate sheet attached herewith.

You are requested kindly to inform your pupils how to fill in the right-hand portion and the left-hand portion of each card. We have assigned numbers to schools for our convenience. Your school No. is ______. Kindly intimate this to your pupils and also the serial number of pupils of your school, which will start from 001 onwards, using any numbering you choose. One specimen of the computer card is attached herewith.

Thanking you,

Yours sincerely,

A.R. Mughol

APPENDIX 3.7.(i)

Sheet of Instructions prepared for Teachers

INSTRUCTIONS TO BE GIVEN TO PUPILS

1. Answers for the list of the concepts will be recorded on PINK computer cards by shading in the appropriate oval using a soft pencil (preferably 2B).

2. Answers for the Sub-test will be recorded on YELLOW computer cards by shading in the appropriate oval using the same pencil.

3. In the right-hand portion of every card, only the date will be written; no need of the name.

4. There are 6 columns in the left-hand portion of every card. The ovals in the columns will be shaded as follows -

   (i) 1st Column: "No. of School" - which your teacher will tell you.

   (ii) 2nd Column: Your year (e.g. 3 = 3rd Year).

   (iii) 3rd Column: No. of Sub-test - (Your teacher will advise you).

   (iv) 4th)
   5th)
   6th Columns) Your number, which your teacher will give you. (e.g. if you are No. 3 - shade in 003; or if you are No. 37, shade in 037).

APPENDIX 3.7.(j)

Showing F.V.; M.F.V.; Index of difficulty and D.F. of the items in sub-tests, and of the common marker items in sub-tests for 1st year university students.

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	III	8.	0.14			-0.14	0.29	0.14
1.	B_2	II	8.	0.87	0.61	3.6	0.20	0.00	0.20
	B_3	I	1.	0.81			0.00	0.55	0.05
	B_1	I	7.	0.77			0.20	-0.03	0.17
2.	B_2	II	18.	1.00	0.80	37.3	0.00	0.00	0.00
	B_3	III	18.	0.64			0.14	-0.05	0.09
	B_1	I	8.	0.84			-0.10	0.36	0.26
3.	B_2	II	19.	0.13	0.61	13.2	0.20	-0.20	0.00
	B_3	III	19.	0.86			-0.29	0.13	-0.16
	B_1	I	2.	0.84			0.00	0.17	0.17
4.	B_2	II	1.	0.87	0.87	19.5	0.10	0.20	0.30
	B_3	III	20.	0.91			0.14	-0.02	0.13
	B_1	I	3.	0.84			-0.10	0.36	0.26
5.	B_2	II	20.	0.83	0.85	26.8	0.00	0.50	0.50
	B_3	III	21.	0.88			0.14	0.00	0.14
	B_1	I	4.	0.90			0.00	0.27	0.27
6.	B_2	II	9.	0.97	0.87	28.9	0.10	-0.10	0.00
	B_3	III	10.	0.73			0.29	0.21	0.50
	B_1	I	5.	0.94			0.00	0.18	0.18
7.	B_2	II	10.	0.43	0.77	26.5	0.10	0.60	0.70
	B_3	III	11.	0.95			0.00	0.13	0.13

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	I	6.	0.84			0.00	0.45	0.45
8.	B_2	II	21.	0.80	0.83	28.9	0.10	0.40	0.50
	B_3	III	12.	0.86			0.00	0.38	0.38
	B_1	I	9.	0.68			0.10	0.44	0.54
9.	B_2	II	11.	0.80	0.74	43.2	0.20	-0.10	0.10
	B_3	III	1.	0.73			-0.14	0.63	0.48
	B_1	III	2.	1.00			0.00	0.00	0.00
10.	B_2	II	12.	0.83	0.90	8.4	0.20	0.10	0.30
	B_3	I	17.	0.87			0.00	0.36	0.36
	B_1	III	13.	0.86			-0.14	0.25	0.11
11.	B_2	II	13.	0.83	0.71	47.5	-0.10	0.10	0.00
	B_3	I	18.	0.45			0.00	0.42	0.42
	B_1	III	3.	0.82			-0.14	0.38	0.23
12.	B_2	I	19.	0.61	0.81	34.9	0.00	0.25	0.25
	B_3	II	2.	1.00			0.00	0.00	0.00
	B_1	III	14.	0.82			0.29	-0.04	0.25
13.	B_2	II	28.	0.90	0.79	15.7	-0.10	0.20	0.10
	B_3	I	20.	0.65			-0.30	0.45	0.15
	B_1	I	10.	0.90			0.00	0.27	0.27
14.	B_2	II	3.	1.00	0.89	14.5	0.00	0.00	0.00
	B_3	III	22.	0.77			0.29	0.09	0.38
	B_1	III	5.	0.68			0.29	0.34	0.63
15.	B_2	I	11.	0.90	0.76	36.1	0.20	-0.11	0.09
	B_3	II	23.	0.70			0.30	0.30	0.60
	B_1	I	12.	0.61			0.20	0.43	0.63
16.	B_2	III	16.	0.82	0.79	25.3	0.14	0.23	0.38
	B_3	II	4.	0.93			0.00	0.20	0.20

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	I	13.	0.71			0.40	0.05	0.45
17.	B_2	II	5.	0.43	0.58	64.6	-0.10	0.40	0.30
	B_3	III	24.	0.59			0.14	0.07	0.21
	B_1	II	6.	0.80			0.20	-0.10	0.10
18.	B_2	I	21.	0.87	0.66	38.5	-0.10	0.01	-0.11
	B_3	III	25.	0.32			0.57	0.02	0.59
	B_1	II	24.	0.70			-0.10	0.50	0.40
19.	B_2	I	14.	0.77	0.78	31.3	0.20	0.25	0.45
	B_3	III	26.	0.86			0.14	0.11	0.25
	B_1	I	22.	0.71			-0.10	0.16	0.06
20.	B_2	II	16.	0.90	0.75	68.6	0.10	0.10	0.20
	B_3	III	6.	0.64			-0.14	0.09	-0.05
	B_1	II	7.	0.40			-0.10	0.20	0.10
21.	B_2	III	7.	0.73	0.53	53.6	0.00	0.36	0.36
	B_3	I	23.	0.45			0.30	0.41	0.71
	B_1	I	24.	0.68			0.40	-0.14	0.26
22.	B_2	II	25.	0.47	0.53	49.4	0.20	0.30	0.50
	B_3	III	27.	0.45			0.29	-0.21	0.07
	B_1	III	17.	0.68			0.43	0.07	0.50
23.	B_2	II	17.	1.00	0.83	10.9	0.00	0.00	0.00
	B_3	I	25.	0.81			0.10	0.35	0.45
				Common Marker Items					
	B_1	I	7.	0.77			0.20	-0.03	0.17
2.	B_1	II	14.	0.93	0.90	37.3	0.10	0.00	0.10
	B_1	III	9.	1.00			0.00	0.00	0.00

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
				Common Marker Items					
	B_3	I	26.	0.68			0.10	0.44	0.54
2.	B_3	II	26.	0.63	0.65	37.3	0.20	0.10	0.30
	B_3	III	18.	0.64			0.14	-0.05	0.09
	B_2	I	16.	0.84			0.10	0.26	0.36
14.	B_2	II	3.	1.00	0.93	14.5	0.00	0.00	0.00
	B_2	III	4.	0.95			0.00	0.13	0.13
	B_2	I	11.	0.90			0.20	-0.11	0.09
15.	B_2	II	15.	0.93	0.93	36.1	0.10	0.00	0.10
	B_2	III	23.	0.95			0.14	-0.14	0.00
	B_3	I	28.	0.42			0.90	-0.08	0.82
17.	B_3	II	27.	0.43	0.48	64.6	0.60	-0.10	0.50
	B_3	III	24.	0.59			0.14	0.07	0.21

APPENDIX 3.7.(k)

Showing F.V., M.F.V., Index of difficulty and D.F. of the items in sub-tests, and of the common marker items in sub-tests for post 'O' grade pupils (5th year).

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	III	8.	0.69			0.15	0.19	0.34
1.	B_2	II	8.	0.69	0.77	10.9	0.19	-0.01	0.18
	B_3	I	1.	0.94			0.05	0.02	0.07
	B_1	I	7.	0.86			0.02	0.02	0.05
2.	B_2	II	18.	0.91	0.83	23.7	0.05	0.15	0.20
	B_3	III	18.	0.71			0.11	0.28	0.38
	B_1	I	8.	0.77			0.14	0.16	0.30
3.	B_2	II	19.	0.70	0.68	23.1	0.33	0.20	0.53
	B_3	III	19.	0.56			0.09	0.38	0.47
	B_1	I	2.	0.55			0.18	0.25	0.43
4.	B_2	II	1.	0.73	0.71	28.7	0.10	0.05	0.15
	B_3	III	20.	0.84			0.04	0.26	0.30
	B_1	I	3.	0.80			0.11	0.09	0.20
5.	B_2	II	20.	0.89	0.85	30.0	0.09	0.10	0.19
	B_3	III	21.	0.87			0.09	0.23	0.32
	B_1	I	4.	0.92			0.05	0.14	0.18
6.	B_2	II	9.	0.90	0.84	43.0	0.03	0.22	0.25
	B_3	III	10.	0.70			0.17	0.17	0.34
	B_1	I	5.	0.89			0.02	0.14	0.16
7.	B_2	II	10.	0.57	0.74	38.9	0.17	0.06	0.23
	B_3	III	11.	0.77			0.11	0.23	0.34

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	I	6.	0.64			0.16	0.23	0.39
8.	B_2	II	21.	0.69	0.63	35.1	0.29	0.18	0.47
	B_3	III	12.	0.56			0.15	0.26	0.40
	B_1	I	9.	0.72			-0.05	0.45	0.41
9.	B_2	II	11.	0.70	0.70	51.6	0.29	0.20	0.49
	B_3	III	1.	0.69			0.15	0.32	0.47
	B_1	III	2.	0.84			0.04	0.19	0.23
10.	B_2	II	12.	0.73	0.79	15.7	0.09	0.23	0.32
	B_3	I	17.	0.80			0.10	0.36	0.48
	B_1	III	13.	0.58			0.28	0.06	0.34
11.	B_2	II	13.	0.59	0.53	52.2	0.09	0.27	0.35
	B_3	I	18.	0.41			0.09	0.16	0.25
	B_1	III	3.	0.79			0.21	-0.04	0.17
12.	B_2	I	19.	0.58	0.72	56.4	0.20	0.18	0.39
	B_3	II	2.	0.78			0.05	0.29	0.34
	B_1	III	14.	0.59			0.17	0.26	0.43
13.	B_2	II	28.	0.74	0.62	39.2	0.05	0.47	0.52
	B_3	I	20.	0.54			0.32	0.34	0.66
	B_1	I	10.	0.85			0.11	0.23	0.34
14.	B_2	II	3.	0.72	0.67	25.1	0.17	0.28	0.46
	B_3	III	22.	0.45			0.19	0.13	0.32
	B_1	III	5.	0.80			0.02	0.30	0.32
15.	B_2	I	11.	0.81	0.76	34.3	0.00	0.23	0.23
	B_3	II	23.	0.67			0.12	0.22	0.34
	B_1	I	12.	0.76			0.23	0.20	0.43
16.	B_2	III	16.	0.89	0.85	20.0	0.04	0.17	0.21
	B_3	II	4.	0.91			0.00	0.07	0.07

Concept No.	Bloom level	Subtest	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	I	13.	0.59			0.05	0.11	0.16
17.	B_2	II	5.	0.35	0.46	57.9	-0.02	0.16	0.14
	B_3	III	24.	0.45			0.15	0.15	0.30
	B_1	II	6.	0.73			0.05	0.34	0.39
18.	B_2	I	21.	0.81	0.63	47.5	-0.02	0.07	0.05
	B_3	III	25.	0.35			0.25	0.09	0.34
	B_1	II	24.	0.73			0.07	0.37	0.47
19.	B_2	I	14.	0.60	0.68	33.6	0.07	0.32	0.39
	B_3	III	26.	0.70			0.17	0.11	0.28
	B_1	I	22.	0.45			0.41	0.09	0.50
20.	B_2	II	16.	0.63	0.54	77.8	0.26	0.18	0.44
	B_3	III	6.	0.54			0.00	-0.02	-0.02
	B_1	II	7.	0.32			0.12	-0.01	0.11
21.	B_2	III	7.	0.62	0.39	57.9	0.23	0.17	0.40
	B_3	I	23.	0.22			0.18	0.07	0.25
	B_1	I	24.	0.60			0.07	0.32	0.39
22.	B_2	II	25.	0.30	0.44	62.6	0.14	0.02	0.16
	B_3	III	27.	0.43			0.15	0.09	0.23
	B_1	III	17.	0.49			0.26	0.13	0.38
23.	B_2	II	17.	0.86	0.71	28.3	0.05	0.32	0.37
	B_3	I	25.	0.77			0.11	0.20	0.32
				Common Marker Items					
	B_1	I	7.	0.86			0.02	0.02	0.05
2.	B_2	II	14.	0.80	0.84	23.7	0.10	0.03	0.13
	B_1	III	9.	0.86			0.13	0.11	0.23

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
				Common Marker Items					
	B_3	I	26.	0.71			0.23	0.14	0.36
2.	B_3	II	26.	0.69	0.70	23.7	0.07	0.32	0.39
	B_3	III	18.	0.71			0.11	0.28	0.38
	B_2	I	16.	0.77			0.23	0.23	0.45
14.	B_2	II	3.	0.72	0.73	25.1	0.17	0.28	0.46
	B_2	III	4.	0.70			0.17	0.36	0.53
	B_2	I	11.	0.81			0.00	0.23	0.23
15.	B_2	II	15.	0.93	0.86	34.3	0.02	0.12	0.14
	B_2	III	23.	0.85			0.13	0.06	0.19
	B_3	I	28.	0.41			0.16	-0.05	0.11
17.	B_3	II	27.	0.41	0.42	57.9	0.24	0.14	0.38
	B_3	III	24.	0.45			0.15	0.15	0.30

APPENDIX 3.7.(1)

Showing F.V., M.F.V., Index of difficulty and D.F. of the items in sub-tests, and of the common marker items in sub-tests for pre '0' grade pupils (4th year).

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	III	8.	0.58			0.12	0.17	0.30
1.	B_2	II	8.	0.71	0.72	12.5	0.71	0.07	0.24
	B_3	I	1.	0.88			0.07	0.17	0.24
	B_1	I	7.	0.79			0.13	0.21	0.34
2.	B_2	II	18.	0.86	0.73	31.5	0.08	0.21	0.28
	B_3	III	18.	0.55			0.07	0.10	0.17
	B_1	I	8.	0.80			0.14	0.06	0.20
3.	B_2	II	19.	0.43	0.51	26.0	0.21	0.35	0.56
	B_3	III	19.	0.29			0.35	0.06	0.41
	B_1	I	2.	0.35			0.26	0.14	0.40
4.	B_2	II	1.	0.64	0.55	43.0	0.35	0.14	0.49
	B_3	III	20.	0.66			0.21	0.31	0.52
	B_1	I	3.	0.65			0.17	0.33	0.50
5.	B_2	II	20.	0.76	0.76	57.1	0.10	0.34	0.43
	B_3	III	21.	0.88			0.05	0.24	0.29
	B_1	I	4.	0.92			0.06	0.03	0.09
6.	B_2	II	9.	0.85	0.78	38.7	0.02	0.22	0.24
	B_3	III	10.	0.57			0.26	0.14	0.40
	B_1	I	5.	0.88			0.01	0.17	0.19
7.	B_2	II	10.	0.50	0.67	44.5	0.25	0.08	0.33
	B_3	III	11.	0.64			0.21	0.33	0.54

Concept No.	Bloom level	Subtest	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	I	6.	0.40			0.23	0.19	0.41
8.	B_2	II	21.	0.57	0.50	35.6	0.25	0.28	0.53
	B_3	III	12.	0.54			0.35	0.10	0.45
	B_1	I	9.	0.70			0.07	0.19	0.26
9.	B_2	II	11.	0.66	0.61	61.3	0.13	0.41	0.54
	B_3	III	1.	0.47			0.19	0.24	0.43
	B_1	III	2.	0.75			0.16	0.23	0.39
10.	B_2	II	12.	0.59	0.67	25.3	0.17	0.31	0.49
	B_3	I	17.	0.66			0.16	0.36	0.51
	B_1	III	13.	0.66			0.30	0.14	0.44
11.	B_2	II	13.	0.48	0.51	55.0	0.25	0.35	0.60
	B_3	I	18.	0.40			0.16	0.17	0.33
	B_1	III	3.	0.69			0.16	-0.03	0.13
12.	B_2	I	19.	0.50	0.65	58.2	0.11	0.29	0.40
	B_3	II	2.	0.76			0.21	0.22	0.43
	B_1	III	14.	0.60			0.23	0.33	0.55
13.	B_2	II	28.	0.63	0.55	45.3	0.44	0.10	0.55
	B_3	I	20.	0.42			0.11	0.30	0.41
	B_1	I	10.	0.72			0.17	0.23	0.40
14.	B_2	II	3.	0.57	0.54	28.5	0.50	0.16	0.66
	B_3	III	22.	0.34			0.37	0.04	0.41
	B_1	III	5.	0.68			0.09	0.19	0.28
15.	B_2	I	11.	0.80	0.71	40.4	0.11	0.13	0.24
	B_3	II	23.	0.66			0.27	0.18	0.45
	B_1	I	12.	0.72			0.17	0.31	0.49
16.	B_2	III	16.	0.75	0.79	31.3	0.18	0.20	0.37
	B_3	II	4.	0.90			0.06	0.11	0.17

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
	B_1	I	13.	0.42			0.16	0.17	0.33
17.	B_2	II	5.	0.17	0.31	54.4	0.00	-0.03	-0.03
	B_3	III	24.	0.34			0.02	0.11	0.13
	B_1	II	6.	0.66			0.25	0.18	0.43
18.	B_2	I	21.	0.73	0.60	60.5	0.23	0.14	0.37
	B_3	III	25.	0.40			0.46	0.08	0.53
	B_1	II	24.	0.47			0.35	0.03	0.37
19.	B_2	I	14.	0.89	0.64	49.2	0.10	0.06	0.16
	B_3	III	26.	0.55			0.19	0.22	0.42
	B_1	I	22.	0.34			0.29	-0.01	0.27
20.	B_2	II	16.	0.55	0.50	73.4	0.08	0.31	0.39
	B_3	III	6.	0.61			0.25	0.05	0.30
	B_1	II	7.	0.43			0.04	0.24	0.27
21.	B_2	III	7.	0.55	0.41	57.4	0.23	0.26	0.48
	B_3	I	23.	0.25			0.13	0.01	0.14
	B_1	I	24.	0.43			0.19	0.13	0.31
22.	B_2	II	25.	0.22	0.32	83.0	-0.02	0.08	0.06
	B_3	III	27.	0.31			0.12	-0.06	0.06
	B_1	III	17.	0.20			0.04	0.06	0.09
23.	B_2	II	17.	0.49	0.36	42.0	0.13	0.22	0.35
	B_3	I	25.	0.39			0.24	0.06	0.30
			Common Marker Items						
	B_1	I	7.	0.79			0.13	0.21	0.34
2.	B_1	II	14.	0.86	0.65	31.5	0.12	0.19	0.30
	B_1	III	19.	0.29			0.35	0.06	0.41

Concept No.	Bloom level	Sub-test	Item No. in test	F.V.	M.F.V.	Concept Index diff.	T_1-T_2	T_2-T_3	T_1-T_3
			Common Marker Items						
	B_3	I	26.	0.57			0.11	0.26	0.37
2.	B_3	II	26.	0.59	0.57	31.5	0.21	0.22	0.43
	B_3	III	18.	0.55			0.07	0.10	0.17
	B_2	I	3.	0.59			0.34	0.34	0.69
14.	B_2	II	4.	0.57	0.56	28.5	0.50	0.16	0.66
	B_2	III	27.	0.53			0.19	0.32	0.52
	B_2	I	11.	0.80			0.11	0.13	0.24
15.	B_2	II	15.	0.85	0.82	40.4	0.00	0.15	0.15
	B_2	III	23.	0.80			0.14	0.20	0.34
	B_3	I	28.	0.40			0.07	0.03	0.10
17.	B_3	II	27.	0.26	0.33	54.4	0.19	0.04	0.23
	B_3	III	24.	0.34			0.02	0.11	0.13

A P P E N D I X 3.7.(m)

Showing categories of response according to subjective and objective assessments.

Concept No.	4th year			5th year			1st year university		
	c: % diff.	M.F.V.	category of resp.	c: % diff.	M.F.V.	category of resp.	c: % diff.	M.F.V.	category of resp.
1.	12.5	0.72	(a)	10.9	0.77	(a)	3.6	0.61	(a)
2.	31.5	0.73	(a)	23.7	0.83	(a)	37.3	0.80	(a)
3.	26.0	0.51	(a)	23.1	0.68	(a)	13.2	0.61	(a)
4.	43.0	0.55	(c)	28.7	0.71	(a)	19.5	0.87	(a)
5.	57.1	0.76	(c)	30.0	0.85	(a)	26.8	0.85	(a)
6.	38.7	0.78	(a)	43.0	0.84	(c)	28.9	0.87	(a)
7.	44.5	0.67	(c)	38.9	0.74	(a)	26.5	0.77	(a)
8.	35.6	0.50	(a)	35.1	0.63	(a)	28.9	0.83	(a)
9.	61.3	0.61	(c)	51.6	0.70	(c)	43.2	0.74	(c)
10.	25.3	0.67	(a)	15.7	0.79	(a)	8.4	0.90	(a)
11.	55.0	0.51	(d)	52.2	0.53	(c)	47.5	0.71	(c)
12.	58.2	0.65	(c)	56.4	0.72	(c)	34.9	0.81	(a)
13.	45.3	0.55	(c)	39.2	0.62	(a)	15.7	0.79	(a)
14.	28.5	0.54	(a)	25.1	0.67	(a)	14.5	0.89	(a)
15.	40.4	0.71	(c)	34.3	0.76	(a)	36.1	0.76	(a)
16.	31.3	0.79	(a)	20.0	0.85	(a)	25.3	0.79	(a)
17.	54.4	0.31	(d)	57.9	0.46	(d)	64.6	0.58	(d)
18.	60.5	0.60	(c)	47.5	0.63	(c)	38.5	0.66	(a)
19.	49.2	0.64	(c)	33.6	0.68	(a)	31.3	0.78	(a)
20.	73.4	0.50	(d)	77.8	0.54	(d)	68.6	0.75	(d)

Concept No.	4th year c: % diff.	4th year M.F.V.	4th year category of resp.	5th year c: % diff.	5th year M.F.V.	5th year category of resp.	1st year university c: % diff.	1st year university M.F.V.	1st year university category of resp.
21.	57.4	0.41	(d)	57.9	0.39	(d)	53.6	0.53	(c)
22.	83.0	0.32	(d)	62.6	0.44	(d)	49.4	0.53	(c)
23.	42.0	0.36	(d)	28.3	0.71	(a)	10.9	0.83	(a)

※ (a) = 8, 14, 17; (b) = 0, 0, 0;
(c) = 9, 5, 4; (d) = 6, 4, 2.

† Category	Subjective	Objective
(a)	easy (low score)	easy (high score)
(b)	easy (low score)	difficult (low score)
(c)	difficult (high score)	easy (high score)
(d)	difficult (high score)	difficult (low score)

※These numbers refer to number of items in each category for each year.

†Items were classed as easy when fewer than 30% of the sample reported them on subjective assessment.
In the objective assessment, items with a F.V. less than 0.50 were taken as difficult.

C H A P T E R 4

STUDY OF CONCEPTS IN DEPTH - DENSITY

CHAPTER 4

STUDY OF CONCEPTS IN DEPTH - DENSITY

The general survey of the difficult topics and concepts shown in the previous chapter revealed that there were many topics and concepts which were proving difficult and troublesome. As it was impossible for the researcher to study in detail all of them, it was decided to choose three difficult concepts from those isolated, for deeper study. These three concepts were: 'density', 'heat and temperature' and 'electrical resistance'. These were one from each of the main areas of difficulty.

Density was chosen as a topic because it was taught in the integrated science section of the syllabus and then not taught formally again till fifth form, where it was required for the oil-drop experiment. As any changes in pupil's understanding with age would be a natural development, it was thought to study this natural development of the concept. Heat and temperature was selected as an area in which there was much confusion in normal everyday language usage. Electrical resistance was chosen as a topic which would have to be taught in that it does not come often into normal use or conversation.

4.1. Scope of the Study.

The experimental techniques for investigating these three areas are similar although they differ considerably in detail. However the work in each area was carried out for a period of two years in different classes and institutions.

4.2. Preparation for the Material and General Techniques.

A. Syllabus.

For each area, the syllabus was carefully studied to identify the necessary sub concepts and topics on which the area was depending upon.

B. The physics teachers in four schools mentioned in section 3.3.C were consulted to fulfil the purposes mentioned in section 3.4.B. All of them agreed with the choice. Section 3.4.C was also followed.

In the light of A and B, the following material was prepared for each concept:

(1) A path diagram.
(2) An interview schedule.
(3) A diagnostic test.

A path diagram was a "net" constructed to show the inter-relationships between the ideas underlying the concept being investigated. This was not a teaching net, but one on which to base test material to check the linkages. For these reasons, the path diagram was preferred to Gagne's hierarchical model.

On the basis of this net, a set of questions was prepared and used in interviews with small numbers of pupils. The interviews were conducted with objects and small experiments to enable the researcher to probe for misconceptions. The technique of interview was preferred to the questionnaire method because one main weakness of the questionnaire method is that inevitably a portion of the sample will not answer, and it is difficult to discover why, or to discover how the non-responders differ from those who do reply.[107] Similarly, interview technique was preferred to the clinical method because of the dangers and drawbacks stated by T.D. Davies (1970)[66] and the criticism made by J.G. Wallace (1965).[42]

Apart from these reasons, the main reason for preferring this technique was to validate the newly prepared test which was to be followed. The interview technique was thought more reliable so results of the test were to be compared with the information collected from the analysis of the interview.

Written diagnostic tests (generally well illustrated) based upon the interview information were constructed and sent out to several schools to enable a wider investigation to take place with a more representative sample of pupils and schools.

Diagnostic tests were preferred because of their nature and the reasons given by West and Fensham.[8] In these tests, multiple choice response form of questions was preferred because of the reasons given in the following section.

4.3. Choice of Type of Test.

Tests are prepared with many reasons. They serve many functions in psychology and education. Some of the functions which a test can serve in education are:

1. To assess if the curriculum is achieving its objectives.
2. To determine the effect on the pupil of teaching particular parts of the curriculum.
3. To assess weakness and strength in the syllabus by measuring pupil performance in each of its aspects.
4. To assess variations in achievement of pupils in the different areas of the course to obtain a profile of performance.

5. To rank pupils in order of merit.[11]

Each function mentioned above gives birth to some type of test. Functions 3 and 4 point towards important uses of a test. These give rise to a special type of test which serve the functions. Before we look at this type of test, let us see the importance of preparing such type of test. Curriculum Paper 7 shows the importance in these words: "We would stress the importance of suitable and properly balanced testing in any form of education. In the field of science, not enough importance has been given to this in the past ... This is a field in which much work remains to be done and it will prove a fruitful field of research for many years to come."[11] R.W. Tylor supports these views by saying: "Research is needed to develop better measuring instruments which appraise all the important objectives in science education, which apply to the entire range of students and which provide measures precise enough to test ... the effectiveness of curricula and of teaching-learning process."[117] Leo Nedelsky (1965)[118] is also of the same opinion and stresses upon the need of preparing new types of tests in science education.

The tests which can serve function 3 and 4 stated above and can fulfil the views mentioned above can be diagnostic tests. These are designed to analyse the individual's specific strengths and weaknesses in a subject and to suggest the causes of his difficulties.[119] E. Stones (1966) supports these views. He says: "Diagnostic tests are designed to give the child a careful graded series of sub-tests which deal with the main aspects of the subjects so that failure on one or more of the sub-tests will pinpoint the particular difficulty or difficulties which the child is experiencing."(87)

To follow these views new types of diagnostic test were prepared. These are novel ideas of constructing tests in physics education. In preparing these tests four factors given by Curriculum Paper 7 were kept in view and followed to make these tests more suitable and effective. These factors are: "... content, the relative importance of the various items of content, the depth of understanding required and the most suitable form for questions to take."(11)

In these tests, the form for questions was important for the researcher. In this context, J.G. Houston (1970) says: "... there can be little doubt that of the various test item forms considered, the most versatile and effective form is multiple choice." He further says: "This is because:

1. It is possible to construct multiple choice items to test any of the educational objectives of a physics course.
2. Guessing can be controlled by increasing the number of responses.
3. Multiple choice items can be readily machine marked.
4. The item form makes item analysis straight forward.
5. Complete objectivity of marking is achieved".(28)

Houston is supported by the views expressed in Curriculum Paper 7. They are "When written answers are required, they should not be long essays about remembered details; instead questions of the multiple choice and one word answer type should be used." At another place, views are, "The form of question is a matter of considerable importance. At this early stage in the child's education we feel that the best form is objective multiple choice question for most purposes. It provides all the necessary cueing to bring relevant ideas to the forefront of the pupil's mind; it can be tailored to suit exactly the content and the depth of understanding; it is quick to correct and although slow to prepare, once it has been proved suitable, any item can be used several times before it need be discarded."[11]

Because of these recommendations, the researcher preferred multiple choice items in newly developed tests.

4.4. Density.

The concept of density is one of the basic concepts defined by Newton. While defining mass he gave an idea about density. He defined mass as the product of density and volume.[3] He, in the "Principia", defined density as the ratio of 'inertia' to 'bulk' (bulk = volume). At the beginning he defined inertia as proportional to mass.[25] In modern terms, density is defined as mass per unit volume.[3]

Scientifically, this concept helps in making fair comparison between two substances which in turn, clarifies two terms 'heavy' and 'dense'. Regarding this comparison, O.W. Nitz (1956) says, "It is not accurate to say that iron is heavier than aluminium since this would permit comparing a small piece of iron with a large piece of aluminium and would not be specific. If however, you say that the density of iron is greater than that of aluminium, you are comparing pieces of the same size."[120]

Psychologically, the concept of density is one of two (i.e. volume and density) principal indexes suggested by Piaget and Inhelder. They have declared this concept as 'proportionality scheme index' which belongs to the category of formal operations.(121)

The work in this chapter is concerning this concept and was carried out in a period of two years in two stages.

4.5. First Stage of the Unit.

A. Design of the stage.

(i) Objectives of the stage were defined.

(ii) Material preparation; this material consisted of (a) path diagram, (b)an interview schedule.

(iii) Material application; the material was applied in 1975-76 session to the pupils of SI to SIII classes in two schools.

B. Objectives of the stage.

To study the concept, the material of this stage was prepared with the following objectives:

(i) To study the concept of mass.

(ii) To learn about the stages of measurement, units and dimensions.

(iii) To study the understanding of the nature of individual particles in substance.

(iv) To study the concepts of volume and conservation of volume.

(v) To study the understanding of the terms 'heavy' and 'dense'.

(vi) To study the concept of density.

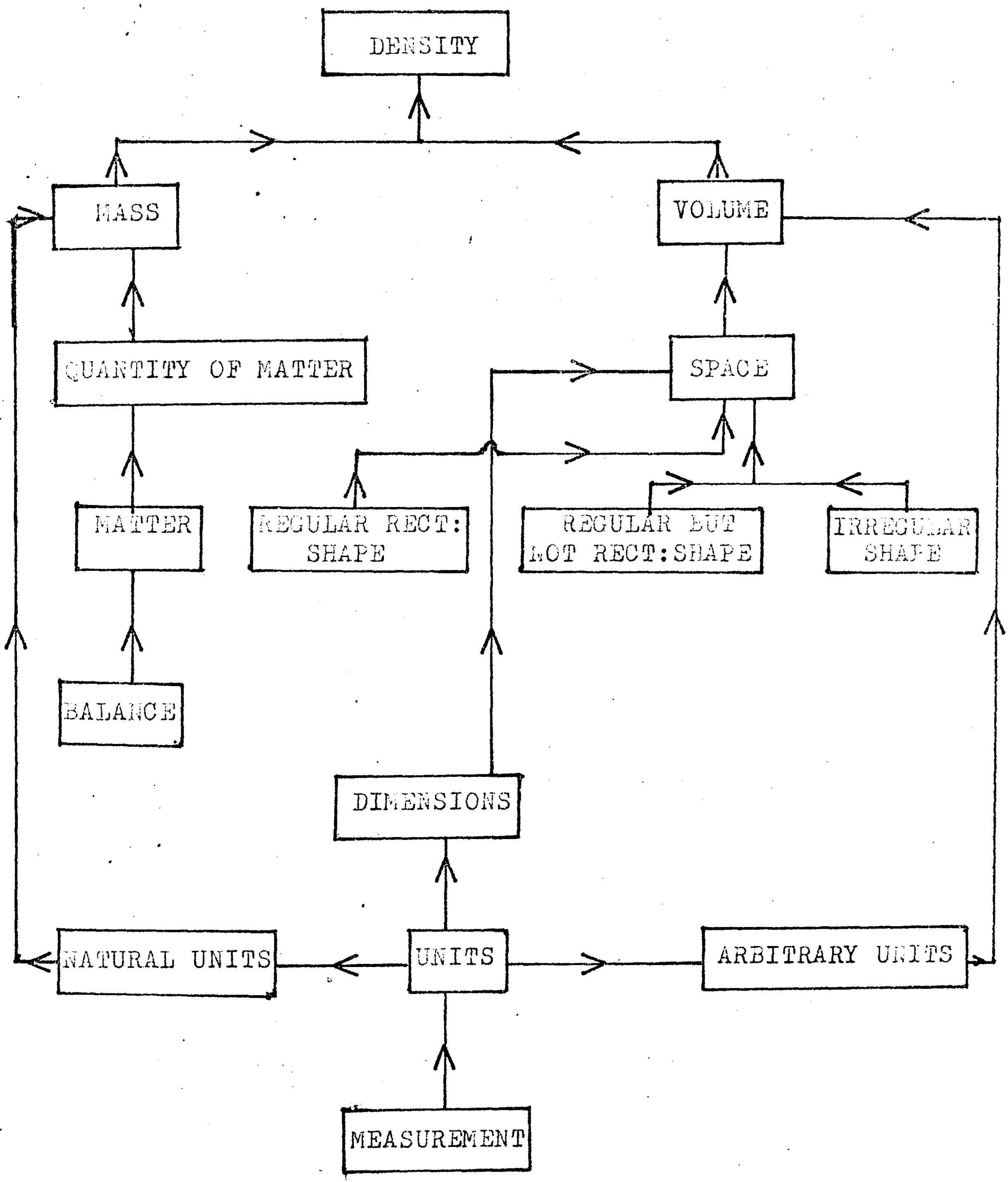


FIGURE 6

Path Diagram for the Concept of Density

C. The material structure.

(i) A framework for the study of the stage was prepared. The main parts of the framework are: measurement, units, matter, mass, volume and density. The path diagram is shown in Figure 6. As it is a path diagram,[122] one can move to any direction. Here we move generally from the bottom to the top and arrows show the direction of the movement and relationship among the parts of the diagram.

(ii) In the light of the path diagram, an interview schedule was prepared in order to collect unbiased information in a form which permits the answers from each subject to be put together to give an accurate picture of the population from which the sample was drawn. As there is a standard procedure for the precise wording for the key questions and the classification of responses, so it is called the standardized interview.[107]

The interview schedule prepared was passed through all the stages given by Nisbet and Entwistle.[107] The interview schedule appears as Appendix 4.5.(a).

D. How the material was applied.

As the concept selected was to be studied in detail and in depth, the information was to be collected from the pupils of the various classes. The interview, therefore, was given to the pupils of SI to SIII in two schools. Six pupils comprising the cross-section of each class participated. The information regarding those pupils is shown in Appendix 4.5.(b). The interview conducted was recorded on tape-recorder.

In conducting and recording the interview, all the conditions and steps mentioned by W.F. Archenhold (1975)[5] H.D. Thier (1965)[123] and Nisbet and Entwistle[107] were followed and fulfilled.

During conduct of the interview, the questions were put after showing the following material: (i)some regular and irregular solid objects; (ii) water and mercury (liquid objects); (iii) cubes of same volume but of different material (i.e. copper and wooden cubes of $8cm^3$); (iv) cubes of same mass but of different volume and material (i.e. aluminium and wooden cubes); (v) cubes of different mass, volume, and material (i.e. lead and wooden cubes); (vi) cubes of same material but of different mass and volume (i.e. copper cubes of $1cm^3$ and $8cm^3$).

The time period of the interview was about 30 minutes.[107] Full details of the interview along with prompts and probes are shown in Appendix 4.5.(c).

E. Results.

After conducting the interview, the tapes recorded were heard and the information given was analysed. The analysis of the interview of the various pupils in two schools is shown in Appendix 4.5.(d).

Before the information was analysed, it was anticipated that if we conducted this interview with first year pupils, they would show least understanding of the concept and its subordinate parts. Similarly if we were to go up and conduct the same interview with second year pupils, the number of pupils showing understanding would increase and this number would be still greater with the third year pupils because at this stage, we were dealing with probably

Table 4.5.1.

Showing the summary of information given by various pupils during the interview regarding the concept of density

School	Class	Concept of mass	Units etc.	Nature of ind. particles	Concept of volume (regular bodies)	Concept of volume (irregular bodies	Conservation of volume in solids	Conservation of volume in liquids	Idea of heavy material	Idea of dense material	Mass-volume relationship	Concept of density
I	1st Year	Not completely clear	Clear	Clear	Clear	Clear	Clear	Not completely clear	Clear	Not com pletely clear	Clear	Clear to one-third pupils
"	2nd Year	"	"	"	"	"	"	Clear	"	"	"	"
II	1st Year	"	"	"	"	"	"	"	"	"	"	"
"	2nd Year	"	"	"	"	"	"	"	"	"	"	"
"	3rd Year	Clear	"	"	"	"	"	"	"	Clear	"	Clear to two-thirds of the pupils

more able sample of the age cohort. Table 4.5.1 shows the summary of information given by the pupils. This table also confirms the order of results regarding the concept of density mentioned in sections 3.6.F and 3.7.F, and reveals that the pupil's understanding of the concept is consistent within any one year and the general trend is that as we proceed from first year pupils to third year pupils, the number of pupils understanding the concept increases, i.e. growth of the concept takes place as the age level increases. In the case of this concept, it is revealed that the growth starts to take place at 3rd Year and without formal teaching. This is shown by the pupils in their answers given during the interviews. For example, when they were asked: "What is mass?", first year and second year pupils could not define it. They only said: "It is weight", but the third year pupils replied "The amount of stuff in a body." Similarly when they were asked: "What term do we use when we compare the masses of equal volume?", there were two pupils in first and second years and four in third year, who gave a satisfactory answer. The answers given by the second school pupils confirmed the answers of the pupils of the first school and strengthened the information obtained in the first set of interviews.

4.6. Second Stage of the Unit.

A. Design of the stage.

(i) Objectives of the second stage were defined.

(ii) Material preparation. This material consisted of a diagnostic test.

(iii) Material application: this material was applied in 1976-77 session, to the pupils of SI to SV (Higher grade) classes in four schools.

B. Objectives of the second stage.

The objectives of this stage remained the same as mentioned in section 4.5.B except that one more objective was added and that is:

(vii) To study the validity of the new test technique introduced for the study of the concept.

C. The material structure.

In the light of the views and recommendations mentioned in section 4.3, a new type of diagnostic test was prepared involving pictures to take the place of the objects used in the interview. Pupils were asked to select pictures or combinations of pictures to answer the questions in the same way as they selected objects in the interview. Because of this it was called "A pictorial multiple response test". The answers were the letter identifier(s) of the appropriate pictures (Appendix 4.7.(b)).

This test was prepared to study the main concept of density and two subordinate concepts. Because of this, the test was divided into three parts. Part one mainly concerned with mass, part two with volume and part three with density. Parts one and two consisted of 4 questions and part three 10 questions. There were some questions introduced to cross-check other items. In all there are 18 questions in the test. There are two main parts of test material: (a) written material, i.e. instructions and items, (b) pictures. In each part there are four sheets. Each sheet in part one corresponds to the sheets in part two. A separate answer sheet was attached at the end of the test, so the test for density consisted of (i) question sheets, (ii) picture sheets and (iii) answer sheet.

As the main purpose of the test was to study the growth of the concept, the items were prepared according to Bloom's[114] first three levels (i.e. knowledge, comprehension and application) and levels of intellectual growth suggested by Piaget. According to him, "The two stages which are of concern in the secondary schools are the second and third: the concrete and the formal. Each of these takes about four years to work through and is sub-divided A and B: B marking the end of a stage, when its conceptual stage has become freely available, and A representing a more loosely defined period when some of its strategies are used, but not consistently, or with confidence."[73] The test specifications and item specifications are shown in Appendix 4.6.(a). The test appears as 'Test One' in Appendix 4.6.(b). As this was a multiple response test, an explanation sheet was prepared in place of key. This sheet appears as Appendix 4.6.(c).

D. How the material was applied.

The test was applied to 633 first year, 558 second year, 268 third year and 245 fourth year pupils in four schools during 1976-77 session. To observe the effect of formal teaching, the test was applied to a small sample of 26 pupils in fifth year in one of the four schools.

As clear instructions were written on the top of the front page of the test, no further instructions were issued

Table 4.6.1

Showing Results (%) of Responses of Test One - Density

Class	Sheet												
		H	J	E	F	EF	AC	CH	AH	G	I	GI	
1st Year	One	25.4	51.3	58.8	7.9	17.1	46.3	6.5	38.4	23.7	16.6	49.6	
2nd "	"	20.1	61.3	57.2	12.5	18.1	49.1	8.6	35.7	24.7	21.5	44.4	
3rd "	"	12.7	66.4	48.9	6.3	31.0	71.3	1.5	25.4	13.1	17.9	57.5	
4th "	"	4.9	79.2	35.9	2.5	52.8	69.8	2.0	23.3	8.6	18.0	70.2	
5th "	"	0.0	96.2	23.1	0.0	73.1	96.1	0.0	3.9	3.9	15.4	76.2	
		AB	ABD	ABEH	ABDEH	D	J	K	JK	F	G	FG	
1st Year	Two	20.5	4.1	6.3	3.2	51.2	4.3	0.3	69.2	6.0	4.9	39.3	
2nd "	"	15.2	2.7	10.9	2.5	54.1	2.7	0.7	76.9	6.5	4.3	43.4	
3rd "	"	18.3	9.0	17.5	14.2	70.2	0.0	1.5	86.2	3.0	14.2	60.1	
4th "	"	19.2	7.4	23.3	13.5	70.2	2.5	0.4	82.9	7.8	4.1	58.0	
5th "	"	15.4	7.7	15.4	26.9	88.5	0.0	0.0	88.5	7.7	0.0	69.2	
		D	F	H	A	E	AEF	B	C	BC	G	E	L
1st Year	Three	95.6	92.7	0.8	0.3	1.9	63.2	39.0	12.5	5.4	31.6	64.1	55.0
2nd "	"	95.0	92.8	0.5	0.0	0.7	74.0	43.7	9.8	8.1	30.8	68.3	60.9
3rd "	"	97.4	95.5	0.4	0.0	0.0	90.7	50.4	7.5	17.5	19.8	75.4	73.9
4th "	"	98.8	98.0	0.0	0.0	0.0	93.9	42.9	9.4	27.8	17.2	85.3	73.9
5th "	"	96.2	96.2	0.0	0.0	0.0	100.0	34.6	3.8	53.9	7.7	84.6	80.8
	Three	A	D	AD	Q	R	QR	M	N	O	T	U	TU
1st Year	& Four	11.7	7.6	25.0	5.4	5.5	72.2	8.4	11.7	73.3	0.8	77.4	8.8
2nd "	"	10.9	3.8	33.7	5.2	3.2	79.9	6.8	7.7	81.2	1.1	74.9	13.3
3rd "	"	7.5	3.7	59.3	1.9	2.6	89.9	4.5	2.3	88.4	0.4	64.2	29.5
4th "	"	6.9	6.9	58.0	3.3	0.8	85.7	2.0	1.6	92.2	0.0	54.3	37.6
5th "	"	0.0	3.3	84.6	0.0	0.0	92.3	0.0	0.0	100.0	0.0	23.1	73.1

Sheet One

Please look at Sheet One and answer the following items.

1. In pictures H and J, there are two cubes. Which cube has the greater mass?
2. Look at pictures D, E and F. In which jar(s) will the contents have the same mass as the ice in jar D?
3. In pictures A, C and H, which two of the objects would have the same mass?
4. Which pair(s) of trollies will contain the same mass as the pair shown in picture B?

to the subject teachers in schools.

E. Results.

The data of the test was processed manually. The percentages of the responses were computed. The results as percentages and the correct responses of the items appear in Table 4.6.1.

4.7. Discussion.

The unit was applied in two stages: (i) the interview and (ii) the picture test. Let us look at the results of the test.

(a) Sheet One.

1. The first question is trying to establish if the pupils have any intuitive feeling for the relative density of common materials - here aluminium and copper. They are presented with an equal volume situation to begin with. The answer J is seen to increase with age and almost linearly.

2. The second question is attempting to establish that the physical state of a given amount of a substance does not affect its mass although it may affect its density. The answer required is E and F but this is weak until 5th year and even then it is by no means accepted. However, about 60% chose E only, revealing that they regarded solids and liquids as 'heavy' and gases as 'light'.

3. This third question is a cross-check on question two. Despite the fact that A and C are both marked as "10g" about half of the pupils chose AH i.e. two obvious solids categorised together and away from the more "nebulous solid feathers". This is only fully rectified at 5th year.

4. The fourth question was intended to look for any

Sheet One

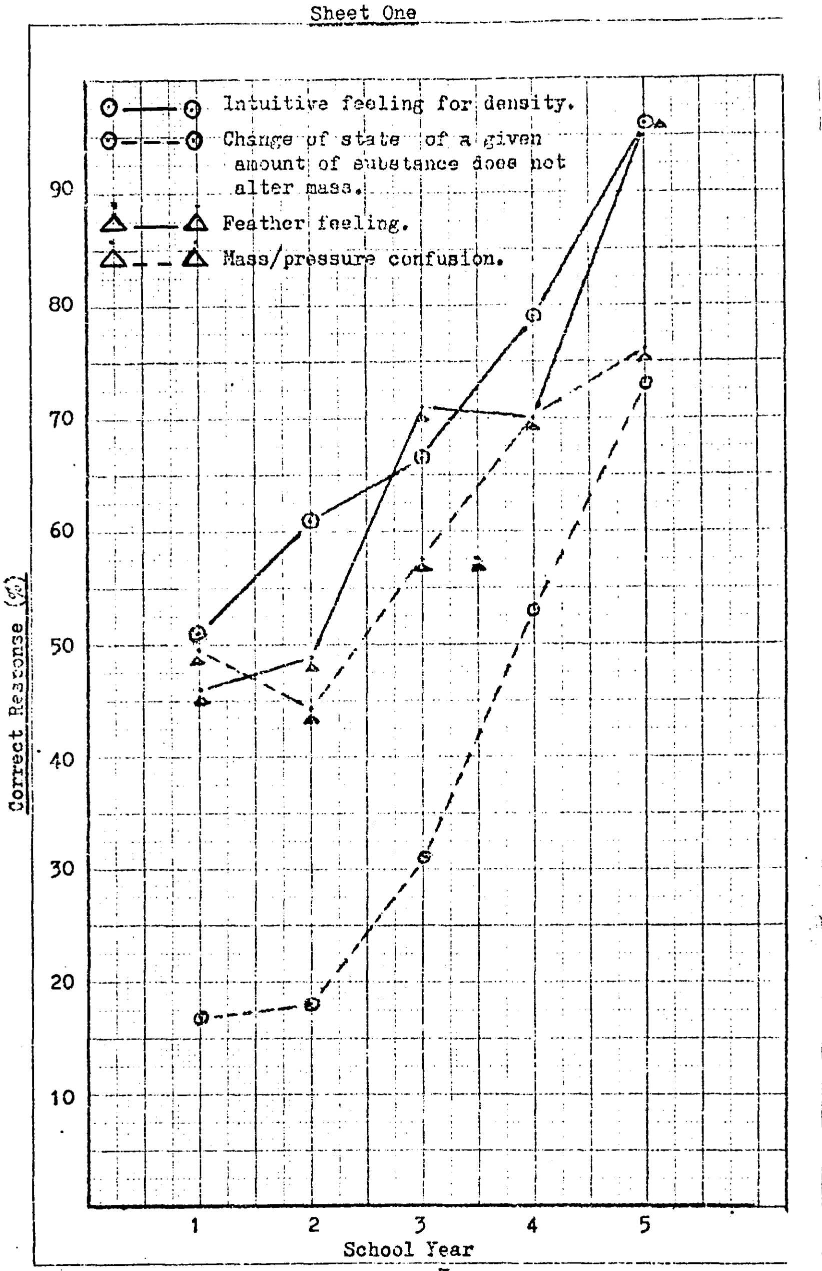


Figure 7

Sheet Two

Please look at Sheet Two and answer the following items.

1. Choose from this grid all the pictures in which the object has a volume of $8cm^3$.
2. Choose the picture from this grid which shows "how to find out the volume of irregular solid".
3. Choose the picture(s) in which there is the same volume of water as shown in picture I.
4. In which picture(s) will the object have the same volume as the object shown in picture C?

confusion between mass and pressure. G and I was the answer sought but even at 5th form, not all pupils were marking this choice.

The results of this sheet are shown in Figure 7. In this figure, two areas show a gradual and almost linear change, presumably as a result of experience of everyday things, while two other areas show a marked improvement with age and with the reappearance of formal teaching in 5th form. The areas of gradual change are intuitive feeling for density and mass/pressure confusion. The areas of marked improvement are: effect of physical state on mass and "feather feeling."

(b) Sheet Two.

1. The first question is trying to establish if the pupils have ideas about volume and conservation of volume. In volume, they have to establish if they know volume by formula or as they have learned it. Here they are presented with solids in different regular shapes. For volume by formula, the answer required is A and B. This is weak and non-linear. The same is the case for the answer ABD required for volume by taught methods including water displacement. In conservation of volume questions, pupils have to show if they are aware of conservation of volume, and the conservation of volume in solids in particular. Here the material presented is the same. The answer required for the conservation of volume in solids is ABEH, which is also weak and non-linear. However the total idea of conservation, whose answer is ABDEH, is weak but is improving slowly with age.

2. The second question is meant to find if pupils have

Sheet Two

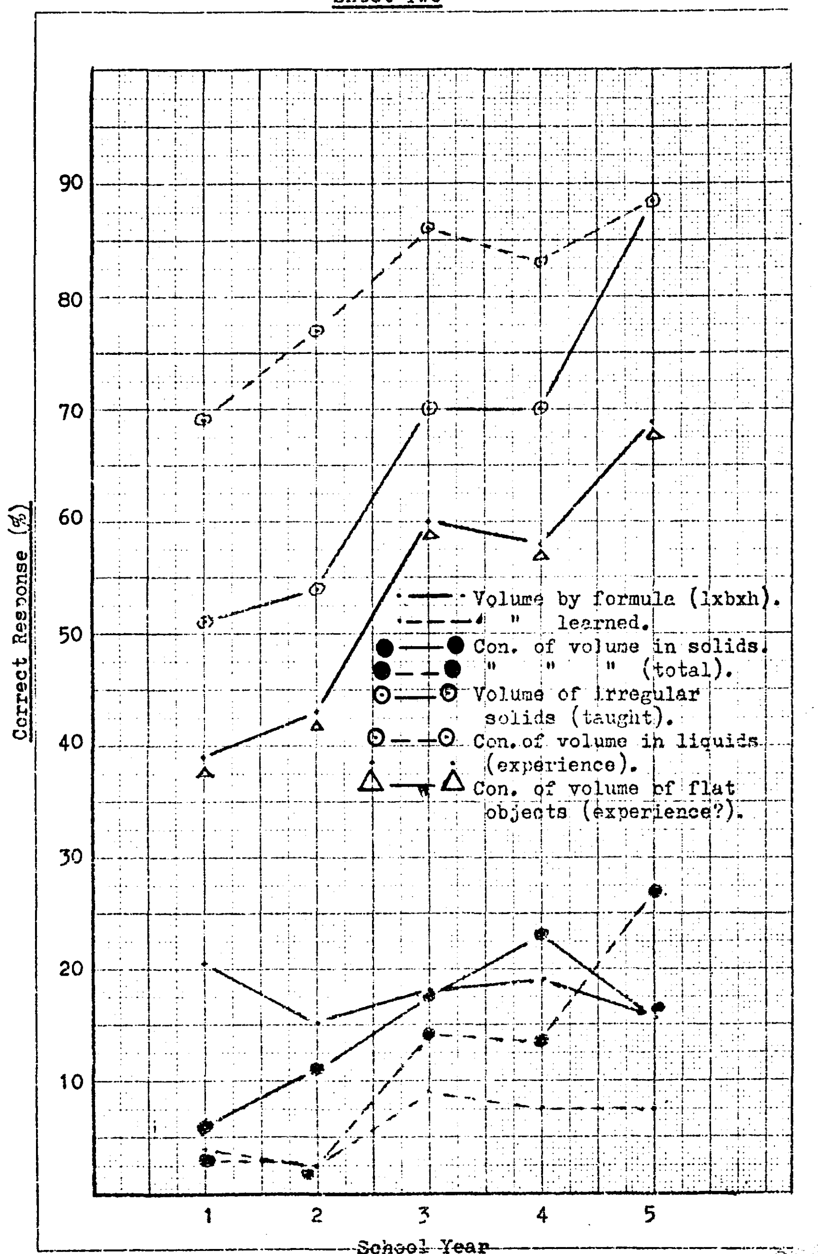


Figure 8

been taught how to find the volume of irregular objects. The answer D appears to increase with age almost linearly.

3. The third question is intended to look for the idea of conservation of volume in liquids. The pupils are presented with an equal amount of the liquid in three different containers of different sizes. The answer required is J and K which is strong and reveals that the pupils understand this idea clearly from the very beginning despite the fact that the conservation of volume in solids is not as well established.

4. The fourth question is a cross-check on the conservation of volume in solids in question one. Pupils are presented with a thin sheet of metal in different forms. FG was the answer sought but even at the 5th form, all the pupils did not attempt this choice. The pattern of scores is more or less the same as that of the scores for ABEH in question one.

The results of this sheet are shown in Figure 8. In this figure, four areas show a gradual improvement with age and three areas showed slow and non-linear changes, presumably due to the format of the question. The areas of gradual improvement are: conservation of volume, volume of irregular solids, conservation of volume in liquids and conservation of volume of flat objects. The areas of non-linear change are: volume by formula, volume learned and conservation of volume in solids.

(c) Sheet Three.

1. The first question is a cross-check on the first question (volume part) in Sheet Two. The answer D reveals that pupils have knowledge about volume. Almost all pupils

Sheet Three

Please look at Sheet Three and answer the following items.

1. In pictures A and D, which object has the greater volume?
2. In pictures F and H, which object is heavier?
3. If you want to compare the density of copper, aluminium and lead, which three blocks would you weigh?
4. Look at the irregular objects in the liquids in pictures B, C and G. In which of the pictures is the object more dense than oil?
5. Which of the objects in pictures A and E is more dense?
6. Which picture shows the table containing the materials arranged in the order of least dense to most dense?
7. Which pictures contain the material having the same density as that in picture I?

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have marked this choice.

2. The second question is trying to establish if the pupils have any ideas about mass-volume relationship and about heaviness of the material, i.e. they know the term 'heavy'. Here, they are presented with two different cubes of the same material - aluminium. The answer F is strong and is seen marked almost by all pupils.

3. The third question is attempting to establish the idea that equal volumes are needed for fair comparison. The answer AEF is seen to increase with age almost linearly.

4. The fourth question is intended to look for the idea of dense material. The answer required is B and C, but this is weak up to 5th year and even then it is by no means accepted completely. However about 40% chose B, revealing that they had some idea about dense material. About 30% chose G, revealing that they have no clear idea about dense material.

5. The fifth question is a cross-check on question four. It is intended to see if the pupils have any idea about the dense material belonging to the same physical state. Here they are presented with an equal volume situation. The answer E is seen to increase gradually and it is almost linear.

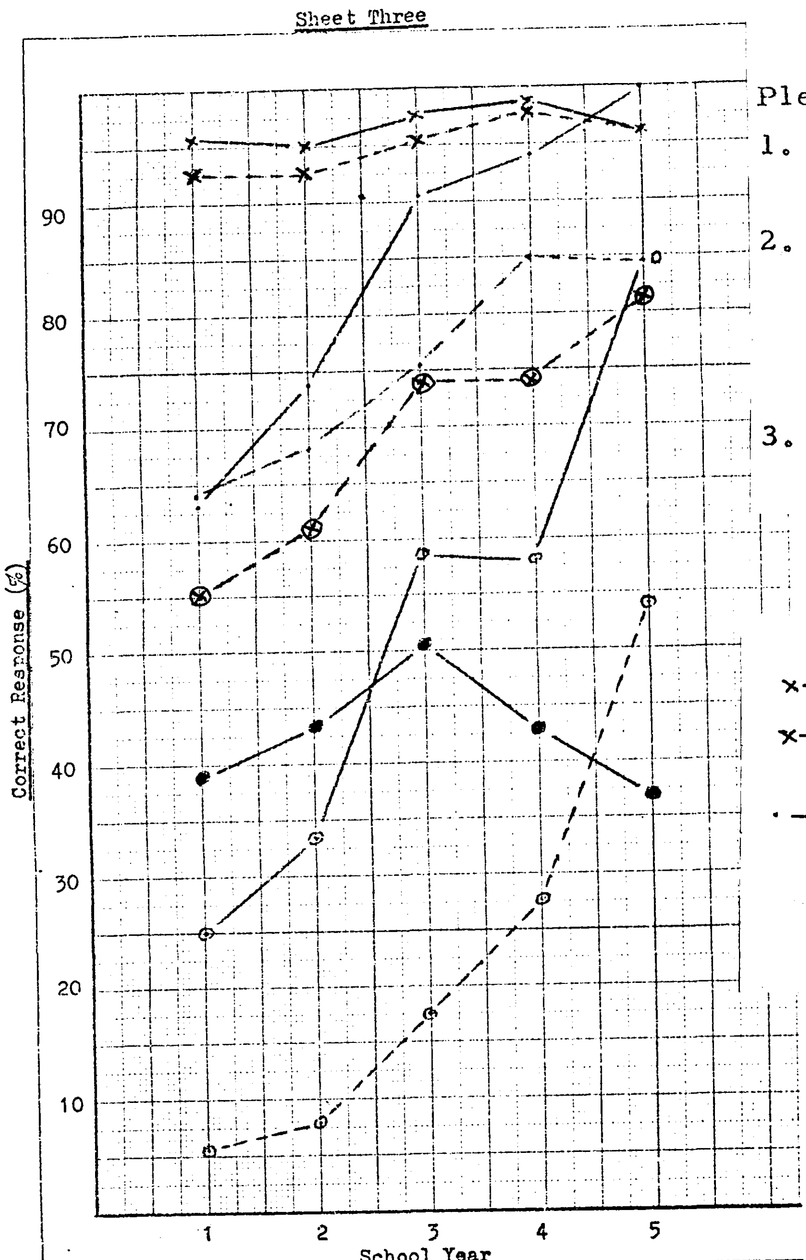
6. The sixth question is a cross-check on the fifth question. Here pupils are presented with different solid material in two orders to establish if they have a knowledge of common dense materials. The answer L is seen to increase with age almost linearly and its pattern of scores is almost the same as that of question 5.

7. This seventh question is intended to establish if

Sheet Four

Please look at Sheet Four and answer the following items.

1. Which objects in the picture will have the same density as the piece of plasticine shown in picture P?
2. Pictures M, N and O show three boxes, all of the same size. M is full of solid wax, N is full of liquid wax, and O is full of wax vapour. Which of these three boxes contains the least dense material?
3. Which object(s) will have the same density as the piece of polystyrene shown in picture S?



Sheet Three

x——x Knowledge about volume.

x- - - -x Mass-volume relationship and idea of heavy.

· ——— · Equal volumes needed for fair comparison in density.

●——● Partial idea about dense material.

⊙- - -⊙ Correct idea about dense material.

· - - - - · Idea about dense material.

⊗- - -⊗ " "

⊙——⊙ Correct idea about density.

Figure 9

the pupils have any clear feeling for density. They are presented with the same material in different sizes and shapes. The answer A+D is seen to increase with age almost linearly.

The results of this sheet are shown in Figure 9. In this figure five areas show a gradual and almost linear change, presumably as a result of experience of everyday things, while two areas show a marked improvement with age and with the reappearance of formal teaching in fifth year. The areas of gradual change are: knowledge about volume, mass-volume relationship, equal volumes needed for fair comparison, idea about common dense material. The areas of marked improvement are: correct idea about dense material, and correct idea about density.

(d) Sheet Four.

1. The first question is attempting to establish that the shape of material does not interfere with the density. The answer required is Q and R, which is strong from the very beginning and is well attempted by the pupils. However, since each is marked "50g" they may simply be equating 'mass' and 'density'. (See question 3.)

2. The second question is in fact the converse of question two in Sheet One. Here it is to establish that the physical state of a given amount of substance affects its density. The answer required is O, which is strong from the very beginning and is seen to increase with age almost linearly.

3. The third question is attempting to establish that the volume and shape of substance does not affect the density. This is also a cross-check on question seven in

Table 4.6.2

Showing the summary of interview information and test results of concept of density.

A. Interview Information

School	Class	Concept of mass	Units etc.	Nature of ind. particles	Concept of volume (regular) bodies	Concept of volume (irregular bodies	Idea of conservation of volume in solids	Idea of conservation of volume in liquids	Idea of heavy material	Mass-volume relationship	Idea of dense material	Idea of equal volumes needed for fair comparison	Concept of density
I	1st Year	Not completely clear	Clear	Clear	Clear	Clear	Clear	Not completely clear	Clear	Clear	Not completely clear	Not completely clear	Clear to one-third pupils
	2nd "	"	"	"	"	"	"	Clear	"	"	"	"	"
II	1st "	"	"	"	"	"	"	"	"	"	"	"	"
	2nd "	"	"	"	"	"	"	"	"	"	"	Clear	"
	3rd "	Clear	"	"	"	"	"	"	"	"	Clear	"	Clear to two-thirds pupils

B. Test Results (%)

		AC			Mean of AB + ABD	D	ABEH	JK	F	F	E	AEF	AD
	I	46.3			12.3	51.2	6.3	69.2	92.7	92.7	64.1	63.2	25.0
	II	49.1			9.0	54.1	10.9	76.9	92.8	92.8	68.3	74.0	33.7
	III	71.3			13.7	70.2	17.5	86.2	95.5	95.5	75.4	90.0	59.3
	IV	69.8			13.3	70.2	23.3	82.9	98.0	98.0	85.3	93.9	58.0
	V	96.1			11.6	88.5	15.4	88.5	96.2	96.2	84.6	100.0	84.6

Sheet Four

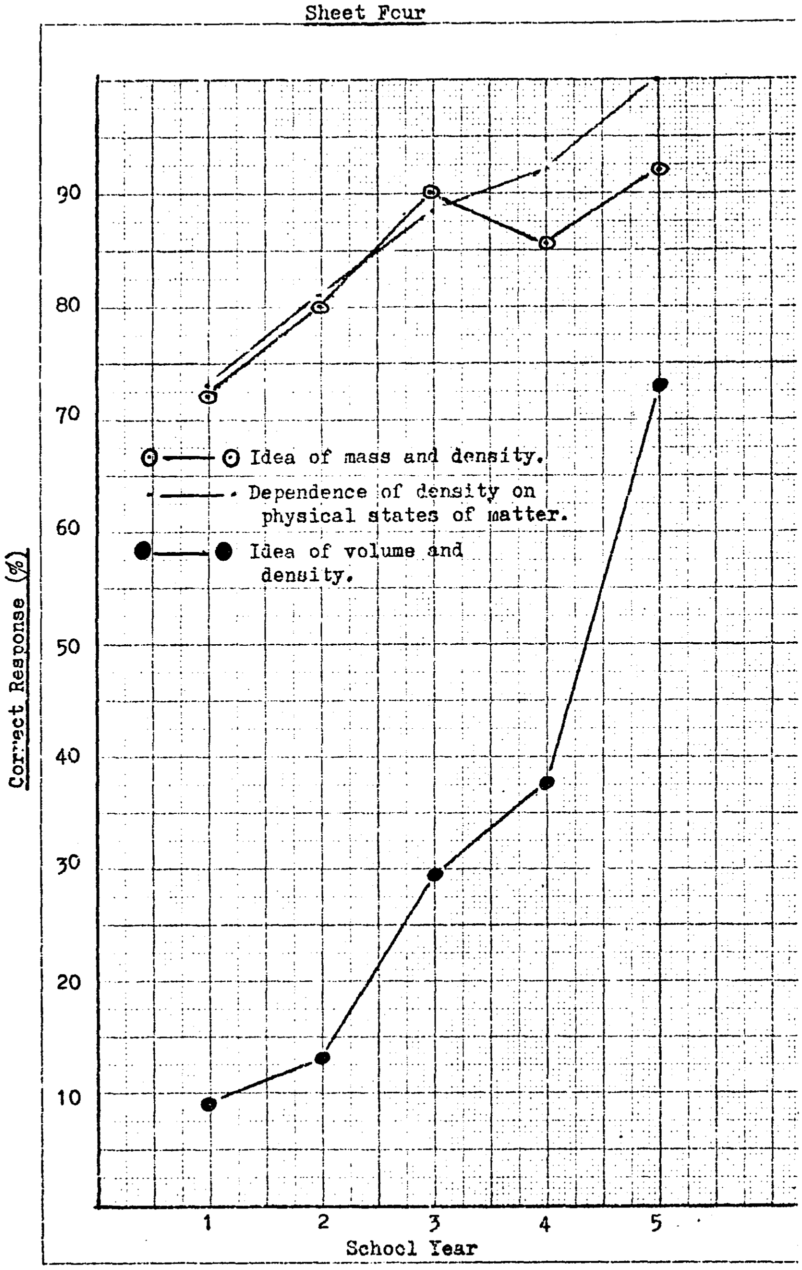


Figure 10

Sheet Three. The answer required is T and U. Despite the fact that T and U are both marked with volume units, about two-thirds of the pupils have chosen U, i.e. one obvious shape having the same volume units as S. To some extent it is rectified at 5th year, but even at 5th year not all pupils were marking the choice TU.

The results of this sheet are shown in Figure 10. In this figure, two areas show a gradual and almost linear change presumably due to experience of daily life, while one area shows a marked improvement with age and with the reappearance of formal teaching in 5th year. The areas of gradual change are: mass and density, physical states and density. The area of marked improvement is volume and density.

A general summary showing the results of the interview and the test is given in Table 4.6.2. By comparing both results it is revealed that for the concept of mass, the test results agree with interview information. As there were no direct questions asked about units and the nature of individual particles, these columns are left vacant in the test portion of the summary. However, indirectly, the results of item 3 (Sheet One) and items 2 and 3 (Sheet Four) reveal that pupils have fairly clear ideas about units. Similarly, item 1 (Sheet One) and items 1, 2 and 5 (Sheet Three) show that the pupils are well versed in the nature of individual particles.

Regarding the understanding of volume of regular bodies and conservation of volume in solids and total conservation of volume, it is observed that the test results do not agree with the interview results. In the view of the researcher, this disagreement is due to the format of question and also the pictures drawn for this question. It seems that question one is ambiguous and complex. It would be better if separate questions were asked for these items and also the pictures drawn would be simpler and clearer so that the pupils could understand the question easily. There is a good agreement between both the results for the volume of irregular objects and the conservation of volume in liquids.

There is a good agreement between test results and interview information for the term 'heavy' and also for heavy material.

Regarding the idea of dense material and the term dense, there is fair agreement between test and interview results.

There is a good agreement between the test results and the interview information regarding the mass-volume relationship.

Regarding the idea that equal volumes are needed for fair comparison, there is fair agreement between both results.

There is fair agreement between both of the results for the understanding of idea of density.

4.8. Conclusion.

After going through the discussion, the researcher arrives at the following conclusions:

1. The intuitive feeling for density increases with age.

2. The concept of mass is not completely clear to first and second year pupils. These pupils also think that mass does not remain constant in the different physical states of matter. However, both these ideas start improving during the third year.

3. Due to formal teaching and constant use in everyday life, the units and dimensions are clear to the pupils from the very beginning.

4. The nature of individual particles is also clear to the pupils of all classes.

5. The concept of volume and conservation of volume is clear to the pupils of all classes.

6. The mass-volume relationship is clear to the pupils of all classes.

7. Pupils of all classes know about the terms 'heavy' and 'dense', and in turn know about the nature of matter. They are more clear about the term 'heavy' than 'dense'.

8. The idea that equal volumes are needed for fair comparison is clear to all pupils.

9. The concept of density is not clear to the pupils of first and second year classes. Though there is intuitive feeling for density in these classes, but perhaps due to teaching of the concept at a premature stage, the pupils are seen to be unable to grasp the idea. However, the improvement in understanding of the idea begins in the third year class. The idea seems to improve markedly at higher levels.

10. From the test results, it is observed that the mass and the physical states of matter do not create confusion in understanding the idea of density. However, the volume of the objects creates difficulty in understanding the idea of density.

11. After comparing the test results with the interview results, it seems that there is a good agreement between the results of both techniques and, to a large extent, the test has worked effectively and has shown its validity. However,

due to the format of questions in Sheet Two, and the pictures of question 4 in Sheet Three, there seems some disagreement, which can be removed by modifying these questions as suggested in previous pages.

12. It is also concluded that as this new idea of test technique is simple and valid, it can be used not only in physics education, but even in other branches of science education.

APPENDIX 4.5.(a)

Interview schedule for the concept of density.

I. Mass.

1. (Showing a piece of plasticine) What is meant by mass?

2. How would you find the mass of this?

3. In what units would this be measured?

4. What is mass?

(Showing two cubes of copper of $1cm^3$ and $8cm^3$)

5. Which is heavier?

6. Why ($8cm^3$ cube) has it got more mass?

II. Volume.

(Showing same cubes)

7. Apart from mass, what can we measure of these cubes?

8. How would you measure their volume?

(Showing a cuboid)

9. How would you measure the volume of that?

10. What will be the unit of volume?

(Showing a piece of irregular solid)

11. How would you measure the volume of that?

12. In what units would you measure its volume?

13. What is volume?

(Showing cubes of polystyrene and metal)

14. What has got more volume?

(By pouring all the water from a big beaker into a small beaker and measuring jar)

15. Is there more water in that (small beaker) or that (measuring jar) or less, or the same amount as original?

(Showing a piece of plasticine in different shapes)

16. Now?

III. Density.

(Giving two cubes of same volume and of lead and zinc)

18. Which has bigger volume?

19. Which is heavier?

(Showing and giving cubes of wood and aluminium, both of same mass but of different volume)

20. Which is heavier?

21. Which has bigger volume?

22. If we want to compare these, how could we make a fair comparison?

23. What term would we use when we compare the masses of equal volumes?

24. Which of these cubes has got greater density?

25. Why has it got greater density?

(Showing $1cm^3$ and $8cm^3$ cubes of copper)

26. Which is heavier?

27. Which is more dense?

(Showing copper wire along with the cubes)

28. Which is denser?

APPENDIX 4.5.(b)

Showing list of pupils, their years in school, C.A., I.Q., and M.A.

School 1

Year	Code letter used for pupil	Rank in class	C. A.		I.Q.	M.A.
			Years	Months		
1st Year	A	Top	13	7	140	16.0+
" "	B	"	14	6	-	-
" "	C	Middle	13	2	111	14.6
" "	D	"	12	9	111	14.2
" "	E	Lower	12	9	109	13.9
" "	F	"	12	7	101	12.7
2nd Year	A	Top	13	7	126	16.0+
" "	B	"	14	2	-	-
" "	C	Middle	14	0	116	16.0+
" "	D	"	14	3	115	16.0+
" "	E	Lower	14	4	105	15.1
" "	F	"	13	11	96	13.4

School 2

1st Year	A	Top	13	0	134	16.0+
" "	B	"	12	2	135	16.0+
" "	C	Middle	12	9	120	15.3
" "	D	"	12	9	112	14.3
" "	E	Lower	12	8	109	13.8
" "	F	"	13	2	97	12.8
2nd Year	A	Top	14	0	138	16.0+
" "	B	"	14	7	119	16.0+
" "	C	Middle	14	4	119	16.0+
" "	D	"	13	5	122	16.0+
" "	E	Lower	14	2	91	12.9
" "	F	"	13	11	99	13.8
3rd Year	A	Top	15	0	140	16.0+
" "	B	"	15	3	126	16.0+
" "	C	Middle	15	0	110	16.0+
" "	D	"	16	5	108	16.0+
" "	E	Lower	14	7	115	16.0+
" "	F	"	15	1	100	15.1

APPENDIX 4.5.(c)

Full details of interview conducted with first year pupils of school one.

I. Mass.

T: (Showing a piece of plasticine) If I say plasticine has mass, do you know what I mean by that?

F: Weight.

T: Weight and mass are the same. O.K. How to measure the mass of that?

C: Put it on balance.

T: What are the units now we use?

E: Kg or g.

T: What do I mean by mass?
(After some effort, the pupils grasp this question.)

B: The real amount of the weight.

T: What is mass, in your idea?

A: The weight of the units in it.

(Showing two pieces of different masses)

T: Why is one 100g and the other 50g?

D: Particles are denser.

(Showing two cubes of copper of $1cm^3$ and $8cm^3$)

T: Which is heavier?

C: (Pointing towards $8cm^3$ cube) That one. It has got more mass and is heavier.

T: Why has it got more mass?

C: It is bigger.

D: It has more mass because it has more weight.

II. Volume.

T: Same cubes, something else which we can measure with regard to this, not just putting it on balance?

A: Volume.

T: How would you measure the volume of that? (Pointing towards one cube)

D: Take the mass.

B: L x B x H.

(Showing cuboid)

T: How would you measure the volume of that object?

F: Same.

T: What will be the unit of volume?

E: cm^3, m^3.

(Showing a piece of irregular solid)

T: Has that got volume?

F: Yes.

T: What units would you measure it in?

F: cms.

C: Cubic cms.

T: Can you imagine cm^3 in that?

All: No, I am not sure.

(Showing cylinder)

T: Has that volume?

All: Yes.

T: In what units would you measure that ?

B: cm^3.

(Showing a piece of coal)

T: How would you measure the volume of that?

B: By putting water in measuring cylinder and then noting down its level before putting it in and then the level after putting it in and taking the difference.

T: What is volume?

B: Space.

(Showing cubes of polystyrene and metal)

T: Which has got more mass?

F: Metal cube.

T: Which has got more volume?

F: Polystyrene cube.

(Putting water from big beaker into small beaker and measuring cylinder, and after showing them)

T: Is there more water in that, or that, or less, or the same amount as original?

C: Less in measuring cylinder.

B: Similar.

A: Same amount.

D: Less.

F: Less.

(Showing a piece of plasticine in different shapes)

T: Now?

All: Same.

III. Density.

(Showing two cubes: one of lead and the other of zinc)

T: What about these cubes?

All: Same size and volume.

T: What about their mass? Which is heavier?

C: Lead is heavy.

T: How would you make fair comparison between them?

No one replied.

(Showing cubes of wood and aluminium, both having same mass and different volume)

T: How would you compare them?

No pupil replied.

T: What about their colours?

C: (Pointing towards wooden cube) It is brown.

D: (Pointing towards wooden cube) It is bigger.

(Showing copper and aluminium cubes of different volumes)

T: What about these?

B: Copper cube is heavier and bigger.

T: If I want to have fair comparison between these two cubes, what would I have to do with this copper one?

C: Have the same volume of copper cube as that of aluminium cube.

T: What term do we use when we compare the masses of equal volumes?

B: Density.

(Pointing towards the same cubes)

T: Which is heavier?

F: Copper.

T: Why has it got greater density?

C: Particles are close together.

E: Particles are heavy.

(Showing $1cm^3$ and $8cm^3$ cubes of copper)

T: Which is heavier?

E: $8cm^3$ cube.

T: Which is more dense?

B: Both the same.

(Showing two different cubes of copper)

T: Now?

C: Again, same.

T: Why should these both be the same?

B: Because both are of copper.

(Showing copper wire and cubes of copper)

T: Which is denser?

A: Same.

C: Copper wire might be denser because it is changed into wire.

D: I am not sure, it might have the same density. I don't think it is so.

T: Could it be more?

E: Possible.

Note: Here T stands for interviewer who was not class teacher or teacher from school. A, B, C, D, E and F are codes for six pupils selected for the interviews. Their details are given in Appendix 4.5.(b)

APPENDIX 4.5.(d)

Analysis of the interviews of the various pupils in two schools.

1. School One

First Year Pupils

I. Mass.

1. The pupils knew mass as weight.

2. They knew how to measure the mass and also knew its units.

3. They were not clear on 'what is mass'.

II. Volume.

1. The word volume was known to pupils.

2. They knew how to find the volume of regular and irregular solid objects.

3. They knew the units of volume.

4. They defined volume clearly.

5. They knew the conservation of volume in solid and liquid objects.

III. Density

A. Cubes of same volume, different material.

1. Pupils knew about heaviness and knew that same volumes had different masses.

B. Cubes of same mass, different volume and material.

1. Pupils recognized that the cubes had same mass but were of different material and volumes.

C. Cubes of different mass, volume and material.

1. Pupils knew that these were different in all respects, and also told that cube of bigger volume had more mass.

2. They told that cubes could be compared if they were of the same size.

3. One pupil told that word density could be used for such comparison.

D. Cubes of same material and different volume.

1. Pupils were clear about 'heavy' but were not clear about 'dense'.
2. Two-thirds of pupils, i.e. 66.8% did not know the idea of density.
3. They told that the objects having the different volumes and of the same material had different densities.
4. One-third of pupils, i.e. 33.4%, knew the idea of density.

Second Year Pupils

I. Mass.

1. The pupils knew about weight but not about mass.
2. They knew how to measure it and also knew its units.
3. They were not clear in 'what is mass'.

II. Volume.

1. The pupils knew the word volume.
2. They knew how to find the volume of regular and irregular solid objects.
3. They knew the units of volume.
4. After much effort, the pupils defined volume, otherwise they were clear in concept.
5. They knew the conservation of volume in solid and liquid objects.

III. Density

A. Cubes of same volume, different material.

1. Pupils knew about 'heaviness' and also knew that same volumes had different masses.

B. Cubes of same mass, different volume and material.

1. Pupils recognized that the cubes had same mass but were of different materials and volumes.

C. Cubes of different mass, volume and material.

1. Pupils knew that cubes were different in all respects.
2. They could not tell how fair comparison could be made between them.
3. Pupils told that the bigger cube had more mass.
4. Four pupils could not tell the word used for such comparison.

D. Cubes of same material and different volume.

1. Pupils were clear about 'heavy' but were not clear about 'dense'.
2. Two-thirds of pupils i.e. 66.8% did not know the idea of density.
3. They told that the objects having the different volumes and of the same material had different densities.
4. One-third of pupils i.e. 33.4% knew the idea of density.

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2. School Two

First Year Pupils

I. Mass.

1. The pupils knew about the weight but not about the mass.
2. They did not hear the word mass but knew how to find weight by balance.
3. They knew the units of mass.
4. They were not clear about 'what is mass'.

II Volume.

1. The word volume was known to pupils.
2. They knew how to find the volume of regular and irregular solid objects.

3. They knew the units of volume.

4. With much effort one pupil in six defined volume, otherwise they were clear in concept.

5. They knew very well about the conservation of volume in solid and liquid objects.

III. Density.

A. Cubes of same volume but different material.

1. Different materials had different masses. This was told by pupils. They also knew about the heaviness.

B. Cubes of same mass, different volume and different material.

1. Pupils recognized that cubes had same mass but different volume.

C. Cubes of different mass, volume, and material.

1. Pupils knew that cubes were different in all respects and also told that the bigger cube had more mass.

2. The pupils were clear in understanding that these cubes could be compared fairly if they were of the same size, i.e. they would have the same volume.

3. Five pupils could not tell the word used for such comparison.

4. They did not know about density.

5. They told that the object was heavy because it had more particles than the other and the particles were also heavy.

D. Cubes of same material but of different volume.

1. Pupils were clear about 'heavy' but were not clear about 'dense'.

2. Two-thirds of pupils, i.e. 66.8% did not know the idea of density. They informed that the objects having different volumes and of the same material had different densities.

3. One-third of pupils, i.e. 33.4% knew the idea of density.

Second Year Pupils

I. Mass.

1. The pupils knew about weight but not about mass.
2. They knew about the units of mass.
3. They did not know how to measure the mass.
4. They were not clear about 'what is mass'.

II. Volume.

1. The word volume was known to pupils.
2. They knew how to find the volume of regular and irregular solid objects.
3. They knew the units of volume.
4. After much effort, pupils defined volume, otherwise they were clear in concept.
5. They knew conservation of volume in solids and liquids.

III. Density.

A. Cubes of same volume but different material.

   1. Pupils knew that different materials have different masses. They also knew about heaviness.

B. Cubes of same mass, different volume and material.

   1. Pupils recognized that cubes had same mass but had different volume.

C. Cubes of different mass, volume and material.

   1. Pupils told the bigger cube had more mass.
   2. Pupils were not clear in making fair comparison between the cubes. Some pupils told "to compare them make both cubes of same mass". Others told, "make both cubes of same size".
   3. Four pupils could not tell the word used for such comparison.
   4. They did not know about density.
   5. They told that the object was heavy because it consisted of heavy particles and the particles were close together.

D. Cubes of same material but of different volume.

1. Pupils were clear about 'heavy' but were not clear about 'dense'.
2. Two-thirds of pupils did not know the idea of density.
3. They told that these objects had different densities.
4. One-third of pupils, i.e. 33.4% knew the idea of density.

Third Year Pupils

I. Mass.

1. The pupils knew about mass.
2. They knew the units of mass.
3. They knew how to measure mass.
4. They were clear about 'what is mass'.

II. Volume.

1. The pupils knew how to find out the volume.
2. They knew the units of volume.
3. They defined volume clearly.
4. They knew conservation of volume in solids and liquids.

III. Density.

A. Cubes of same volume, different material.

1. Pupils knew that different materials have different mass and also knew about 'heaviness'.

B. Cubes of same mass, different volume and material.

1. Pupils recognized that cubes had same mass but different volume.

C. Cubes of different mass, volume and material.

1. For making fair comparison among the cubes, they should be of the same volume.
2. Two pupils could not tell the word used for such comparison.

D. Cubes of same material, different volume.

1. Pupils knew about the difference between 'heavy' and dense.
2. One-third of pupils, i.e. 33.4% did not know the idea of density.
3. Two-thirds of pupils, i.e. 66.8% knew the idea of density.
4. About the objects of the same material and having different volume, the pupils told that these had the same density.
5. They also told that the dense object consisted of heavy particles which were closely packed.

APPENDIX 4.6.(a)

Showing test specifications and item specifications.

I. Test Specifications

Piaget's and Bloom's levels

A. Piaget's levels

Piaget level	Sheet One		Sheet Two		Sheets Three & Four	
	No. of items	Weightage (%)	No. of items	Weightage (%)	No. of items	Weightage (%)
Concrete (2A)	1	25.0	-	-	-	-
" (2B)	3	75.0	2	50.0	2	20.0
Formal (3A)	-	-	2	50.0	1	10.0
" (3B)	-	-	-	-	7	70.0
Total	4	100.0	4	100.0	10	100.0

B. Bloom's levels

Bloom level	Sheet One		Sheet Two		Sheets Three & Four	
	No. of items	Weightage (%)	No. of items	Weightage (%)	No. of items	Weightage (%)
Knowledge (B1)	2	50.0	1	25.0	2	20.0
Comprehension(B2)	-	-	1	25.0	4	40.0
Application(B3)	2	50.0	2	50.0	4	40.0
Total	4	100.0	4	100.0	10	100.0

II. Item Specifications

Question No.	Sheet One	Sheet Two	Sheet Three	Sheet Four
1	2A-B1	2B-B1	2B-B1	3B-B2
2	2B-B1	2B-B3	2B-B2	3B-B3
3	2B-B3	3A-B2	3A-B2	3B-B3
4	2B-B3	3A-B3	3B-B3	
5			3B-B2	
6			3B-B1	
7			3B-B3	

APPENDIX 4.6.(b)

UNIVERSITY OF GLASGOW

SCIENCE EDUCATION DEPARTMENT

Test One

This is a new form of testing: I would like to have your help. We have chosen a fairly elementary part of physics to try this method.

You will need to examine pictures in a grid and your answers will consist of a letter or several letters, which appear in the bottom right-hand corner of each cell in the grid.

For example in Sheet One, if you are asked to pick out the cubes, your answer would be A, H and J.

Now let's look at Sheet One in detail and follow the others in the same way.

Sheet One

Please look at Sheet One and answer the following items.

1. In pictures H and J, there are two cubes. Which cube has the greater mass?
2. Look at pictures D, E and F. In which jar(s) will the contents have the same mass as the ice in jar D?
3. In pictures A, C and H, which two of the objects would have the same mass?
4. Which pair(s) of trollies will contain the same mass as the pair shown in picture B?

Sheet Two

Please look at Sheet Two and answer the following items.

1. Choose from this grid all the pictures in which the object has a volume of $8cm^3$.
2. Choose the picture from this grid which shows "how to find out the volume of irregular solid".
3. Choose the picture(s) in which there is the same volume of water as shown in picture I.
4. In which picture(s) will the object have the same volume as the object shown in picture C.

Sheet Three

Please look at Sheet Three and answer the following items.

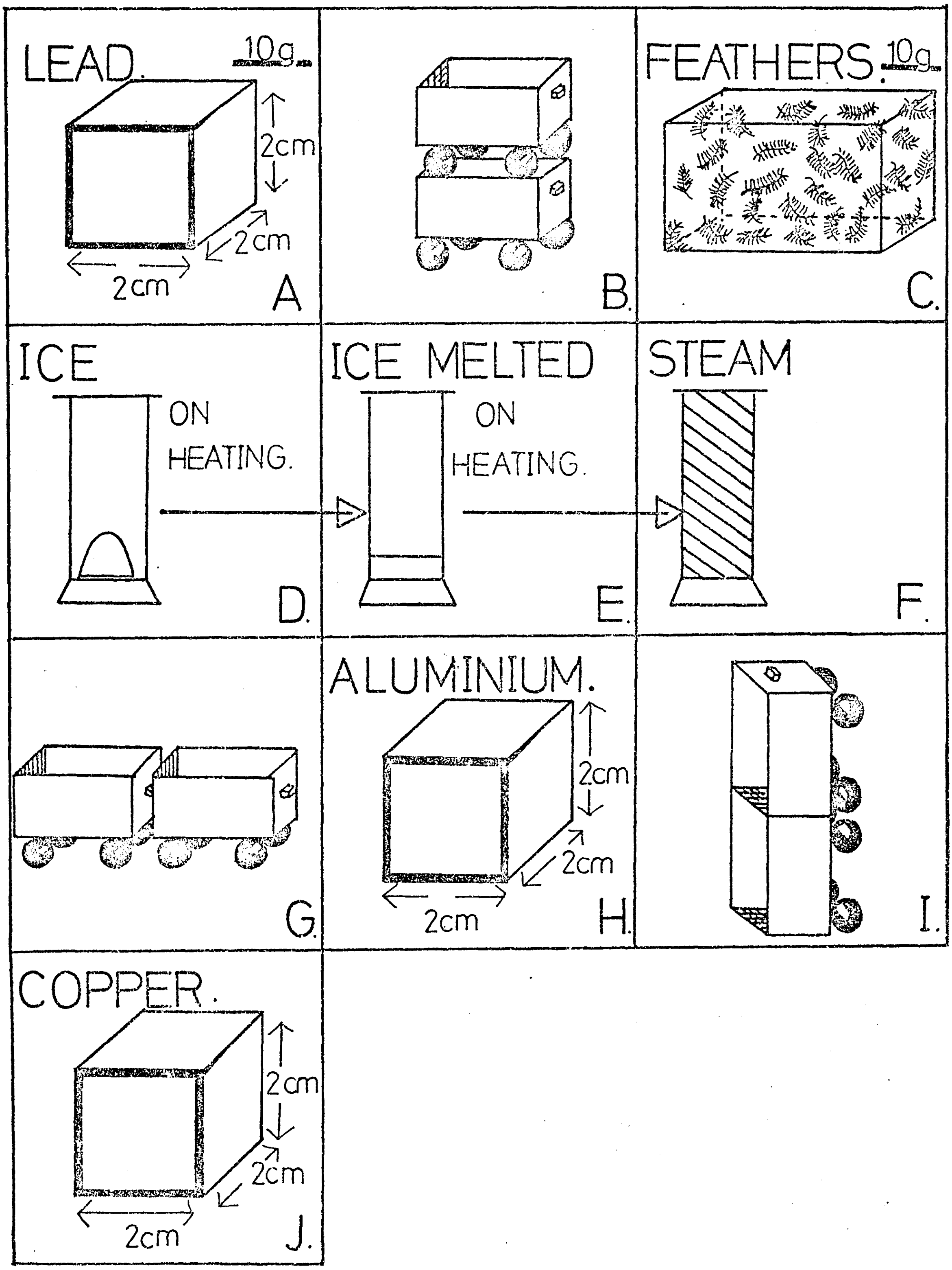
1. In pictures A and D, which object has the greater volume?
2. In pictures F and H, which object is heavier?
3. If you want to compare the density of copper, aluminium and lead, which three blocks would you weigh?
4. Look at the irregular objects in the liquids in pictures B, C and G. In which of the pictures is the object more dense than oil?
5. Which of the objects in pictures A and E is more dense?
6. Which picture shows the table containing the materials arranged in the order of least dense to most dense?
7. Which pictures contain the material having the same density as that in picture I?

Sheet Four

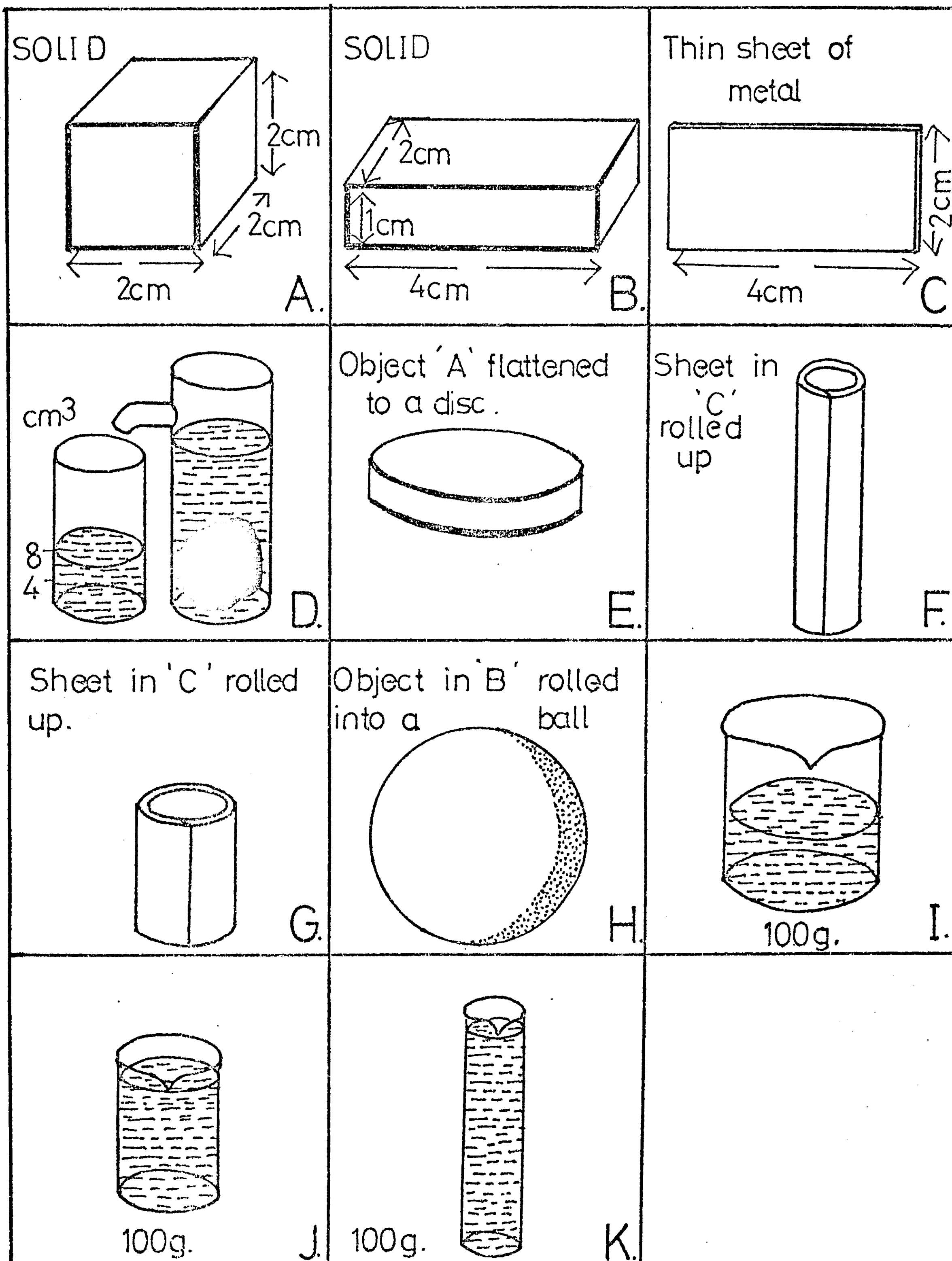
Please look at Sheet Four and answer the following items.

1. Which objects in the picture will have the same density as the piece of plasticine shown in picture P?
2. Pictures M, N and O show three boxes, all of the same size. M is full of solid wax, N is full of liquid wax, and O is full of wax vapour. Which of these three boxes contains the least dense material?
3. Which object(s) will have the same density as the piece of polystyrene shown in picture S?

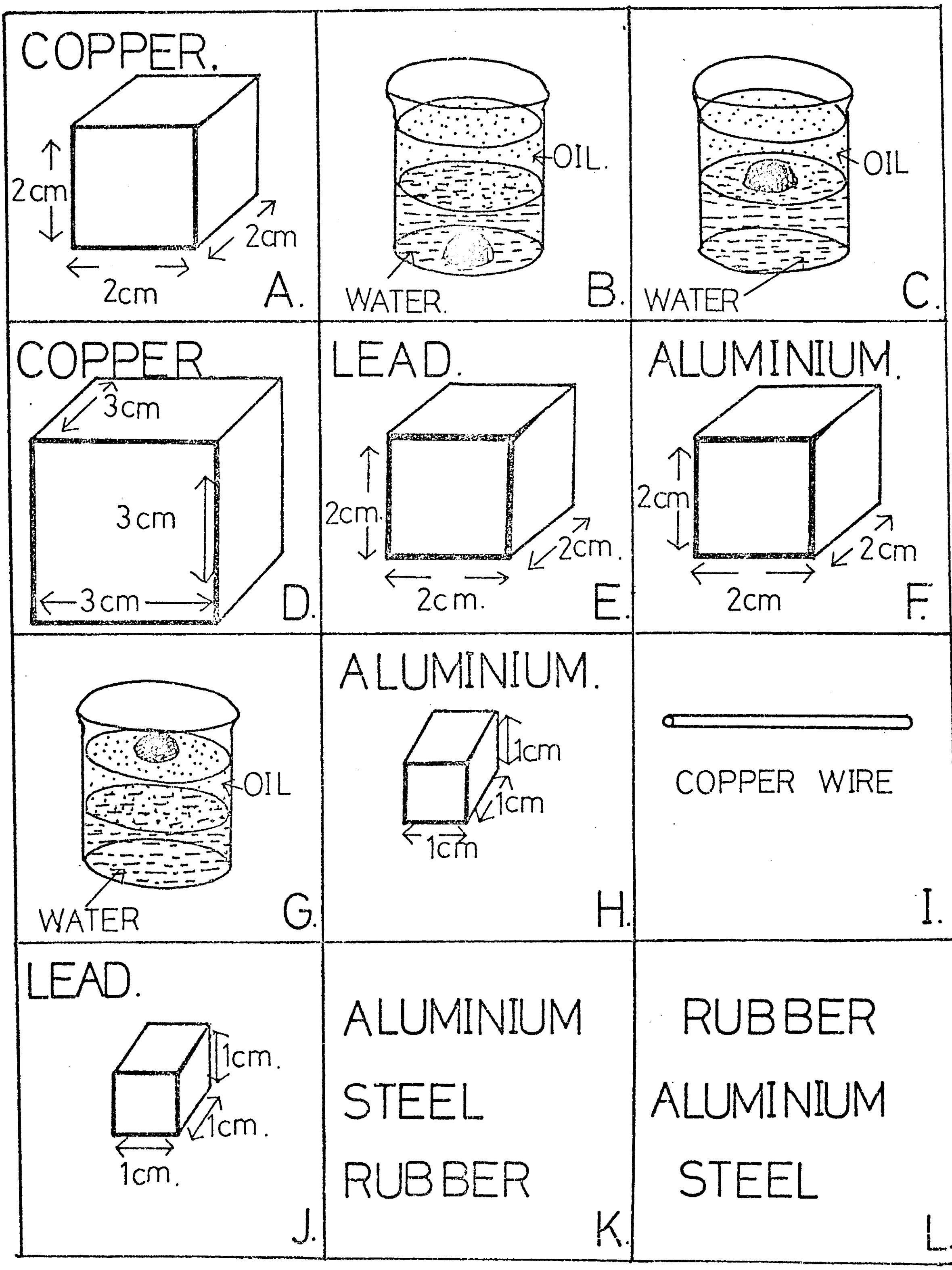
Sheet 1.


LEAD.
10g.
2cm
2cm
2cm
A
B.
FEATHERS.
10g.
C.
ICE
ON HEATING.
D.
ICE MELTED
ON HEATING.
E.
STEAM
F.
G.
ALUMINIUM.
2cm
2cm
2cm
H.
I.
COPPER.
2cm
2cm
2cm
J.

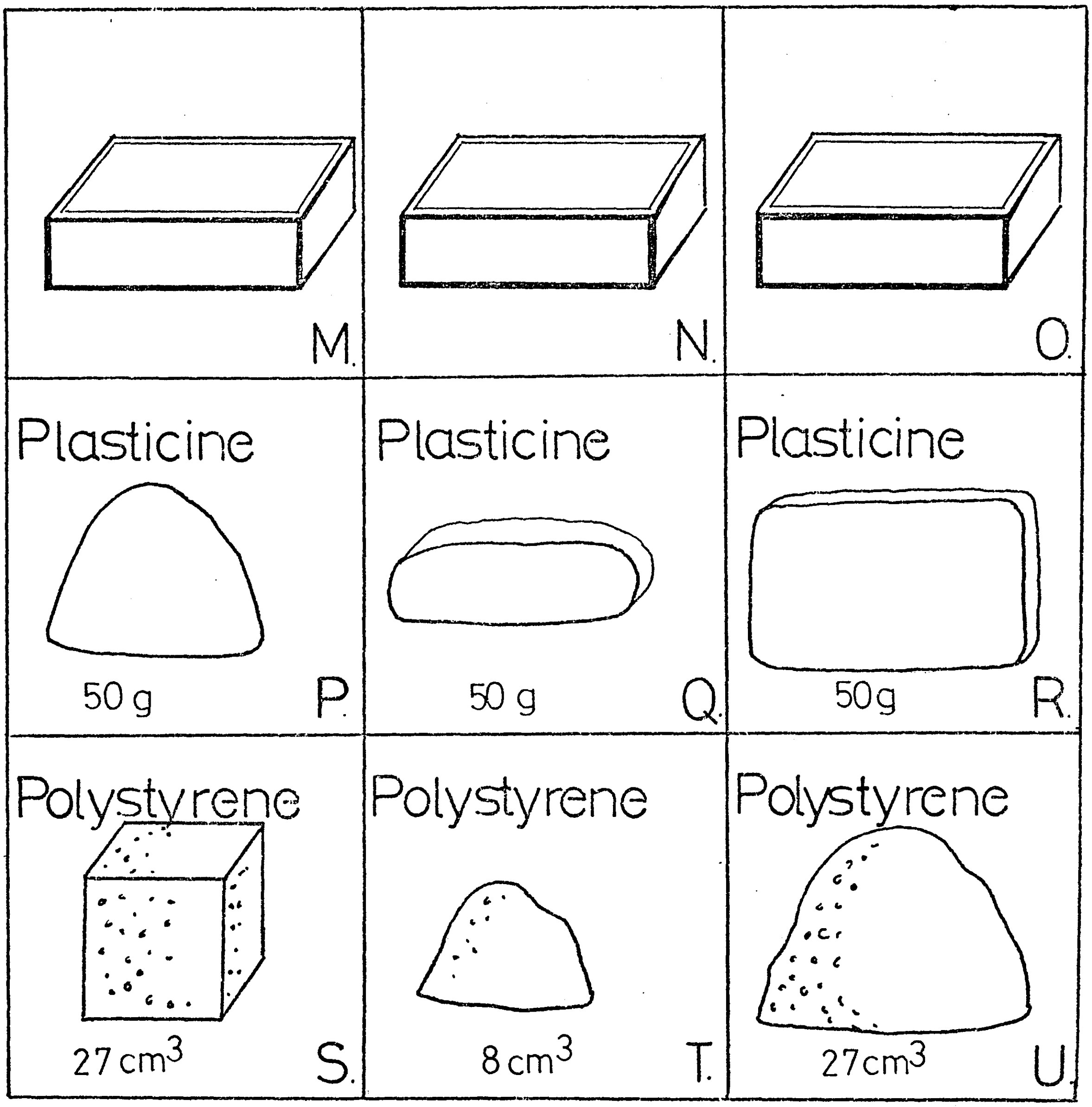
Sheet 2


SOLID
2cm
2cm
2cm
A.
SOLID
2cm
1cm
4cm
B.
Thin sheet of metal
2cm
4cm
C.
cm3
8
4
D.
Object 'A' flattened to a disc.
E.
Sheet in 'C' rolled up
F.
Sheet in 'C' rolled up.
G.
Object in 'B' rolled into a ball
H.
100g.
I.
100g.
J.
100g.
K.

Sheet 3


COPPER.
2cm
2cm
2cm
A.
OIL.
WATER.
B.
OIL
WATER
C.
COPPER
3cm
3cm
3cm
D.
LEAD.
2cm.
2cm.
2cm.
E.
ALUMINIUM.
2cm
2cm
2cm
F.
OIL
WATER
G.
ALUMINIUM.
1cm
1cm
1cm
H.
COPPER WIRE
I.
LEAD.
1cm.
1cm.
1cm.
J.
ALUMINIUM
STEEL
RUBBER
K.
RUBBER
ALUMINIUM
STEEL
L.

Sheet 4


M.
N.
O.
Plasticine
50 g
P.
Plasticine
50 g
Q.
Plasticine
50g
R.
Polystyrene
27 cm³
S.
Polystyrene
8 cm³
T.
Polystyrene
27cm³
U.

Answer Sheet

Name ____________________

School ____________________

Class ____________________

Boy or girl ____________

Date of birth ____________________
date month year

Sheet 1

Item No. 1 ....
" " 2 ....
" " 3 ....
" " 4 ....

Sheet 2

Item No. 1 ....
" " 2 ....
" " 3 ....
" " 4 ....

Sheet 3

Item No. 1 ....
" " 2 ....
" " 3 ....
" " 4 ....

Item No. 5 ....
" " 6 ....
" " 7 ....

Sheet 4

Item No. 1 ....
" " 2 ....
" " 3 ....

APPENDIX 4.6.(c)

Explanation of Items of the Test.

Sheet One

Item 1. J - intuitive feeling for density - knowledge item.

Item 2. EF - mass is the same regardless of physical state.

Item 3. If AC - mass idea is correct. If AH, density idea is interfering with mass. If C - no idea.

Item 4. If GI - no confusion between mass and pressure.

Sheet Two

Item 1. If AB only, volume known by formula (l x b x h); if ABD, volume learned. If ABEH, conservation of volume in solids and if ABDEH, conservation of volume is clear.

Item 2. D - measurement of volume of irregular solids known.

Item 3. JK - conservation of volume in liquids known, and no confusion with height.

Item 4. GF - conservation of volume of flat bodies known. If F, height and if G, thickness are interfering.

Sheet Three

Item 1. D - knowledge about volume.

Item 2. F - mass-volume relationship clear and also idea of heaviness clear.

Item 3. AEF - idea of equal volumes needed for fair comparison clear.

Item 4. B, and BC - idea correct; C - only partial idea. If anything, including G, idea is not clear.

Item 5. E - idea of 'dense material' clear.

Item 6. General experience of density.

Item 7. If AD, shows complete understanding of density. Anything, idea not clear.

Sheet Four

Item 1. QR - ideas of mass and density clear - no interference of shape.

Item 2. Converse of DEF (Sheet One). If O, idea of density clear.

Item 3. TU - idea of density clear, no interference of volume. If T, volume is interfering and if U, shape is interfering.

C H A P T E R 5

HEAT AND TEMPERATURE

CHAPTER 5

HEAT AND TEMPERATURE

Energy is one of the fundamental concepts in physics. This concept can be studied and understood intelligently only after we have acquired a knowledge of mechanics. This energy, which is essentially movement of one form or another, manifests itself in various ways depending on how it is perceived by our senses. Heat is also one form of energy. It is considered as kinetic energy due to molecular motion.[124] When this kinetic energy contained in a body is measured, it gives rise to another important concept and that is temperature. According to E.M. Rogers (1960), the temperature is hotness measured on some definite scale.[49] G.R. Noakes (1953) has explained what is meant by measuring the temperature. He says: "We cannot in the strict sense of the word measure the temperature; temperature can be compared ... We usually observe differences in hotness not ratios between hotness and the practical measurement of temperature is thus really the comparison of temperature differences."[125]

In describing the degree to which heating has taken place, temperature does not describe the amount of heat contained in a body.[126] This view shows that heat and temperature are two different concepts and there exists a distinction between them. In the view of J.A. Ripley (1964) "It is necessary to keep these two concepts heat and temperature clearly distinguished. Temperature merely gives an indication of the direction in which what we call heat will flow. It does not itself measure the amount of heat in a material body... Amount of heat depends upon mass."[127] Nelkon and Parker (1958) have shown the difference between these two concepts in these words: "Roughly speaking, temperature is analogous to electrical potential and heat is analogous to quantity of electricity."[128] A.E.E. McKenzie (1956) sees the difference in this way, ".. heat corresponds to quantity of water and temperature to level."[129] All these statements support the above mentioned view that heat and temperature are two different concepts.

In this chapter work is done to study the growth of understanding these concepts and the difference between them. This unit was carried out over a period of two years in two stages.

5.1. <u>First Stage of the Unit.</u>

A. Design of the stage.

(i) Objectives of the stage were defined.

(ii) The material preparation: this unit consisted of (a) path diagram, (b) interview schedule.

(iii) The material application: the material was applied in 1975-76 session to the pupils of SII to SIV classes. The details of the above mentioned items are as follows.

B. Objectives of the stage.

To study the concepts of heat and temperature, the material was prepared with the following objectives in mind: to see the understanding of the pupils and so

(i) To study the concept of molecules.

(ii) To study the concept of energy.

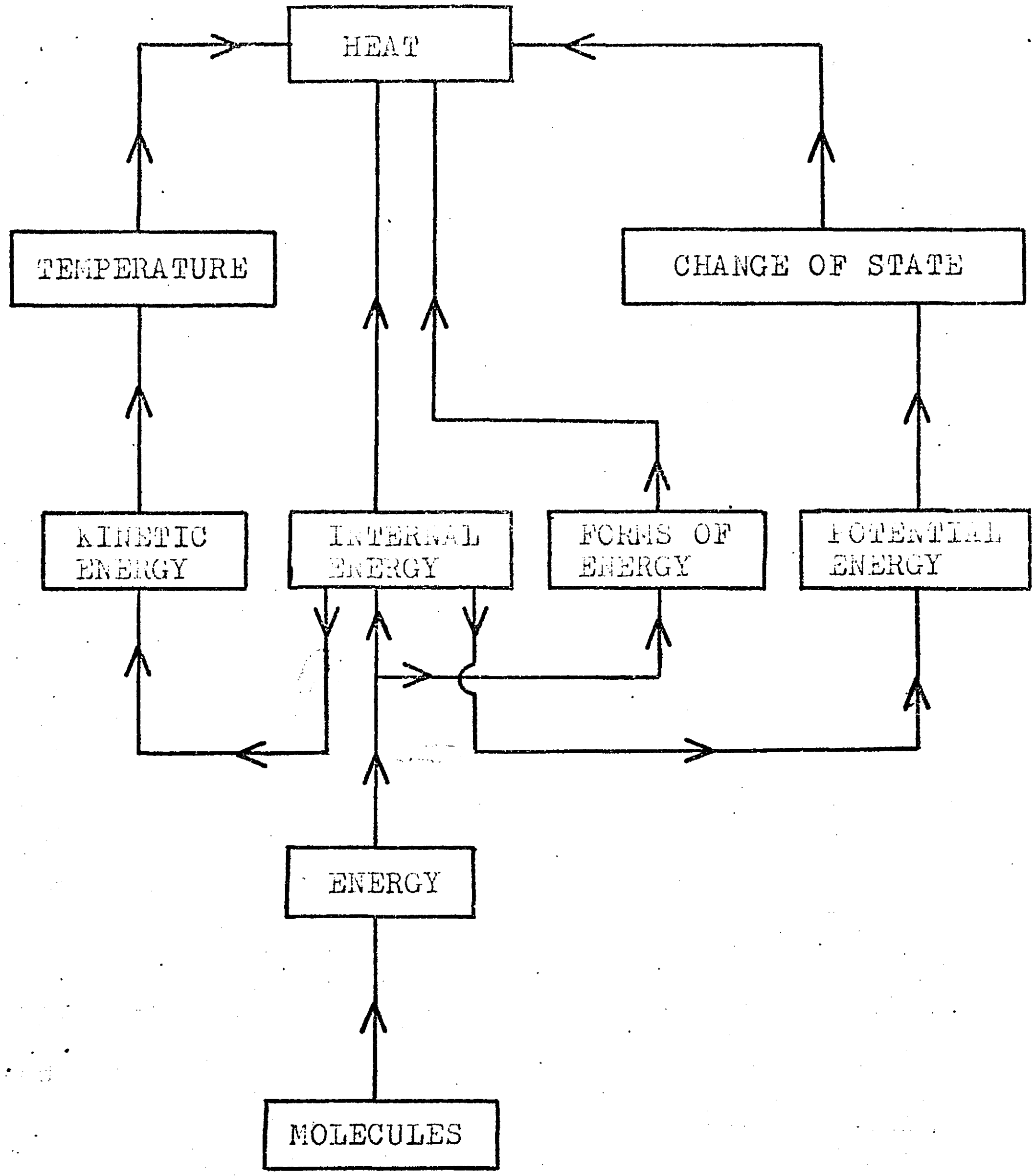


FIGURE 11

Path Diagram for the Concepts of Heat and Temperature.

(iii) To study the concept of internal energy.

(iv) To study the concepts of kinetic and potential energies.

(v) To study the change of state.

(vi) To study the concept of temperature.

(vii) To study the concept of heat energy.

(viii) To study the difference between heat and temperature.

C. Material structure.

Keeping in view the objectives of the unit, a net called a 'path diagram', was prepared for the study of the unit. The main parts of this path diagram are: molecules, energy, forms of energy, change of state, temperature and heat. This path diagram is shown in Figure 11. The purposes and way of working of this diagram are the same as mentioned in Section 4.5.C.

In the light of the path diagram, an interview schedule was prepared. The purposes and the procedure adopted for this interview schedule are also the same as mentioned for the interview schedule in Section 4.5.C. The interview schedule appears as Appendix 5.1.(a).

D. How the material was applied.

To collect the information in the same way as done in Section 4.5.D, the interview was given to the pupils of SII to SIV classes in two schools. Six pupils, comprising a cross-section of the class, participated. The information regarding these pupils is shown in Appendix 5.1.(b).

The same steps were followed in conducting and recording the interview as those which are mentioned in

Table 5.1.1

Showing the summary of the interview information.

School 2

Class	Idea about Molecules	Concept of Energy	Concept of Internal Energy	Idea of Kinetic Energy	Idea of Potential Energy	Concept of Temp-erature	Depend-ence of Temp-erature on Mass	Change of State	Concept of Heat Energy	Depend-ence of Heat on Mass	Differ-ence be-tween Heat & Temp. (small masses)	Difference between Heat and Temp. (large masses)
2nd Year	Clear	Not clear	Not clear	Clear	Clear	Not clear	Clear to one-third of pupils	Clear	Not clear	Clear to one-sixth of pupils	Clear to one-third of pupils	Clear to one-third of pupils
3rd "	"	"	"	"	"	Clear to half of the pupils	Clear to half of the pupils	"	Clear to one-third of pupils	Clear to half of the pupils	Clear to half of the pupils	Clear to half of the pupils
School 1												
3rd Year	Clear	Clear to one-sixth of pupils	Not clear	Clear	Clear	Clear to half of the pupils	Clear to half of the pupils	Clear	Clear to one-third of pupils	Clear to half of the pupils	Clear to half of the pupils	Clear to half of the pupils
4th "	Clear	"	"	"	"	Clear	Clear	"	Clear to two-thirds of pupils	Clear to two-thirds of pupils	Clear	Clear

Note: Generalized idea of energy is not clear but specific forms seemed clear.

Section 4.5.D.

In interview, the questions were put after showing the following material: (i) chunk of metal (iron), (ii) flask, (iii) ball-bearings of different sizes, (iv) ball, (v) different cubes of wood and lead, and (vi) different beakers containing different amounts of water.

The interview was conducted by a third person and the time taken was about 30 minutes. Full details of interview conducted in one class are shown in Appendix 5.1.(c).

E. Results.

After conducting the interview, the tapes recorded were heard and the information collected was analysed. The analysis of the interviews of the various pupils in two schools is shown in Appendix 5.1.(d).

Table 5.1.1 shows the summary of the information given by the pupils. The table confirms the trend of results mentioned in Chapters 3 and 4; and reveals that pupils' understanding of concepts and their difference, is consistent, and the general trend is that as we proceed from second year pupils to fourth year pupils, the number of pupils showing understanding of the concepts increases, i.e. the understanding of the concepts depends on the age level. When the age level increases, more growth takes place. For the concept of heat, it is revealed that rapid growth takes place in fourth year and this may be the proper natural level and age at which this concept be taught effectively. In practice, this is taught in third year. But understanding is postponed till fourth year. This is shown by the pupils in their answers given in the interview. For example, when they were asked "What is energy?", pupils of all classes mixed it either with force, or with work or with power. In fourth year, only one-sixth of the pupils replied "Energy can make the things happen." Similarly when they were asked "What is heat energy?", pupils of second and third years confused it either with light or with friction. In fourth year, two thirds of the pupils replied "that which makes the molecules faster." The number of pupils showing the understanding of the concepts, was more at fourth year level than the other two earlier classes.

5.2. The Second Stage of the Unit.

A. Design of the stage.

(i) Objectives of the second stage were defined.

(ii) The material preparation: this material consisted of a diagnostic test.

(iii) The material application: this material was applied in 1976-77 session, to the pupils of SII to Higher grade classes.

The details of the above mentioned items are as follows.

B. Objectives of the second stage.

The objectives of this stage remained the same except that one more objective was added and that is:

(ix) To study the validity of the new test introduced for the study of the concepts.

C. The material structure.

In the light of the views and recommendations mentioned in Section 4.3, a new diagnostic test was prepared.

It was a multiple choice test. This test was prepared to study three main concepts, i.e. energy, heat and temperature and also the difference between heat and temperature. In all, the test comprised 20 questions. The detail of distribution of questions is shown in Appendix 5.2.(a).

Keeping in view the purposes mentioned in Section 4.6.C the items were prepared according to Bloom's first three levels and developmental levels given by Piaget mentioned in the same section. The test specifications are shown in Appendix 5.2.(a) and the item specifications, key and explanation of items appear as Appendix 5.2.(c). The test appears as 'Test Two' in Appendix 5.2.(b).

D. How the material was applied.

In order to study the understanding of the pupils about these concepts and also to learn about their growth, the test was applied to 554 second year, 218 third year, 258 fourth year and 266 fifth year pupils in four schools during 1976-77.

As the design of the test used at this stage was changed, the technique of the data processing was also changed. This time, 'a computer mark sense card' method was used.

To reduce the management problems, the same measures were taken as mentioned in Section 3.6.D. Separate letters were issued to the principal teachers and a separate sheet of instructions was prepared for the subject teachers. The covering letter is shown as Appendix 5.2.(d) and the sheet of instructions appears as Appendix 5.2.(e).

E. Results.

Table 5.2.1

Showing facility values of the test items for 2nd to 5th Year pupils.

Item No.	2nd Year Mean: T1 +T2	3rd Year	4th Year	5th Year
1	0.56	0.53	0.78	0.80
2	0.66	0.73	0.79	0.82
3	0.24	0.26	0.32	0.56
4	0.35	0.27	0.26	0.19
5	0.47	0.67	0.78	0.83
6	0.66	0.61	0.72	0.83
7	0.52	0.43	0.50	0.53
8	0.31	0.42	0.52	0.76
9	0.31	0.33	0.53	0.75
10	0.49	0.45	0.52	0.50
11	0.22	0.22	0.45	0.48
12	0.48	0.56	0.77	0.80
13	0.40	0.45	0.68	0.73
14	0.50	0.51	0.69	0.69
15	0.10	0.04	0.05	0.12
16	0.21	0.28	0.29	0.39
17	0.42	0.37	0.49	0.61
18	0.24	0.25	0.33	0.46
19	0.25	0.32	0.36	0.44
20	0.25	0.24	0.29	0.42

The data of the test were processed by computer. The facility value (F.V.), the discriminatory factors and the frequency of the answers were computed for each item in the test. This whole description for second, third, fourth and fifth year pupils appears in Appendix 5.2.(f), 5.2.(g), 5.2.(h) and 5.2.(i) respectively.

As the second year pupils belonged to a mixed ability group, and since pupils from the two top groups (thirds) were expected to take physics in higher academic classes, so mean facility value of these two groups, i.e. T_1 and T_2 mentioned in Appendix 5.2.(f) were taken as the facility value for second year pupils so that their scores could be fairly compared with 3rd and subsequent years. The summary of the facility values of these four years is shown in Table 5.2.1.

5.3. Discussion

The unit was applied in two stages: (i) interview and (ii) test. To facilitate the discussion and to present the results of the questions in an 'easy to see' manner, the test questions are divided into four parts. Part I comprised the questions one to five, Part II: questions six to ten, Part III: questions eleven to fifteen and Part IV: questions sixteen to twenty. Let us look at each part.

Part I.

1. When solids are heated without melting, the molecules in the solid

A are in stationary positions.

B move around in different directions.

C vibrate more about their mean positions.

D circulate in an orderly fashion within the solid.

This first question is meant to learn about the state of molecules in a solid. Choice 'C' was the answer sought but even at fifth year not all pupils were marking this choice. However, in every year, choice 'B' had been marked in second place, indicating that the state of molecules in gas is interfering with the solid idea.

2. Which of the following statements describes the arrangement of particles in a solid? The particles are

A far apart and do not change their places.

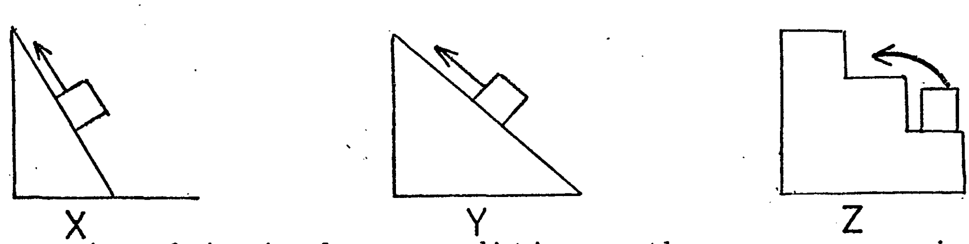
B close together and do not change their places.

C far apart and constantly changing their places.

D close together and are constantly changing their places.

This question was attempting to establish if the pupils have any knowledge about the arrangement of molecules in solids. The answer required is choice 'B' which is strong and is seen to increase with age almost linearly. Here choice 'D' is in second place, showing that some pupils could not distinguish between solids and liquids.

3. The diagrams show three ways in which a box could be raised to a height of 5m.



Assuming frictionless conditions, the energy required to raise the box is

A greatest using method X.

B greatest using method Y.

C greatest using method Z.

D the same in each case.

This question is trying to establish that path does not affect the energy. Here pupils were presented with inclined and steps situations. The answer required was choice 'D' which is weak until fifth year and even then it is by no means completely accepted. The majority of pupils chose choice 'C' revealing that by using the steps, more energy is required.

4. In solids, the internal energy is the total sum of the kinetic energies of individual particles. In liquids and gases, it is the total sum of the

A kinetic energy of individual particles.

B potential energy of individual particles.

C kinetic energy and potential energy of individual particles.

D average kinetic energy of individual particles.

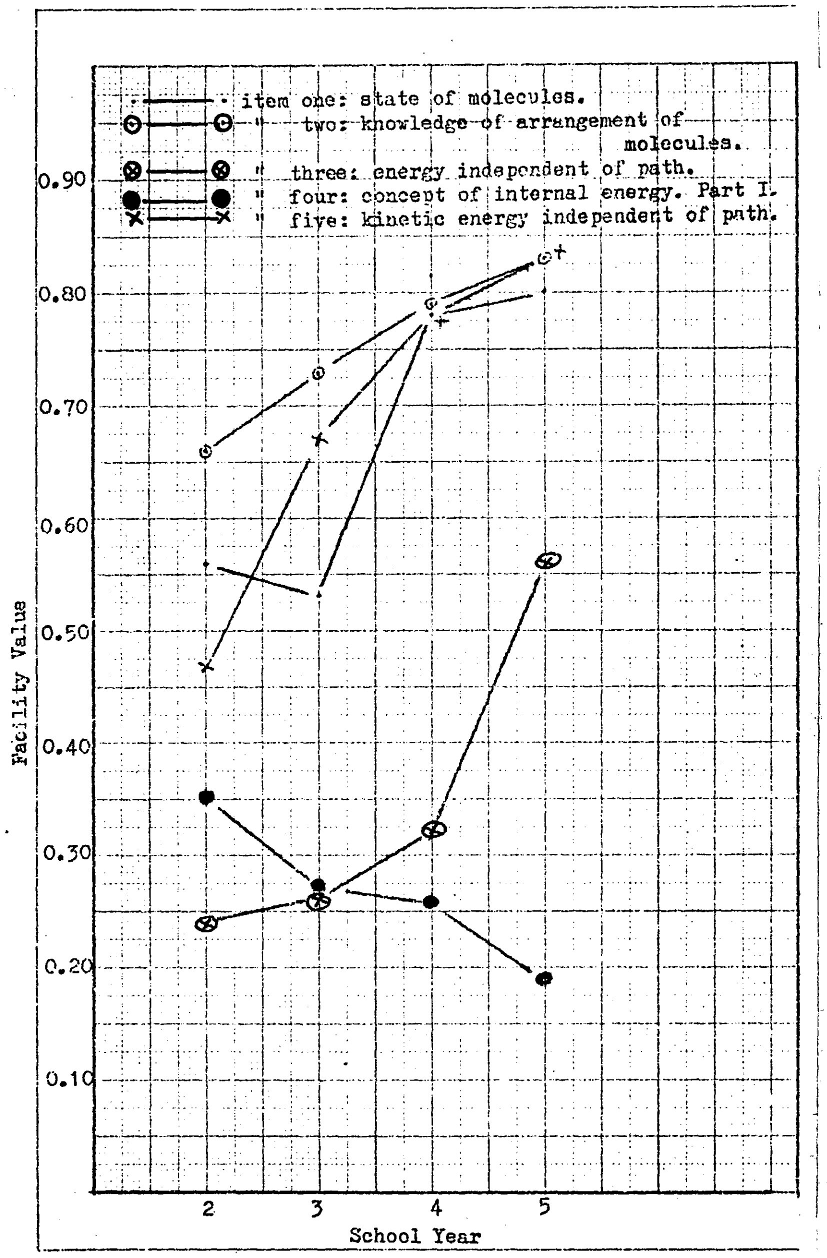
This question was intended to look for the idea of internal energy in liquids and gases. Choice 'C' was the answer sought, which is weak and in descending order showing that as we proceed to higher classes, the idea is not becoming clearer. The majority of the pupils chose 'A', revealing that they think that heat energy and internal energy are the same. Results also indicate that more guessing has taken place in this question.

5. Two objects X and Y are identical except that X is moving in a circle and Y in a straight line, both with the same velocity. The kinetic energy of X will be

A less than the kinetic energy of Y.

B equal to the kinetic energy of Y.

C greater than the kinetic energy of Y.



item one: state of molecules.
" two: knowledge of arrangement of molecules.
" three: energy independent of path.
" four: concept of internal energy. Part I.
" five: kinetic energy independent of path.
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
Facility Value
2
3
4
5
School Year

Figure 12

This question is a cross-check on question 3. This is attempting to establish that path does not affect the kinetic energy. The answer choice 'B' is seen to increase with age almost linearly.

The results of this part are plotted, and are shown in Figure 12. In this figure, two areas show a gradual and almost linear change as possible result of experience of their chemistry, biology and other studies. These areas are: state of molecules and knowledge of molecular arrangement in solids. Two areas show a marked improvement with age and with reappearance of formal teaching in fifth year and these areas are: energy and kinetic energy and their paths. One area shows a gradual and non-linear change, presumably due to misunderstanding of the concept of internal energy or some defect in the question.

Part II.

6. An aeroplane flying overhead will possess

A kinetic energy only.

B potential energy only.

C neither kinetic energy nor potential energy.

D both kinetic energy and potential energy.

This question is intended to look for ideas of kinetic and potential energies. The answer, choice 'D', is strong and is seen to increase with age almost linearly.

7. By stepping bare-foot from a rug to a linoleum floor in the same room, the linoleum feels colder than the rug. The temperature of the linoleum is

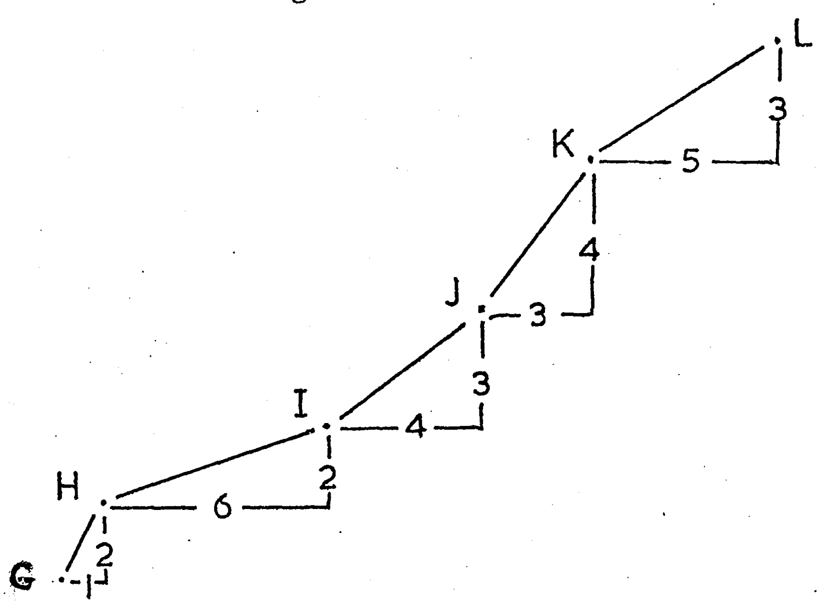
A less than the temperature of the rug.

B greater than the temperature of the rug.

C the same as the temperature of the rug.

This question is attempting to establish if the pupils have a clear idea of temperature. The answer required is choice 'C' which is not so strong and is almost fifty-fifty up to fifth year. Choice 'A' is marked by the majority of pupils in every class, revealing that the pupils have a superficial idea about the temperature.

8. A cat climbs up the roof of a building from point 'G' to point 'L'. All the measurements shown on the cross-sectional diagram of the roof are in metres.



During which section of its climb does the cat gain most potential energy?

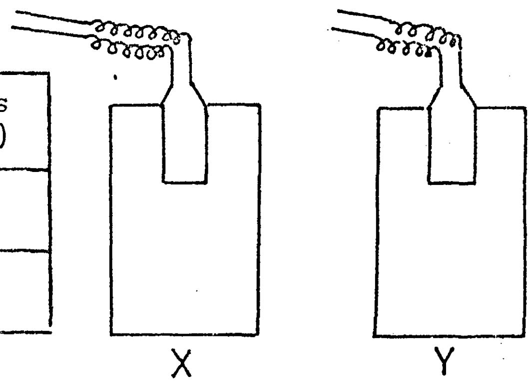
A H-I. C J-K.

B I-J. D K-L.

This question is a cross-check on question 3. Here pupils are presented with a step situation. This question is used to establish whether pupils have a clear idea about potential energy. The answer choice 'C' is seen to increase with age almost linearly. In second and third years, a majority of pupils have chosen 'A', revealing that distance is interfering with the position.

9. Identical low voltage heaters are inserted in two metal blocks, X and Y, details of which are shown in the table.

	Specific heat capacity = $J\ Kg^{-1}K^{-1}$	Mass (Kg)
X	200	1
Y	400	$\frac{1}{2}$



When the heaters are switched on, it is found that the temperature of

A X rises twice as fast as Y.

B Y rises twice as fast as X.

C Y rises four times as fast as X.

D X rises at the same rate as Y.

This question is trying to establish that temperature rise depends upon the mass and specific heat capacity of the material. The answer, choice 'D', is seen to increase with age almost linearly. However, pupils of second and third year classes have marked choice 'A' as frequently as the correct answer. This reveals that, at lower level, specific heat capacity is creating trouble.

10. If the same amount of heat is applied to the equal masses of fat and water in troughs X and Y, which are made of the same material,

how will the temperature rise in X and Y compare?

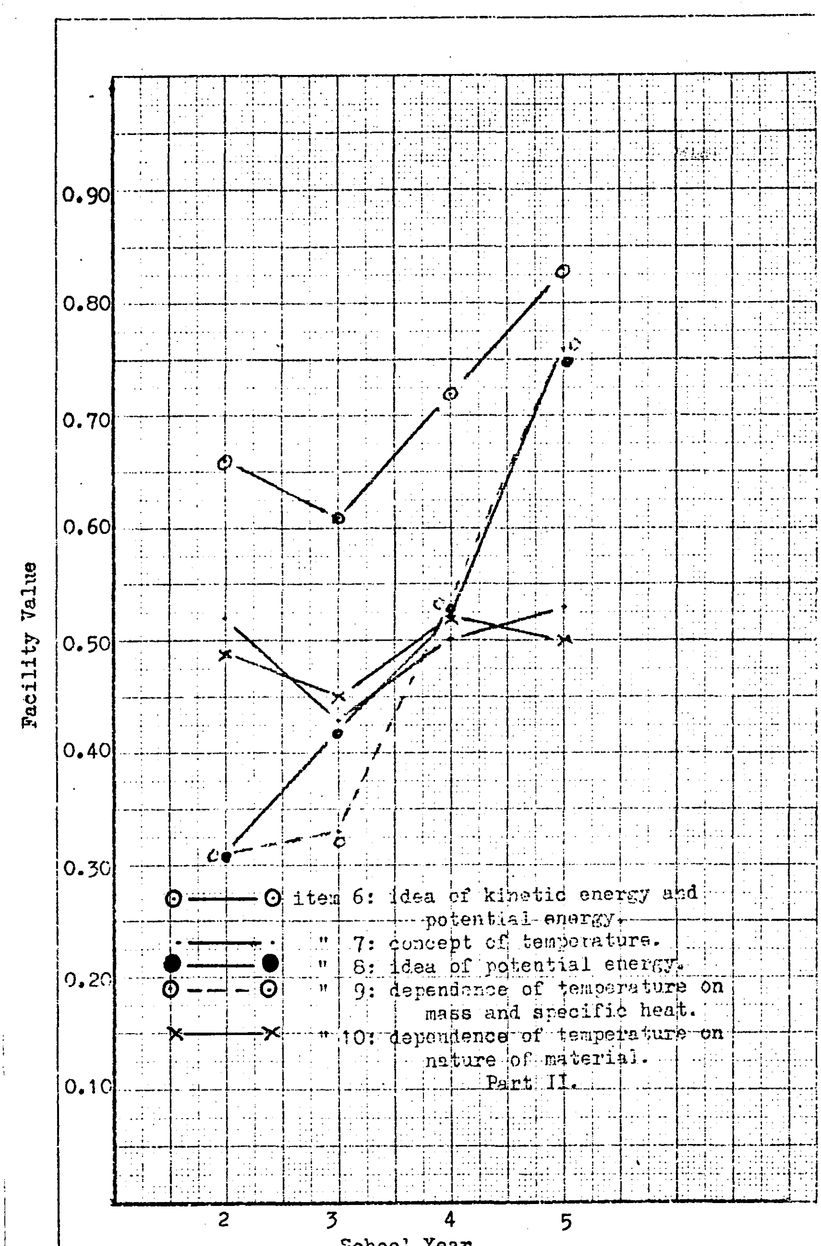

Facility Value
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
2
3
4
5
School Year
item 6: idea of kinetic energy and potential energy.
" 7: concept of temperature.
" 8: idea of potential energy.
" 9: dependence of temperature on mass and specific heat.
" 10: dependence of temperature on nature of material.
Part II.

Figure 13

Trough X	Trough Y
A Smaller temperature rise.	Greater temperature rise.
B Greater temperature rise.	Smaller temperature rise.
C Greater temperature rise.	Constant temperature.
D Constant temperature.	Greater temperature rise.

This question is a cross-check on question 9 and is attempting to establish that the temperature rise is depending upon the nature of material which in turn points towards the specific heat capacity of the material. Here pupils are presented with different materials - same mass - same heat - situations. The answer required is choice 'B', which is almost equally chosen by all pupils and is also weak up to fifth year. A majority of pupils in second year chose 'C' and in third, fourth and fifth years, choice 'A', revealing that specific heat capacity creates trouble. These results also confirm the views stated in question 9.

The results of this part are plotted and are shown in Figure 13. In this figure, two areas show a gradual change due to everyday application of the areas. These are kinetic and potential energies, and idea of temperature. Two areas show a marked improvement with age and teaching. These are: idea of potential energy and dependence of temperature on certain factors. One area shows a gradual and non-linear change due to interference of specific heat capacity. This is the area of temperature.

Part III.

11. When the kinetic energy of molecules increases the temperature rises. When potential energy of molecules increases the

A state of the body changes.

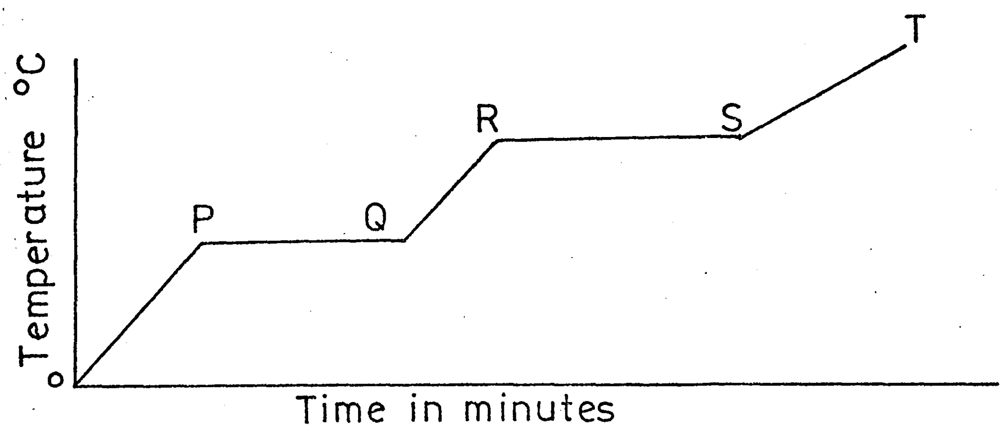
B mass of the body changes.

C temperature of the body changes.

D specific heat capacity of the body changes.

This question is attempting to establish if the pupils have an idea about change of state. The answer required is choice 'A', which is weak until fifth year and even then, it is by no means accepted. However, the majority of pupils in all classes chose 'C', revealing that they think that change of state and temperature are the same.

12. A substance is heated at a constant rate from a low temperature to a high temperature. A graph of temperature against time is drawn and is shown below:



Which part(s) of the graph correspond(s) to the substance existing in two states?

A ST. C PQ, RS.

B QR. D OP, QR, ST.

This question is a cross-check on question 11. This is to establish if the pupils understand that temperature is constant during a change of state. The answer required is choice 'C', which is seen to increase with age almost linearly.

13. The specific heat capacity of aluminium is 880 $JKg^{-1}K^{-1}$ and of lead 130 $JKg^{-1}K^{-1}$. From this

information it is concluded that, compared with equal mass of lead, aluminium needs

A more heat energy to produce the same temperature rise.

B less heat energy to produce the same temperature rise.

C the same heat energy to produce the same temperature rise.

This question is intended to look for the relationship among heat, specific heat capacity and nature of material. The answer required is choice 'A', which is seen to increase with age almost linearly. However, pupils of second year chose 'B' as often as 'A', revealing that they believe that there exists an inverse relationship between heat and the specific heat capacity of the material. This is also shown by the pupils of higher classes but to small extent.

14. If you are applying heat to a body, the amount of heat absorbed by the body is related to certain factors such as the

1) mass of the body.

2) shape of the body.

3) temperature rise.

4) nature of the material of the body.

In your opinion, which factors may be considered.

A Factors 1), 2) and 3).

B Factors 2), 3) and 4).

C Factors 4), 1) and 2).

D Factors 1), 3) and 4).

This question is meant to show whether pupils have

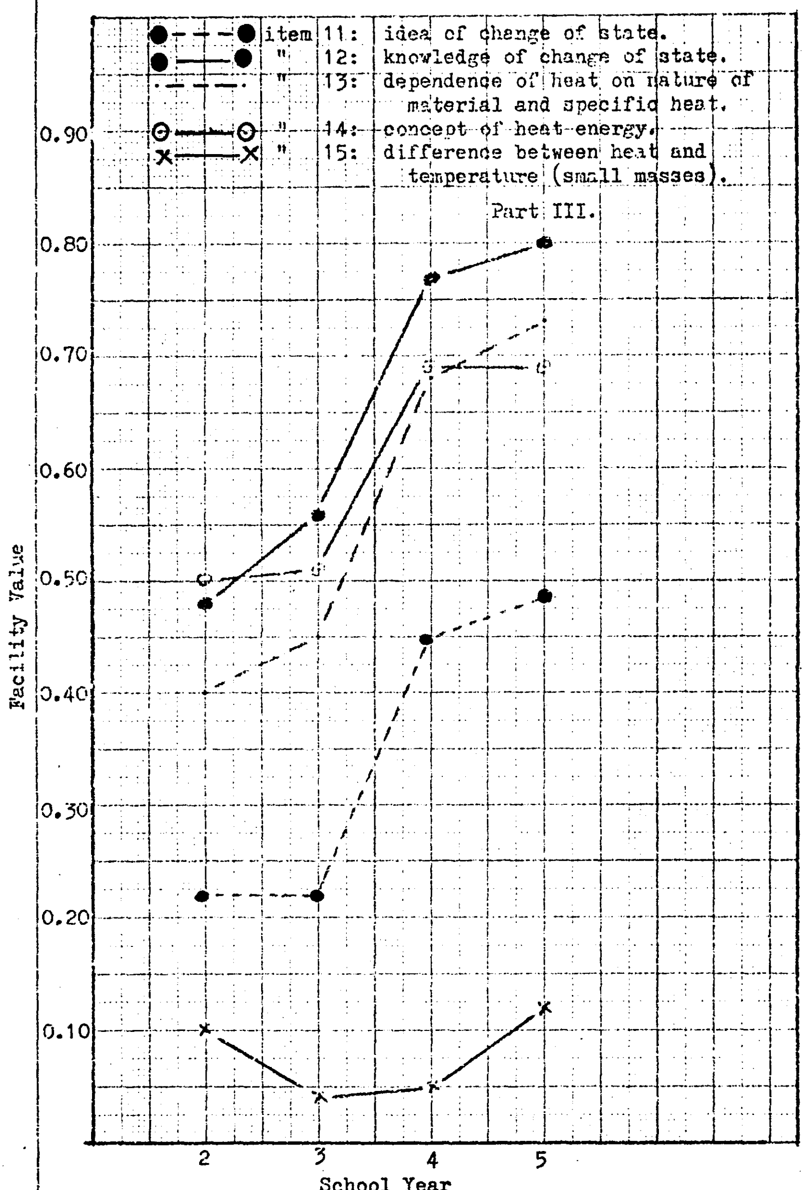

item 11: idea of change of state.
" 12: knowledge of change of state.
" 13: dependence of heat on nature of material and specific heat.
" 14: concept of heat energy.
" 15: difference between heat and temperature (small masses).
Part III.
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
Facility Value
2
3
4
5
School Year

Figure 14

got a clear concept of heat energy. The answer, choice 'D', is seen to increase slowly with age. Choice 'C' is second in popularity, which reveals that shape of body is creating trouble in understanding the concept of heat.

15. The sparks from the type of firework called a "sparkler" are harmless. When they fall on the back of the hand they can hardly be felt. They contain

A a large amount of heat energy and have a low temperature.

B a small amount of heat energy and have a low temperature.

C a large amount of heat energy and have a high temperature.

D a small amount of heat energy and have a high temperature.

This question is attempting to establish if the pupils have an idea that there exists a difference between heat and temperature for small masses. The answer required is choice 'D', which is very weak until fifth year and even then it is by no means accepted. Choice 'B' is chosen to a large extent by the pupils of all classes, revealing that there is no difference between heat and temperature and that there is direct relationship among mass, heat and temperature.

The results of this part are plotted and shown in Figure 14. In this figure, four areas show gradual and almost linear change due to a result of experience of everyday things. These are: idea and knowledge of change of state, dependence of heat on certain factors and concept of heat energy. Remaining area shows a gradual and non-linear change due to an unexpected situation presented in the stem of the question. This is area of difference between heat and temperature.

Part IV.

16. The water in a stream or river contains

A a small amount of heat energy and has a low temperature.

B a small amount of heat energy and has a high temperature.

C a large amount of heat energy and has a low temperature.

D a large amount of heat energy and has a high temperature.

This question was intended to look for the difference between heat and temperature for large masses. The answer choice 'C' is weak until fifth year and even then it is by no means accepted. However, choice 'A' is attempted more than choice 'C', revealing that, in large masses there is a little temperature rise and that the large masses contain a small amount of heat energy.

Note: Items 17 and 18 are based on the following statement.

There are two beakers which have been in the laboratory for several hours. Beaker X contains more water than beaker Y.

17. The water in beaker X will have

A a higher temperature than the water in beaker Y.

B a lower temperature than the water in beaker Y.

C the same temperature as that of the water in beaker Y.

This question is a converse of question 10. Here it is intended to learn about the relationship between temperature and the mass of the body. Pupils are presented with the same material (i.e. same specific heat capacity) and a different mass situation. Choice 'C' was the answer sought but even at fifth form, not all pupils were making this choice. The majority of pupils have chosen 'B', revealing that for large masses, there is a little temperature rise. These results also confirm the views stated in the end of question 16.

18. The water in beaker Y will contain

A more heat energy than beaker X.

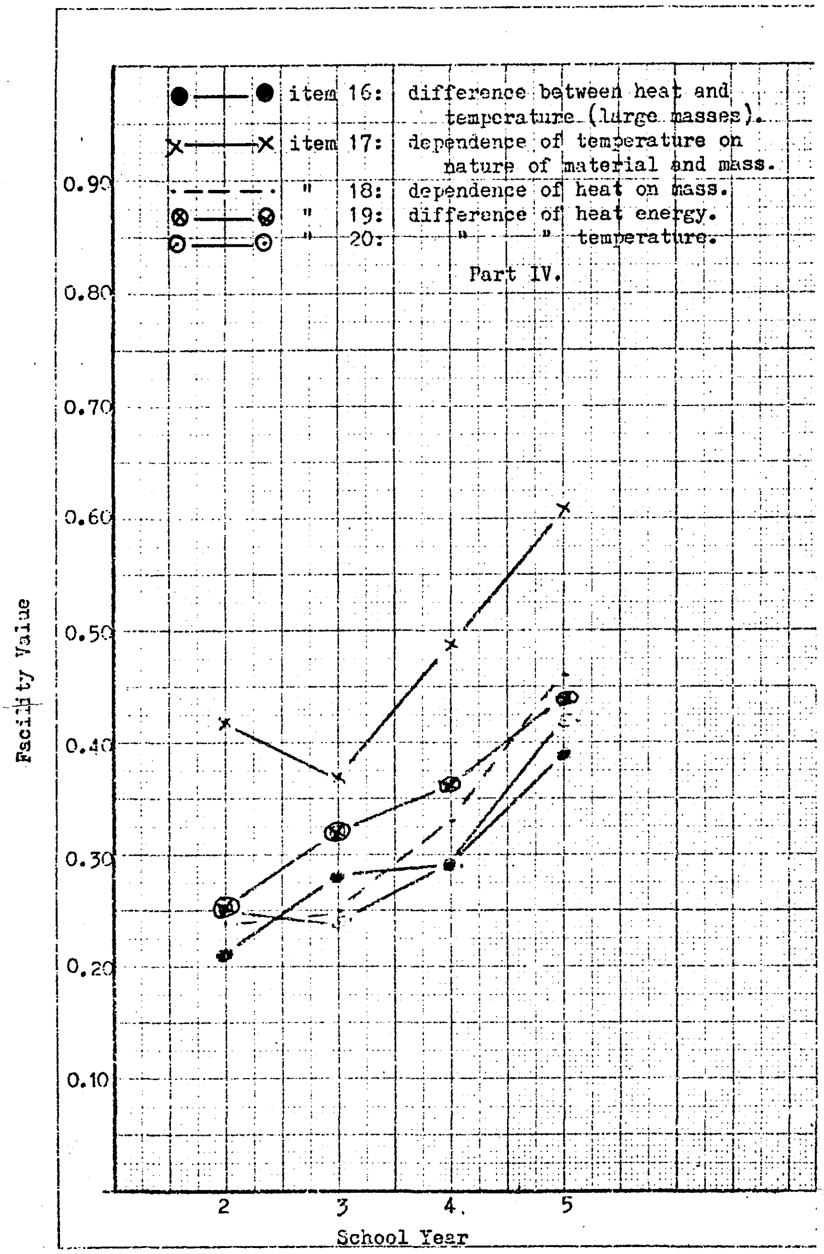
B less heat energy than beaker X.

C the same heat energy as that in beaker X.

This question is an indirect cross-check on question 16. Here it is intended to learn whether the pupils have an idea about the relationship between heat and mass of the material. The required answer is choice 'B', which is weak until fifth year and even then it is by no means fully accepted. The equal distribution of scores in second and fourth year classes show clear guessing. However, 'C' is chosen at second place, revealing that there is an inverse relationship between heat energy and mass of the material. This, in turn confirms the views stated at the end of question 16.

Note: The following responses describe the amounts of kinetic energy of the molecules of the body.

A Total kinetic energy of the molecules of the body.



item 16: difference between heat and temperature (large masses).
item 17: dependence of temperature on nature of material and mass.
" 18: dependence of heat on mass.
" 19: difference of heat energy.
" 20: " " temperature.
Part IV.
Facility Value
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
2
3
4
5
School Year

Figure 15

B Average kinetic energy of the molecules of the body.

C Total potential energy of the molecules of the body.

D Average potential energy of the molecules of the body.

Describe which response mentioned above corresponds to the

19. Heat energy of the body.

20. Temperature of the body.

19. This question is trying to establish if the pupils know the definition of heat energy. The required answer is choice 'A', which is weak until fifth year and even then it is by no means accepted. Second and fifth year pupils have marked 'B' as second choice, revealing that heat is temperature. Third and fourth year pupils have chosen 'C' in second place, revealing that heat is potential energy of the molecules of a body. This all shows that even the definition of heat energy is not clear to the pupils, and that they can not distinguish between heat and temperature and this in turn confirms the results of questions 15 and 16.

20. This question is attempting to establish if the pupils know the definition of temperature. The required answer is choice 'B', which is weak until fifth year and even then it is by no means accepted. A majority of pupils in all classes have chosen 'A' in second place, revealing that temperature and heat are the same. This confirms the views stated in questions 15, 16 and 19.

The results of this part are plotted and shown in Figure 15. In this figure, all areas show a gradual and almost linear change, presumably as a result of experience

Table 5.2.2.

Showing the general summary of interview information and test results.

Interview Results

School 2

Class	Idea about Molecules	Concept of Energy	Concept of Internal Energy	Idea of Kinetic Energy	Idea of Potential Energy	Concept of Temperature	Dependence of Temperature on Mass	Change of State	Concept of Heat Energy	Dependence of Heat on Mass	Difference between Heat and Temp. (small masses)	Difference between Heat and Temp. (large masses)
2nd Year	Clear	Not clear	Not clear	Clear	Clear	Not clear	Clear to one-third pupils.	Clear	Not clear	Clear to one-sixth pupils.	Clear to one-third pupils.	Clear to one-third pupils.
3rd "	"	"	"	"	"	Clear to half of the pupils.	Clear to half of the pupils.	"	Clear to one-third pupils.	Clear to half of the pupils.	Clear to half of the pupils.	Clear to half of the pupils.
School 1												
3rd Year	Clear	Clear to one-sixth pupils.	Not clear	Clear	Clear	Clear to half of the pupils.	Clear to half of the pupils.	Clear	Clear to one-third pupils.	Clear to half of the pupils.	Clear to half of the pupils.	Clear to half of the pupils.
4th "	"	"	"	"	"	Clear	Clear	"	Clear to two-thirds of pupils.	Clear to two-thirds of pupils	Clear.	Clear.

Table 5.2.2 (continued)

Test Results

Class	Idea about Molecules	Concept of Energy	Concept of Internal Energy	Idea of Kinetic Energy	Idea of Potential Energy	Concept of Temp-erature	Depend-ence of Tempera-ture on Mass	Change of State	Concept of Heat Energy	Depend-ence of Heat on Mass	Differ-ence be-tween Heat and Temp. (small masses)	Difference between Heat and Temp. (large masses)
	Item 2	Item 3	Item 4	Item 5	Item 8	Item 7	Item 17	Item 12	Item 14	Item 18	Item 15	Item 16
2nd Year	0.66	0.24	0.35	0.47	0.31	0.52	0.42	0.48	0.50	0.24	0.10	0.21
3rd "	0.73	0.26	0.27	0.67	0.42	0.43	0.37	0.56	0.51	0.25	0.04	0.28
4th "	0.79	0.32	0.26	0.78	0.52	0.50	0.49	0.77	0.69	0.33	0.05	0.29
5th "	0.83	0.56	0.19	0.83	0.76	0.53	0.61	0.80	0.69	0.46	0.12	0.39

of everyday applications. These areas are: difference between heat and temperature, dependence of temperature on certain factors, dependence of heat on mass and definitions of heat and temperature.

A general summary showing the results of the interview and the test is given in Table 5.2.2. Comparing both results we find that for the concept of molecules there is a good agreement between both the results.

There is a fair agreement between both the results for the concept of energy.

Regarding internal energy, there is some agreement between interview and test results. However, in the test, the score is found in descending order. The frequency of answers shows that more pupils have chosen 'A' up to fourth year, revealing that internal energy is the same as heat energy, and that there is no difference between them. In fifth year more pupils have swung to choice 'D', revealing that internal energy is temperature. To the researcher, it seems that this is because the idea of internal energy may not be taught properly in schools. This is why there is mixed opinion of the pupils revealed in the responses. E.S. Greene (1960)[130] has shown and explained the difference among these three concepts. It seems that really the pupils do not know about them.

For ideas of kinetic and potential energies, there is good agreement in both the results.

There is some agreement between both the results for the concept of temperature. This is not encouraging and it may be due to teaching. The concept of temperature is being taught in the classes either as a sense perception idea or as thermometry. Pupils are not presented with clear ideas and this concept is misunderstood by the pupils and the true picture is shown in the test results.

Regarding the temperature-mass relationship, there seems fair agreement between both the results.

About the change of state, the test results are in good agreement with interview results.

There is fair agreement between both the results for the concept of heat energy.

There is some agreement between both the results for heat-mass relationship. This agreement is not encouraging. This may be due to teaching. It seems as if some static and rigid things are being taught and very little attention is paid to the things of everyday application.

Regarding the difference between heat and temperature (for small masses), it is found that there is no agreement between the test and interview results. In the view of the researcher, this is due to the situation presented in the question. This has created an ambiguity. The other possible reason is the language used in the choices written for the questions. There may be some complexity, and this is why the question has not been understood clearly. If the situation is changed and the choices are written in a simple way, it is hoped that the question will work properly.

For large masses, there is some agreement between the results. In the view of the researcher, the conditions for the disagreement are the same. It is hoped that the modification proposed in the above paragraph can also work for this question.

5.4. Conclusion.

After going through the discussion, the researcher has arrived at the following conclusions.

1. The concept of molecules is clear to the pupils.

2. The concept of energy is not clear to the pupils even up to fifth year.

3. The concept of internal energy is not clear to the pupils. This is mixed with heat up to fourth year and in fifth year, the concept is mixed with temperature.

4. The concepts of kinetic and potential energies are clear to the pupils.

5. The concept of temperature is not clear. Pupils have learned this idea superficially.

6. Specific heat capacity and mass create trouble in understanding the concepts of heat and temperature.

7. The idea of change of state improves with age and at higher levels, it becomes clear.

8. The concept of heat energy is not completely clear to the pupils even at higher levels.

9. The difference between heat and temperature (for small and large masses) is not clear to the pupils. Even the definitions of both the concepts are not clear to the pupils.

10. It is concluded that there is a good agreement between test and interview results in general and so, the test is generally valid.

APPENDIX 5.1.(a)

Showing interview schedule with prompts and probes.

(Showing a piece of iron/copper)
1. Of what is this piece of iron/copper made up?

2. What would you call these tiny particles?

(Showing a flask)
3. When air is heated how would its molecules behave?

4. Why do the molecules of air move fast when the flask is heated?

5. What is energy?

6. A frying pan is placed on a gas flame. When its temperature rises, what type of energy would it possess?

7. What is internal energy?

(Showing a ball in motion)
8. What type of energy does this possess now?

(Showing a ball at rest)
9. What type of energy does this possess now?

10. When kinetic energy of the molecules of an object increases, what would you notice to the touch?

11. What does the increased speed of the molecules indicate?

12. When potential energy of the molecules of an object increases, what happens?

13. What would you have to apply to a piece of lead to make it melt?

14. What is heat?

(Touching a piece of wood and a piece of metal, both approximately at the same temperature)
15. Which object has the higher temperature?

(Touching a small warm piece of iron and a large cold piece of wood)
16. Which contains more heat?

17. The cup and a tub contain water. If these are at the same temperature, will they both contain the same amount of heat?

18. If the same amount of heat is added to both of these at 15^{o}C, how will the temperature of the two compare?

A P P E N D I X 5.1.(b)

Showing list of pupils, their years in schools, chronological age, I.Q., and mental age.

School 1

Year	Code letter used for pupil	Rank in class	C.A. Years	C.A. Months	I.Q.	M.A.
3rd Year	A	Top	15	5	140+	16+
" "	B	"	16	8	-	-
" "	C	Middle	15	9	138	16+
" "	D	"	15	8	130	16+
" "	E	Lower	15	4	96	14.7
" "	F	"	15	4	-	-
4th Year	A	Top	16	1	138	16+
" "	B	"	14	1	135	16+
" "	C	Middle	17	5	-	-
" "	D	"	16	5	119	16+
" "	E	Lower	16	7	114	16+
" "	F	"	16	3	106	16+
School 2						
2nd Year	A	Top	14	1	129	16+
" "	B	"	14	3	121	16+
" "	C	Middle	13	7	121	16+
" "	D	"	14	4	113	16+
" "	E	Lower	13	11	112	15.6
" "	F	"	14	0	104	14.6
3rd Year	A	Top	14	10	135	16+
" "	B	"	14	11	129	16+
" "	C	Middle	15	7	124	16+
" "	D	"	15	1	120	16+
" "	E	Lower	14	11	118	16+
" "	F	"	15	8	106	16+

APPENDIX 5.1.(c)

Details of interview conducted in third year class in school 1.

T: (Showing a chunk of metal) What is this made up of?

A: Steel.

T: What is iron or steel made up of?

D: Atoms.

C: Molecules.

T: (Showing empty flask) What about the contents of this flask?

E: Air.

T: What is air?

C: Atoms.

T: What happens to the molecules of air when I keep the air heated gently?

F: Separate.

B: They go apart more.

T: Suppose we have supermicroscopic eyeball and you could actually see an individual atom or molecule and you are roasting it with heat, what do you imagine?

D: A chemical reaction.

T: Suppose you did not get chemical reaction, then?

D: The particles move faster.

T: What do you think about the atoms or molecules of iron or steel, when the chunk is heated on bunsen burner?

B: They would not move.

T: On more heating, what will happen?

B: It will start melting.

T: If this chunk is heated more, what happens to atoms?

D: They will start vibrating.

T: What is energy?

A: It is work and makes things move.

B: Work.

T: What kind of energy is connected with a rise of temperature?

No reply.

T: When I heat the air in the flask, what kind of energy is involved with this rising temperature?

No reply.

T: What sort of thing can the molecules do when they have got more energy?

D: It is movement energy.

T: What do you call this movement energy?

B: Kinetic energy.

T: If I roll a ball, what energy does it possess?

By all: Kinetic energy.

T: If I raise it?

By all: Potential energy.

T: If I put hot chunk on hand, what would happen?

B: The heat will affect the nerves.

T: What do you mean by the heat affecting the nerves?

A: The molecules will be vibrating faster and will stimulate his feelings.

T: What is heat energy?

No reply.

T: Can you give an idea of what the molecules are doing when they are hot?

B: They are moving.

T: So?

B: Heat energy is causing the vibrations.

Teacher defined the term in a refined way.

T: (Showing two ball-bearings, one small and one big) Suppose I have these two ball-bearings sitting in this room at the same temperature, which has got more heat energy?

E: Bigger one has got more heat energy.

T: Why?

F: Because it has got more particles.

T: (Showing beakers containing different amounts of water at the same temperature) Are they both at the same temperature?

B: Yes.

T: What about their heat content?

F: Both have the same heat content.

C: The heat content is more for more water in the beaker.

T: Why?

C: Because it has more particles.

T: Two ball-bearings, same in shape and size, are heated at the same temperature and dropped in these beakers, what will happen to the temperature of water in the beakers?

D: They will get hot and the beaker with small water will have more temperature than the other.

Note: Here T stands for interviewer and A, B, C, D, E and F are codes used for the pupils who participated. The details of pupils are given in Appendix 5.1.(b).

APPENDIX 5.1.(d)

Showing the analysis of interview given to various classes.

School 2.

Second Year

I. Molecules.

Pupils were clear about molecules. They were not clear about the arrangement of molecules in solids but were clear about their arrangement in gases.

II. Energy.

Pupils were not clear in the concept of energy. Some pupils defined it as force and some as power. Nobody could define it clearly. However, they knew about the forms of energy.

III. Internal Energy.

Pupils were not clear about internal energy.

IV. Kinetic Energy and Potential Energy.

Pupils were very clear about these types of energy.

V. Temperature.

Pupils knew about hot and cold objects.

They could not reply to "What is temperature?".

One-third of the pupils were clear about the relationship between temperature and mass.

VI. Change of State.

Pupils knew about change of state.

VII. Heat Energy.

Pupils could not define what heat energy is. Some pupils said "it is light", some pupils told "it is friction".

One-sixth of the pupils were clear about the relationship between heat energy and mass.

VIII. Difference between Heat and Temperature.

For small masses, one-third pupils differentiated between heat and temperature.

For large masses, one-third pupils made distinction between heat and temperature.

Third Year

I. Molecules.

Pupils were clear about molecules. One-third pupils were clear about the arrangement of molecules in solids, but all were clear about the arrangement in gases.

II. Energy.

Pupils were not clear in the concept of energy. However, they did not mix it with power or force.

III. Internal Energy.

Pupils were not clear about internal energy.

IV. Kinetic Energy and Potential Energy.

Pupils were clear about both types of energy.

V. Temperature.

Pupils knew about hot and cold objects.

Half of the pupils knew about the concept of temperature.

Half of the pupils also knew about the relationship between temperature and mass.

VI. Change of State.

Pupils knew about change of state.

VII. Heat Energy.

Some pupils defined heat energy.

The concept was clear to one-third pupils.

Half of the pupils were clear about the relationship between heat and mass.

VIII. Difference between Heat and Temperature.

For small masses, half of the pupils were clear about the difference between heat and temperature.

Half of the pupils were clear about the difference between heat and temperature for large masses.

School 1.

Third Year

I. Molecules.

Pupils were clear about molecules.

They were also clear about the arrangement of molecules in solids and gases.

II. Energy.

One-sixth pupils were clear about the concept of energy.

Some pupils mixed it with work.

III. Internal Energy.

Pupils were not clear about internal energy.

IV. Kinetic Energy and Potential Energy.

Pupils were clear about these types of energy.

V. Temperature.

Pupils knew about hot and cold objects.

Concept is clear to half of the pupils.

Half of the pupils knew about the relationship between temperature and mass.

VI. Change of State.

Pupils were clear about the change of state.

VII. Heat Energy.

Some pupils defined heat energy.

The concept was clear to one-third pupils.

Half of the pupils knew about the relationship between heat and mass.

VIII. Difference between Heat and Temperature.

For small masses, half of the pupils were clear about this difference.

Half of the pupils were also clear about this difference for large masses.

Fourth Year.

I. Molecules.

Pupils were clear about molecules.

They were also clear about the arrangement of molecules in solids and gases.

II. Energy.

One-sixth pupils were clear about the concept.

Some pupils mixed it with power.

III. Internal Energy.

Pupils were not clear about internal energy.

IV. Kinetic Energy and Potential Energy.

Pupils were clear about both types of energy.

V. Temperature.

Pupils were clear about the concept.

They were also clear about the relationship between temperature and mass.

VI. Change of State.

Pupils were clear about it.

VII. Heat Energy.

More pupils defined heat energy.

The concept was clear to two-thirds of the pupils.

Two-thirds of the pupils knew about the relationship between heat and mass.

VIII. Difference between Heat and Temperature.

Pupils were clear about this difference for small and large masses.

A P P E N D I X 5.2.(a)

Test Specifications

Showing Piaget's developmental levels and Bloom's levels.

A. Piaget's levels

Main Topic	2A		2B		3A		3B	
	Items	% weighting	Items	% weighting	Items	% weighting	Items	% weighting
1. Molecules	2	10.0	-	-	-	-	-	-
2. Energy	2	10.0	3	15.0	-	-	-	-
3. Change of state	1	5.0	1	5.0	-	-	-	-
4. Temperature	1	5.0	4	20.0	-	-	-	-
5. Heat energy	-	-	-	-	1	5.0	3	15.0
6. Difference between heat and temperature	-	-	-	-	-	-	2	10.0
Total	6	30.0	8	40.0	1	5.0	5	25.0

B. Bloom's levels

Main Topic	B1 (Knowledge)		B2 (Comprehension)		B3 (Application	
	Items	% weighting	Items	% weighting	Items	% weighting
1. Molecules	2	10.0	-	-	-	-
2. Energy	-	-	1	5.0	4	20.0
3. Change of state	1	5.0	-	-	1	5.0
4. Temperature	-	-	3	15.0	2	10.0
5. Heat and energy	-	-	3	15.0	1	5.0
6. Difference between heat and temperature	-	-	2	10.0	-	-
Total	3	15.0	9	45.0	8	40.0

APPENDIX 5.2.(b)

UNIVERSITY OF GLASGOW

SCIENCE EDUCATION DEPARTMENT

Test Two

Heat and Temperature

1. When solids are heated without melting, the molecules in the solid

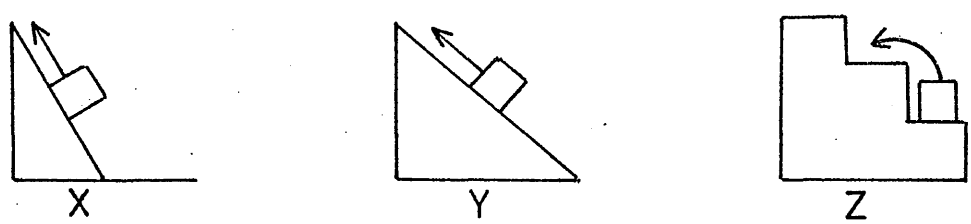
    A are in stationary positions.
    B move around in different directions.
    C vibrate more about their mean positions.
    D circulate in an orderly fashion within the solid.

2. Which of the following statements describes the arrangement of particles in a solid?

    The particles are

    A far apart and do not change their places.
    B close together and do not change their places.
    C far apart and constantly changing their places.
    D close together and are constantly changing their places.

3. The diagrams show three ways in which a box could be raised to a height of 5m.



Assuming frictionless conditions, the energy required to raise the box is

    A greatest using method X.
    B greatest using method Y.
    C greatest using method Z.
    D the same in each case.

4. In solids, the internal energy is the total sum of the kinetic energies of individual particles. In liquids and gases, it is the total sum of the

A kinetic energy of individual particles.
B potential energy of individual particles.
C kinetic energy and potential energy of individual particles.
D average kinetic energy of individual particles.

5. Two objects X and Y are identical except that X is moving in a circle and Y in a straight line, both with the same velocity. The kinetic energy of X will be

A less than the kinetic energy of Y.
B equal to the kinetic energy of Y.
C greater than the kinetic energy of Y.

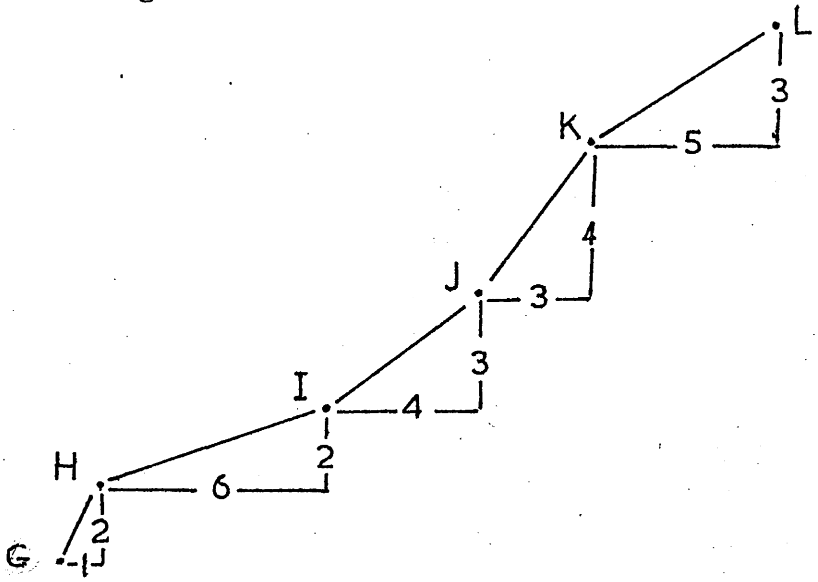
6. An aeroplane flying overhead will possess

A kinetic energy only.
B potential energy only.
C neither kinetic energy nor potential energy.
D both kinetic energy and potential energy.

7. By stepping bare-foot from a rug to a linoleum floor in the same room, the linoleum feels colder than the rug. The temperature of the linoleum is

A less than the temperature of the rug.
B greater than the temperature of the rug.
C the same as the temperature of the rug.

8. A cat climbs up the roof of a building from point 'G' to 'L'. All the measurements shown on the cross-sectional diagram of the roof are in metres.

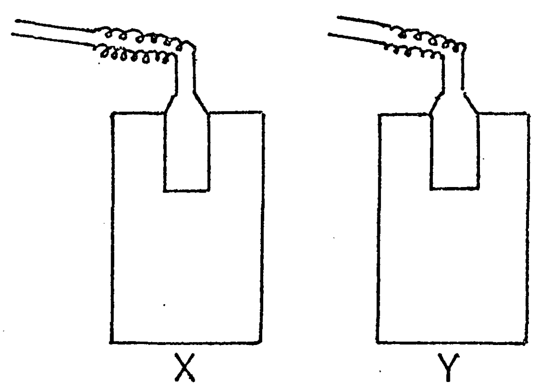


During which section of its climb does the cat gain most potential energy?

A H-I.
B I-J.
C J-K.
D K-L.

9. Identical low voltage heaters are inserted in two metal blocks, X and Y, details of which are shown in the table.

	Specific heat capacity = $J\ Kg^{-1}\ K^{-1}$	Mass (Kg)
X	200	1
Y	400	$\frac{1}{2}$



When the heaters are switched on, it is found that the temperature of

A X rises twice as fast as Y.
B Y rises twice as fast as X.
C Y rises four times as fast as X.
D X rises at the same rate as Y.

10. If the same amount of heat is applied to the equal masses of fat and water in troughs X and Y, which are made of the same material,

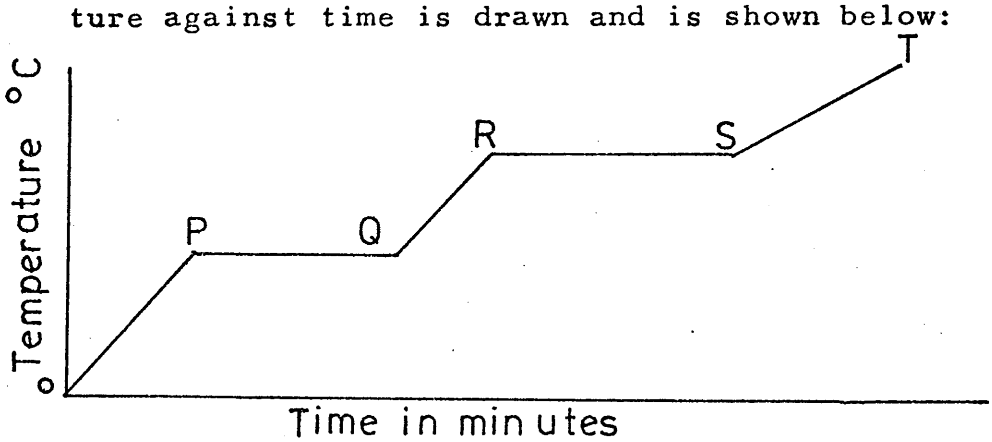
how will the temperature rise in X and Y compare?

	Trough X	Trough Y
A	Smaller temperature rise.	Greater temperature rise.
B	Greater temperature rise.	Smaller temperature rise.
C	Greater temperature rise.	Constant temperature.
D	Constant temperature.	Greater temperature rise.

11. When the kinetic energy of molecules increases the temperature rises. When potential energy of molecules increases the

A state of the body changes.
B mass of the body changes.
C temperature of the body changes.
D specific heat capacity of the body changes.

12. A substance is heated at a constant rate from a low temperature to a high temperature. A graph of temperature against time is drawn and is shown below:



Which part(s) of the graph correspond(s) to the substance existing in two states?

A ST. B QR. C PQ, RS. D OP, QR, ST.

13. The specific heat capacity of aluminium is 880 $JKg^{-1}K^{-1}$ and of lead 130 $JKg^{-1}K^{-1}$. From this information it is concluded that, compared with equal mass of lead, aluminium needs

A more heat energy to produce the same temperature rise.

B less heat energy to produce the same temperature rise.

C the same heat energy to produce the same temperature rise.

14. If you are applying heat to a body, the amount of heat absorbed by the body is related to certain factors such as the

1) mass of the body.
2) shape of the body.
3) temperature rise.
4) nature of the material of the body.

In your opinion, which factors may be considered.

A Factors 1), 2) and 3).

B Factors 2), 3) and 4).

C Factors 4), 1) and 2).

D Factors 1), 3) and 4).

15. The sparks from the type of firework called a "sparkler" are harmless. When they fall on the back of the hand they can hardly be felt. They contain

A a large amount of heat energy and have a low temperature.

B a small amount of heat energy and have a low temperature.

C a large amount of heat energy and have a high temperature.

D a small amount of heat energy and have a high temperature.

16. The water in a stream or river contains

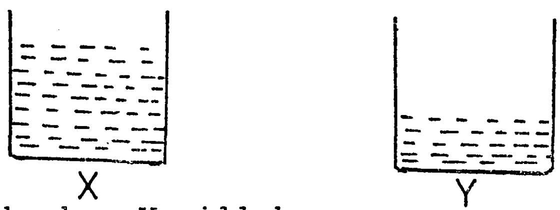
A a small amount of heat energy and has a low temperature.

B a small amount of heat energy and has a high temperature.

C a large amount of heat energy and has a low temperature.

D a large amount of heat energy and has a high temperature.

Note: Items 17 and 18 are based on the following statement. There are two beakers which have been in the laboratory for several hours. Beaker X contains more water than beaker Y.



17. The water in beaker X will have

A a higher temperature than the water in beaker Y.

B a lower temperature than the water in beaker Y.

C the same temperature as that of the water in beaker Y.

18. The water in beaker Y will contain

A more heat energy than beaker X.

B less heat energy than beaker X.

C the same heat energy as that in beaker X.

Note: The following responses describe the amounts of kinetic energy of the molecules of the body.

A Total kinetic energy of the molecules of the body.

B Average kinetic energy of the molecules of the body.

C Total potential energy of the molecules of the body.

D Average potential energy of the molecules of the body.

Describe which response mentioned above corresponds to the

19. Heat energy of the body.

20. Temperature of the body.

APPENDIX 5.2.(c)

Showing item specifications, key and explanation of items.

Item No.	Item specification	Key	Item Explanation
1	2A-B1	C	State of molecules in a solid is known, - if A, B and D, idea not clear.
2	2A-B1	B	Knowledge of arrangement of molecules in a solid, - if A, C and D, idea not clear.
3	2A-B3	D	Energy independent of path - definition clear, - if A, B and C, definition not clear - idea not clear.
4	2B-B2	C	Concept of internal energy in liquids and gases clear, - if A, B and D, not clear - even mixing heat and temperature with internal energy.
5	2B-B3	B	Kinetic energy independent of path, idea clear, - if A and C, idea not clear.
6	2A-B3	D	Idea of potential and kinetic energy clear, definition clear, - if A, B and C, idea not clear.
7	2A-B2	C	Clear concept of temperature - check on superficial learning, - if A and B idea not clear - concept wrongly acquired.
8	2B-B3	C	Idea of potential energy clear, definition also clear, - if A B and D, idea not clear.

9	2B-B3	D	Dependence of temperature on mass, specific heat and heat, clear, (different masses and specific heats and same heat) - if A, B and C - idea not clear.
10	2B-B2	B	Dependence of temperature on nature of material - idea clear (same masses, same heat) - if A, C and D, idea not clear.
11	2A-B1	A	Idea of change of state clear - if B, C and D, idea not clear.
12	2B-B3	C	Knowledge of change of state - idea clear, - if A, B and D, idea not clear.
13	3A-B2	A	Dependence of heat on nature of material and specific heat, idea clear, - if B and C, idea not clear.
14	3B-B2	D	Dependence of heat quantity absorbed on mass, temperature and nature of material - factors clearly known, - if A, B and C, knowledge imperfect, idea not clear.
15	3B-B2	D	Small masses, difference clear, - if A, B and C, difference not clear.
16	3B-B2	C	Large masses, difference clear, - if A, B and D, difference not clear.
17	2B-B3	C	Dependence of temperature on nature of material and mass, idea clear, - if A and B, mass and volume interfering with temperature.

18	3B-B3	B	Dependence of heat on mass, idea clear, - if A and C, relationship between heat and mass not clear.
19	3B-B2	A	Definition of heat energy, clear, - if B, C and D, definition not clear, idea not clear.
20	2B-B2	B	Definition of temperature, clear, - if A, C and D, definition not clear, idea not clear.

APPENDIX 5.2.(d)

Showing covering letter to principal teachers.

Science Education
Research Group

Chemistry Department,
University of Glasgow,
GLASGOW G12 8QQ.

Dear

I am sending herewith copies of the Test Two and Test Three. The answers for Test Two will be recorded on YELLOW computer cards and for Test Three on PINK computer cards. The instructions for pupils are given on separate sheets sent herewith.

You are requested kindly to inform your pupils how to fill in the right-hand portion and the left-hand portion of each card. We have assigned numbers to schools for our convenience. Your school number is . Kindly intimate this to your pupils and also the serial number of pupils of your school, which will start from 001 onwards, using any numbering you choose. Specimen cards are also sent herewith.

Thanking you for your co-operation.

Yours sincerely,

APPENDIX 5.2.(e)

Sheet of instruction prepared for teachers.

INSTRUCTIONS TO BE GIVEN TO PUPILS

1. This test is printed on both sides of the paper.
2. Answers for this test will be recorded on YELLOW computer cards by shading in the appropriate oval using a soft pencil (preferably 2B).
3. In the right-hand portion of every card, only the date will be written; no need of the name.
4. There are 6 columns in the left-hand portion of every card. The ovals in the columns will be shaded as follows:

   (i) 1st Column: "No. of School" - which your teacher will tell you.

   (ii) 2nd Column: Your year (e.g. 3 = 3rd Year).

   (iii) 3rd Column: No. of test.

   (iv) 4th)
   5th)
   6th Columns) (Your number, which your teacher will give you. (e.g. if you are No. 3 - shade in 003; or if you are No. 37, shade in 037).

(Your school No. is)

A P P E N D I X 5.2.(f)

Showing question analysis, and frequency of answers of <u>second year</u> pupils

(No. of pupils - 554)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	0.60	0.51	0.27	0.46	0.10	0.23	0.33	75	149	255*	54
2	0.71	0.61	0.35	0.56	0.10	0.26	0.36	27	310*	39	162
3	0.26	0.21	0.07	0.18	0.04	0.14	0.19	125	51	254	99*
4	0.46	0.24	0.13	0.28	0.22	0.11	0.33	118	115	153*	76
5	0.56	0.37	0.24	0.39	0.19	0.13	0.32	92	216*	202	9
6	0.77	0.54	0.46	0.59	0.22	0.09	0.31	115	48	34	326*
7	0.58	0.45	0.32	0.45	0.13	0.13	0.26	272	24	250*	2
8	0.33	0.28	0.21	0.27	0.05	0.07	0.12	221	35	152*	114
9	0.41	0.21	0.10	0.24	0.20	0.11	0.31	99	182	51	131*
10	0.54	0.43	0.21	0.39	0.10	0.23	0.33	85	218*	108	68
11	0.24	0.19	0.08	0.17	0.05	0.11	0.17	94*	77	201	98
12	0.61	0.35	0.15	0.37	0.27	0.20	0.46	57	81	205*	85
13	0.49	0.30	0.15	0.31	0.18	0.16	0.34	173*	173	75	13
14	0.59	0.41	0.22	0.40	0.17	0.20	0.37	91	58	117	224*
15	0.15	0.05	0.02	0.07	0.10	0.03	0.14	126	319	25	40*
16	0.26	0.16	0.08	0.17	0.09	0.08	0.17	338	41	92*	14
17	0.51	0.32	0.23	0.35	0.20	0.08	0.28	62	230	195*	8
18	0.25	0.22	0.15	0.21	0.03	0.07	0.10	184	115*	160	20
19	0.31	0.18	0.09	0.19	0.13	0.09	0.22	108*	120	113	73
20	0.33	0.17	0.08	0.19	0.16	0.09	0.25	86	108*	89	110

* denotes correct answer

APPENDIX 5.2.(g)

Showing question analysis, and frequency of answers of <u>third year</u> pupils

(No. of pupils - 218)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	0.76	0.60	0.24	0.53	0.17	0.35	0.52	35	53	116*	11
2	0.88	0.79	0.54	0.73	0.08	0.25	0.33	8	160*	5	44
3	0.43	0.24	0.12	0.26	0.19	0.11	0.31	38	11	111	57*
4	0.32	0.35	0.15	0.27	-0.03	0.20	0.17	70	44	59*	36
5	0.89	0.69	0.43	0.67	0.19	0.26	0.46	29	146*	35	6
6	0.72	0.67	0.46	0.61	0.06	0.21	0.26	51	19	11	134*
7	0.58	0.47	0.24	0.43	0.11	0.23	0.34	112	8	94*	1
8	0.63	0.35	0.30	0.42	0.28	0.05	0.33	73	12	92*	37
9	0.50	0.31	0.18	0.33	0.19	0.13	0.32	25	71	41	71*
10	0.53	0.47	0.35	0.45	0.06	0.12	0.18	63	98*	37	13
11	0.33	0.18	0.15	0.22	0.15	0.03	0.18	48*	42	65	53
12	0.68	0.56	0.43	0.56	0.13	0.12	0.25	21	20	121*	47
13	0.63	0.40	0.32	0.45	0.22	0.08	0.30	98*	76	30	1
14	0.67	0.51	0.35	0.51	0.15	0.16	0.32	26	26	45	111*
15	0.07	0.03	0.03	0.04	0.04	0.00	0.04	61	142	3	9*
16	0.38	0.21	0.24	0.28	0.17	-0.03	0.13	140	8	60*	5
17	0.56	0.29	0.26	0.37	0.26	0.03	0.30	23	110	80*	2
18	0.35	0.22	0.18	0.25	0.13	0.05	0.17	75	54*	80	3
19	0.50	0.31	0.15	0.32	0.19	0.16	0.35	69*	44	59	32
20	0.38	0.19	0.15	0.24	0.18	0.05	0.23	56	52*	38	49

* denotes correct answer

A P P E N D I X 5.2.(h)

Showing question analysis, and frequency of answers of fourth year pupils

(No. of pupils - 258)

Question No.	Question Analysis							Frequency of answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	0.93	0.80	0.62	0.78	0.13	0.19	0.31	21	29	202*	5
2	0.91	0.83	0.64	0.79	0.08	0.19	0.27	9	204*	7	36
3	0.47	0.29	0.20	0.32	0.17	0.09	0.27	38	10	125	82*
4	0.31	0.23	0.23	0.26	0.08	0.00	0.08	69	61	67*	58
5	0.92	0.84	0.58	0.78	0.08	0.26	0.34	24	201*	31	1
6	0.93	0.73	0.50	0.72	0.20	0.23	0.43	37	18	8	186*
7	0.57	0.47	0.48	0.50	0.10	-0.01	0.09	123	3	130	1
8	0.80	0.52	0.22	0.52	0.28	0.30	0.58	51	10	133*	58
9	0.76	0.57	0.27	0.53	0.19	0.30	0.49	30	43	46	137*
10	0.67	0.51	0.36	0.52	0.16	0.15	0.31	73	133*	32	16
11	0.65	0.39	0.29	0.45	0.26	0.10	0.36	115*	33	64	41
12	0.90	0.83	0.59	0.77	0.07	0.24	0.30	15	13	199*	28
13	0.79	0.84	0.41	0.68	-0.05	0.43	0.38	175*	63	14	5
14	0.83	0.71	0.53	0.69	0.12	0.18	0.29	22	14	42	178*
15	0.06	0.06	0.03	0.05	0.00	0.02	0.02	76	161	7	13*
16	0.48	0.23	0.16	0.29	0.24	0.07	0.32	157	16	75*	9
17	0.69	0.51	0.27	0.49	0.17	0.24	0.42	15	113	126*	2
18	0.49	0.31	0.20	0.33	0.17	0.12	0.29	83	86*	84	1
19	0.59	0.37	0.13	0.36	0.22	0.24	0.47	94*	59	74	28
20	0.48	0.23	0.16	0.29	0.24	0.07	0.31	77	75*	55	44

* denotes correct answer

A P P E N D I X 5.2.(i)

Showing question analysis and frequency of answers of fifth year pupils

(No. of pupils - 266)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	0.91	0.82	0.68	0.80	0.09	0.14	0.23	11	30	213*	5
2	0.88	0.85	0.77	0.83	0.02	0.09	0.11	4	221*	3	35
3	0.76	0.55	0.38	0.56	0.22	0.17	0.38	28	9	80	149*
4	0.23	0.22	0.12	0.19	0.01	0.09	0.11	82	17	50*	114
5	0.90	0.85	0.73	0.83	0.05	0.12	0.16	12	220*	29	3
6	0.98	0.82	0.69	0.83	0.16	0.13	0.29	26	8	6	220*
7	0.66	0.59	0.34	0.53	0.07	0.25	0.31	116	7	141*	1
8	0.94	0.80	0.54	0.76	0.15	0.25	0.40	35	5	202*	24
9	0.95	0.80	0.50	0.75	0.16	0.30	0.45	21	14	30	199*
10	0.51	0.51	0.47	0.50	0.0	0.04	0.04	99	132*	17	14
11	0.67	0.48	0.29	0.48	0.19	0.19	0.38	127*	43	63	28
12	0.95	0.82	0.63	0.80	0.14	0.18	0.32	3	9	213*	39
13	0.93	0.75	0.50	0.73	0.18	0.25	0.43	193*	63	7	1
14	0.81	0.72	0.54	0.69	0.09	0.17	0.26	9	19	51	183*
15	0.26	0.07	0.04	0.12	0.19	0.02	0.22	76	153	3	33*
16	0.59	0.30	0.29	0.39	0.30	0.01	0.30	150	10	104*	1
17	0.82	0.68	0.32	0.61	0.14	0.36	0.50	14	89	161*	0
18	0.66	0.45	0.27	0.46	0.20	0.19	0.39	55	122*	87	2
19	0.65	0.40	0.29	0.44	0.25	0.11	0.36	118*	79	39	25
20	0.63	0.39	0.24	0.42	0.24	0.14	0.38	70	111*	30	45

* denotes correct answer

CHAPTER 6

RESISTANCE

CHAPTER 6

RESISTANCE

In an electrical circuit, there are two distinct quantities. They are: (1) the driving power (or electric pressure) of the source, (2) the current or flow of electricity. The relationship between the size of the current and the size of the potential difference is one of the most important concepts in the study of the electricity.[131] This relationship gives rise to a new concept and it is the concept of resistance. P.E. Fayers (1972) has defined this term as "the ratio of the potential difference across a conductor to the current flowing through it."[132] This is the traditional definition of resistance. In the view of J.W. Warren (1976), this definition has mixed resistance with Ohm's law. He says "... confusion between the definition of resistance and the statement of Ohm's law is very common. It most likely originates in the absurd custom of stating the law first in terms of the proportionality of p.d. to the current and then defining resistance as the constant in the law." He adds, "This means that one cannot then logically consider any variation of resistance from any cause since it is a defined invariable." He further says, "Resistance is a more general concept which should be defined first, then Ohm's law should be stated as a rule for particular substances under defined conditions."[133] These views show that Ohm's law and resistance are two different things.

In this chapter, work is done to study the growth of understanding of the concept of resistance and the concepts of current and voltage on which resistance depends. This study was carried out over a period of two years in two stages.

6.1. First Stage of the Unit.

A. Design of the stage.

(i) Objectives of the stage were defined.

(ii) Material preparation: this material consisted of (a) a path diagram, (b) an interview schedule.

(iii) Material application: the material was applied in 1975-76 session to the pupils of SII to SIV classes.

The details of the above mentioned items are as follows.

B. Objectives of the stage.

To study the concept of resistance, the material was prepared with the following objectives in mind: to learn about the pupils' knowledge of

(i) electric charge.

(ii) the electrical material, i.e. conductors and insulators.

To study the pupils' understanding of

(iii) the concept of voltage.

(iv) the concept of current.

(v) the effects of length and area of cross-section of a conductor (wire) on current.

(vi) the concept of resistance.

(vii) the effects of length and area of cross-section of conductor (wire) on resistance.

C. The material structure.

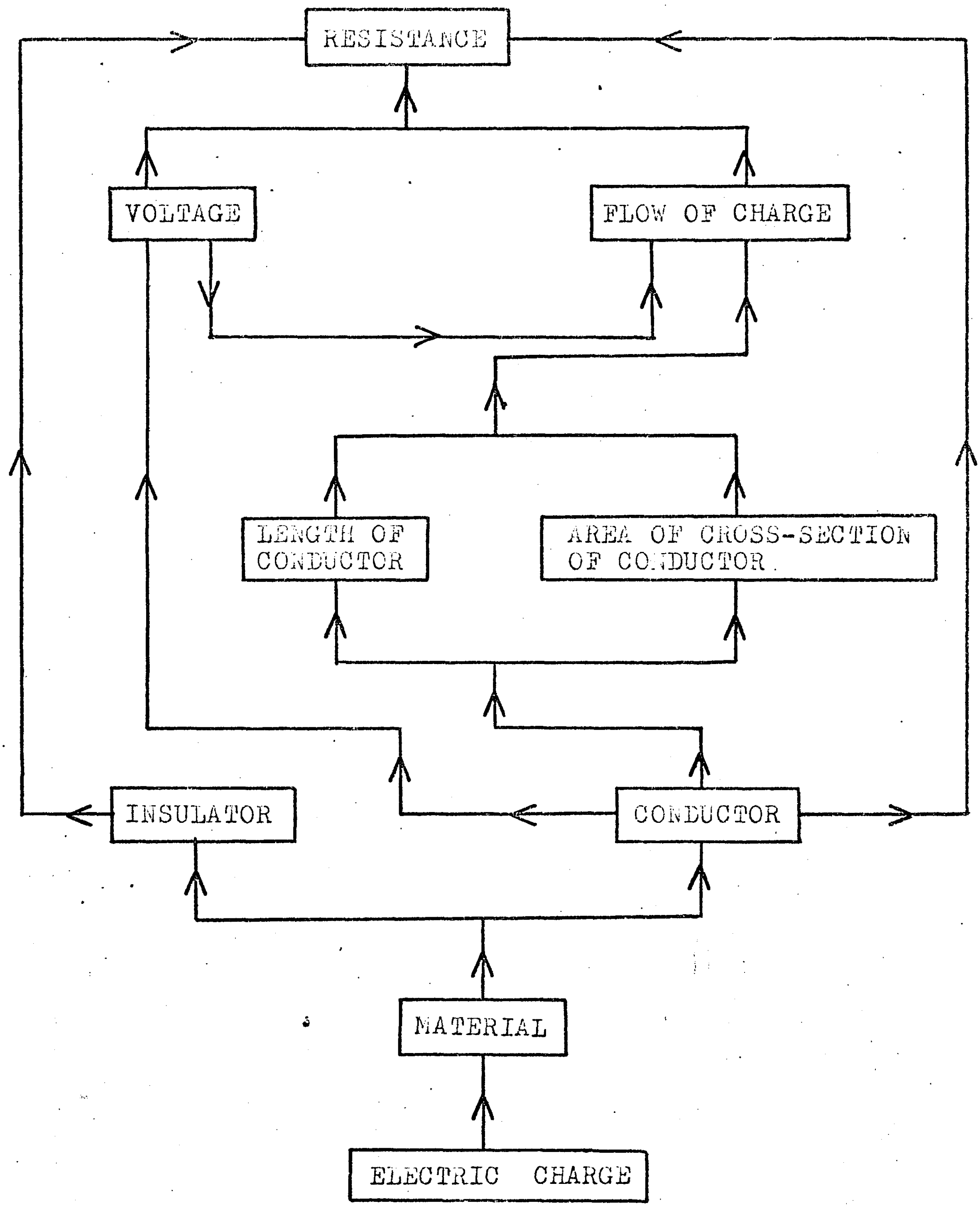


FIGURE 16

Path Diagram for the Concept of Resistance

Keeping in view the objectives of the unit, a 'net' for the study of the unit was prepared. The main parts of this net are: electric charge, material (conductor and insulator) length and area of cross-section of conductor, voltage, flow of charge (current) and resistance. The net or 'path diagram' is shown in Figure 16.

In the light of the path diagram, an interview schedule was prepared. The interview schedule appears as Appendix 6.1.(a).

D. How the material was applied.

The material was applied for the same purposes and in the same way as mentioned in section 5.1.D, to the pupils of SII to SIV classes. The information regarding the pupils who participated in interview appear as Appendix 6.1.(b). All the conditions mentioned in section 4.5.D. were fulfilled in conducting and recording the interview.

During the interview, the questions were asked after showing the following material: (i) polythene and glass rods, (ii) pieces of cloth, (iii) various insulators and conductors, (iv) pieces of wires of different material having different lengths and areas of cross-section, (v) battery cells, (vi) bulbs.

The interview was conducted by a third person and the time taken was about 30 minutes. Full details of an interview conducted in one class, along with prompts and probes[107] are shown in Appendix 6.1.(c).

E. Results.

After conducting the interview, the tapes were

Table 6.1.1

Showing summary of interview information given by various pupils for the concept of resistance

School 2

Class	Concept of charge	Idea about nature of elec. material	Effect of length of conductor on current	Effect of area of cross-section on current	Concept of current	Concept of voltage	Current-voltage relationship	Effect of length of conductor on resistance	Effect of area of cross-section on resistance	Concept of resistance
2nd Year	Not clear	Clear	Clear	Clear to half of the pupils	Clear to one-sixth of the pupils	Clear to one-sixth of the pupils	Clear	Clear	Clear to one-sixth of the pupils	Clear to one-sixth of the pupils
3rd "	Clear to one-third of the pupils	"	"	Clear to two-thirds of the pupils	Clear to half of the pupils	Clear to one-third of the pupils	"	"	Clear to one-third of the pupils	"
School 1										
3rd Year	"	"	"	"	Clear to half of the pupils	"	"	"	Clear to half of the pupils	"
4th Year	"	"	"	"	Clear to two-thirds of the pupils	Clear to half of the pupils	"	"	"	Clear to half of the pupils

analysed. The analysis of the interview of the various pupils conducted in two schools is shown in Appendix 6.1.(d).

Table 6.1.1 shows the summary of the information given by the pupils. This table confirms the trend of results mentioned in chapters 3, 4 and 5 and, reveals that pupils' understanding of the concept is consistent and the general trend is that as we proceed from second year to fourth year pupils, the number of pupils showing understanding of the concept increases, i.e. the understanding of the concept also depends upon the age level. When the age level increases, more growth takes place. For the concept of resistance, it is revealed that more growth starts taking place in fourth year and this is due to teaching. This is also shown by the pupils in their answers given in the interview. For example, when the pupils were asked "what is current?", the number of pupils who answered "it is flow of charge", was one in second year, three in third year and four in fourth year classes. When they were asked "what is voltage?", the answer "it pushes the electrons" was given by one pupil in second year. In third year, two pupils answered, others mixed it either with power or with electricity. There were three pupils who replied correctly in fourth year. Similarly, when they were asked about "what is resistance?", no one replied in second year. In third year one pupil replied "stopping the electricity flow". In fourth year, three pupils replied "electricity does not pass easily". So the number of pupils showing the understanding of the concept was more in fourth year level than the other two earlier classes but even this was only half of the pupils and, moreover, the topic was taught in this year. To the researcher, it seems that the natural level and the age at which this concept can be taught effectively is fifth year.

6.2. The Second Stage of the Unit.

A. Design of the stage.

(i) Objectives of this stage were defined.

(ii) Material preparation: this material consisted of a diagnostic picture test.

(iii) Material application. This material was applied in 1976-77 session to the pupils of SII through to Higher grade (SV) classes. The details of the above mentioned items are as follows.

B. Objectives of the second stage.

The objectives of this stage remained the same except that one more objective was added and that is:

(viii) To study the validity of the new test technique introduced for the study of the concept.

C. The material structure.

In the light of the views and recommendations mentioned in Section 4.3, a new type of diagnostic test, somewhat similar to the test mentioned in Section 4.6.C was prepared. In this test, the technique used in Section 4.6.C was slightly modified. In place of 'multiple response', multiple choices were given in this test and the pupils were asked to select a 'correct choice' with the help of picture(s) in the same way as they selected objects in the interview. Because of this, it was called "a pictorial multiple choice test."

This test was prepared to study the main concept of resistance and two subordinate concepts, i.e. current and voltage. In all, the test comprises 14 questions. Keeping in view the purposes mentioned in section 4.6.C, the items were prepared according to Bloom's first three levels. The item specifications, key and explanation of items appear as Appendix 6.2.(a). The test appears as Test Three in Appendix 6.2.(b).

D. How the material was applied.

In order to study the understanding of the pupils about the concept and also to learn about its growth, the test was applied to 102 second year, 236 third year, 283 fourth year and 247 fifth year pupils in four schools during 1976-77.

As the design of the responses in the test was the same as that of Test Two, mentioned in Section 5.2.C, 'a computer mark sense card' method was used for data processing.

The steps mentioned in Section 5.2.D were taken to reduce the management problems. The covering letter to the principal teachers is the same as mentioned in Section 5.2.D and is shown in Appendix 5.2.(d) and the sheet of instructions for subject teachers appears as Appendix 6.2.(c).

E. Results.

The data of the test was processed by computer in a similar way as done in section 5.2.E. The details of the results of second, third, fourth and fifth year pupils appear in Appendix 6.2.(d), 6.2.(e), 6.2.(f) and 6.2.(g)

Table 6.2.1

Showing the facility values of the pupils

Question No.	2nd Year*	3rd Year	4th Year	5th Year
1	0.85	0.83	0.96	1.00
2	0.70	0.66	0.80	0.89
3	0.29	0.21	0.40	0.65
4	0.49	0.63	0.74	0.74
5	0.77	0.75	0.84	0.91
6	0.81	0.78	0.83	0.92
7	0.94	0.86	0.90	0.96
8	0.43	0.34	0.38	0.57
9	0.17	0.07	0.23	0.26
10	0.37	0.36	0.38	0.50
11	0.75	0.72	0.87	0.91
12	0.25	0.35	0.47	0.69
13	0.68	0.60	0.64	0.72
14	0.81	0.81	0.92	0.98

* F.V. = Mean of $T_1 + T_2$ appearing in Appendix 6.2.(d)

respectively.

Table 6.2.1 shows the summary of the facility values of these years. The facility values of second year pupils were computed in the same way and for the same reasons mentioned in section 5.2.E.

6.3. Discussion.

The unit was applied in two stages: (i) interview and (ii) test. To facilitate the discussion and to present the results of the questions in an 'easy to see' manner, the test questions are divided into three parts. Part I comprised questions 1 to 5; Part II, questions 6 to 10; and Part III, questions 11 to 14. Let us look at each part.

Part I.

1. Look at the diagram in box 1. Which object in the circuit diagram is the resistor?

This question is intended to look for the knowledge of symbols. The answer, choice 'A' is strong and is seen to increase with age almost linearly.

2. In picture 1 the bulb is not glowing. To find out why, the first thing you would check would be

   A. the e.m.f. of the cell.

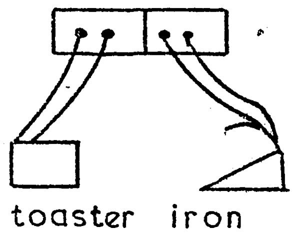
   B. that the switch is closed.

   C. the filament of the bulb.

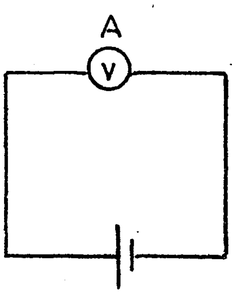
   D. the resistance of the resistor.

This question is meant to learn about the knowledge of circuits. The answer required is choice 'B' which is strong and is seen to increase with age almost linearly.

3. The two appliances in picture 14 are wired to



14



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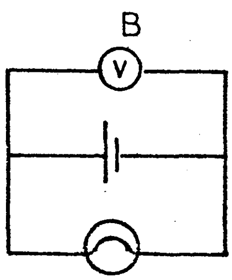

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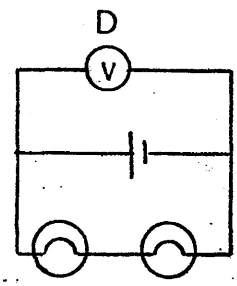

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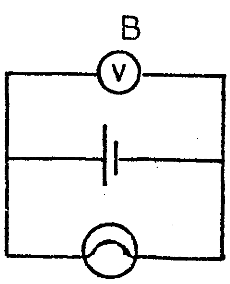
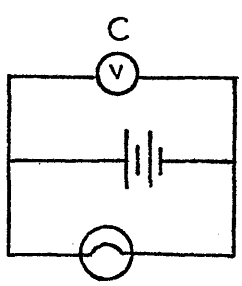
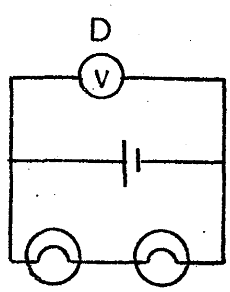


7



8



9

the mains parallel with each other so that they may have the same

A. current in them.

B. operating temperature.

C. voltage across them.

D. power supplied to them.

This question attempted to establish if the pupils had any idea about voltage in a parallel system. Choice 'C' was the answer sought but, even in fifth year not all pupils were making this choice. However, choice 'D' was chosen almost twice as frequently as 'C' by second and third year pupils revealing that they were mixing voltage with power. This was also revealed in the interview. Fourth and fifth year pupils marked this choice 'D' in second place, revealing the same confusion between power and voltage.

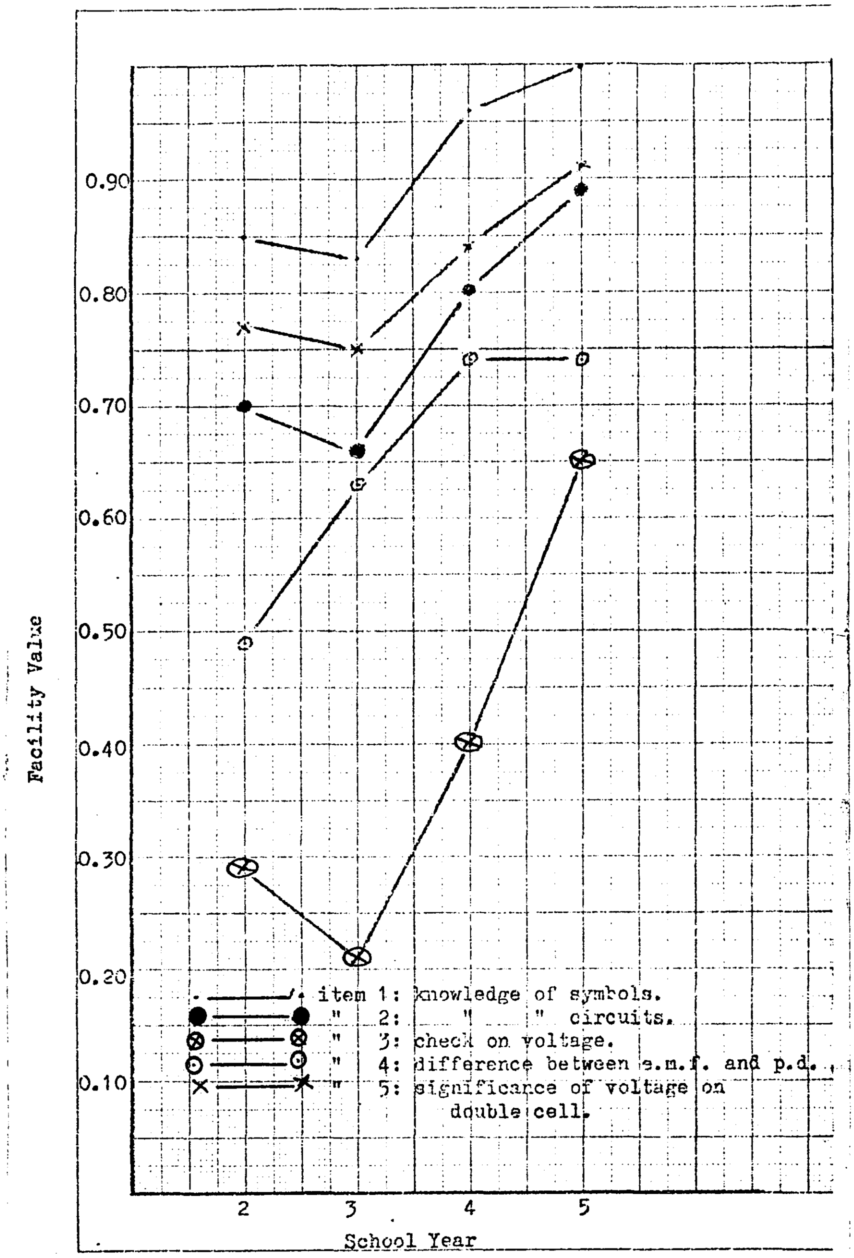
4. In pictures 6, 7 and 9, which voltmeter (V) would have the highest reading?

(Please fill in boxes on the card, the letter written over (V).)

This question is trying to establish if the pupils know about the difference between p.d. and e.m.f. Here pupils are presented with no lamp; one lamp-one cell; and two lamps - one cell situations. The answer required is choice 'A', which is seen to increase with age almost linearly.

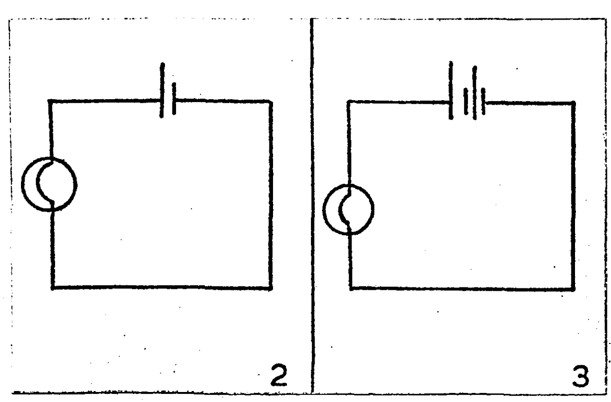
5. In pictures 7, 8 and 9, which voltmeter (V) would have the highest reading?

(Please fill in boxes on the card, the letter written over (V).)



Facility Value
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
2
3
4
5
School Year
item 1: knowledge of symbols.
" 2: " " circuits.
" 3: check on voltage.
" 4: difference between e.m.f. and p.d.
" 5: significance of voltage on double cell.

Figure 17



2
3

This question is intended to look for the significance of the double cell, which in turn is related to greater voltage in the circuit. Here pupils are presented with one cell - one lamp, two cells - one lamp and, one cell - two lamps situations. The answer choice 'C' is strong and is seen to increase with age almost linearly showing that they realise the importance of the two cells.

The results of this part are plotted and are shown in Figure 17. In this figure, four areas show a gradual and almost linear change as a possible result of their constant use in the laboratory. These areas are: knowledge of symbols and circuits; difference between e.m.f. and p.d.; and significance of double cell in circuit. One area shows a marked improvement with age and with the reappearance of formal teaching in fifth form. This is the area of 'voltage'.

Part II.

6. Look at pictures 2 and 3. In picture 2, the bulb is not lit but in picture 3, it is lit fairly brightly. This is because there

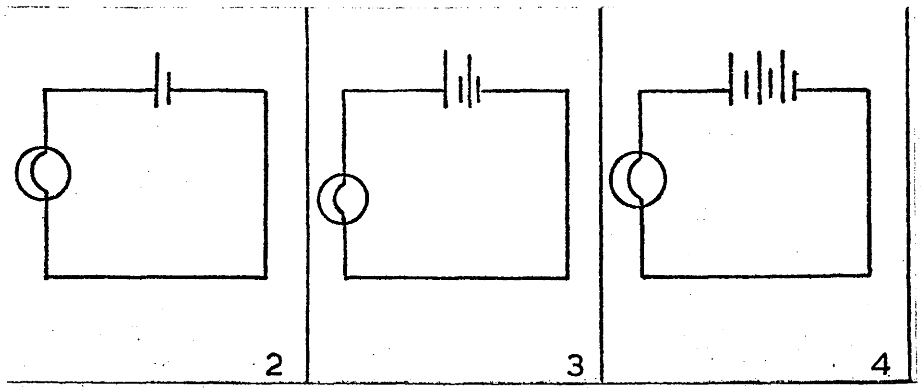
A. is more power in 2 than in 3.

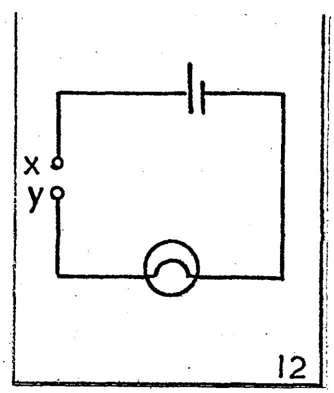
B. is more voltage in 3 than in 2.

C. are more electrons flowing in 2 than in 3.

D. is more resistance in 3 than in 2.

This question is trying to establish if the pupils have any idea about the relationship between voltage and current. Here pupils are presented with one lamp - one cell and one lamp - two cell situations. The answer required is choice 'B' which is strong and is seen to increase with age almost linearly.


2
3
4


x
y
12

7. Compare the circuit in picture 4 with the circuits in pictures 2 and 3. How would you expect the brightness of the bulb in picture 4 to appear?

A. Same as the bulb in 2.

B. Same as the bulb in 3.

C. Brighter than the bulb in 3.

D. Dimmer than the bulb in 2.

This question is a cross-check on question 6. Here pupils are presented with one lamp - one cell, one lamp - two cells, one lamp - three cells situations. The answeris choice 'C' which is strong and is seen to increase with age almost linearly.

8. In picture 12, a pupil wishes to bridge the gap between x and y so that the lamp may glow as brightly as possible. He should use a

A. short thick conductor.

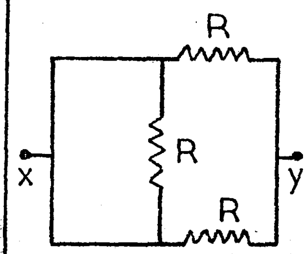
B. short thin conductor.

C. long thick conductor.

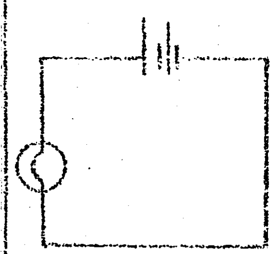
D. long thin conductor.

This question was attempting to establish if the pupils have ideas about the effects of length and cross-sectional area of conductor (wire) on current. The answer required is choice 'A' which is weak until fifth year. However, 'B' is chosen more than the correct answer by the pupils of second, third and fourth year classes. Pupils of fifth year have marked this choice in second place. This reveals that the effect of area of cross-section on current is not clear to the pupils and this is creating trouble.

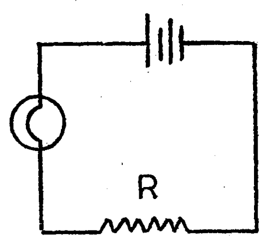
9. In picture 16, each resistor has the same



16



3



5

resistance. The resistance measured between the terminals x and y will be

A. 3R. C. R.

B. 2R. D. R/2.

This question was intended to look for the idea of series parallel resistance arrangement which in turn points towards the concept of resistance. The answer required was choice 'D' which is weak until fifth year and even then it is by no means accepted. However, the majority of the pupils in all classes chose 'B' in second place, revealing that they were not clear in the concept of resistance in parallel.

10. Look at the circuits in pictures 3 and 5. In picture 3, the bulb is well lit but in 5, it is not lit so brightly. This is because

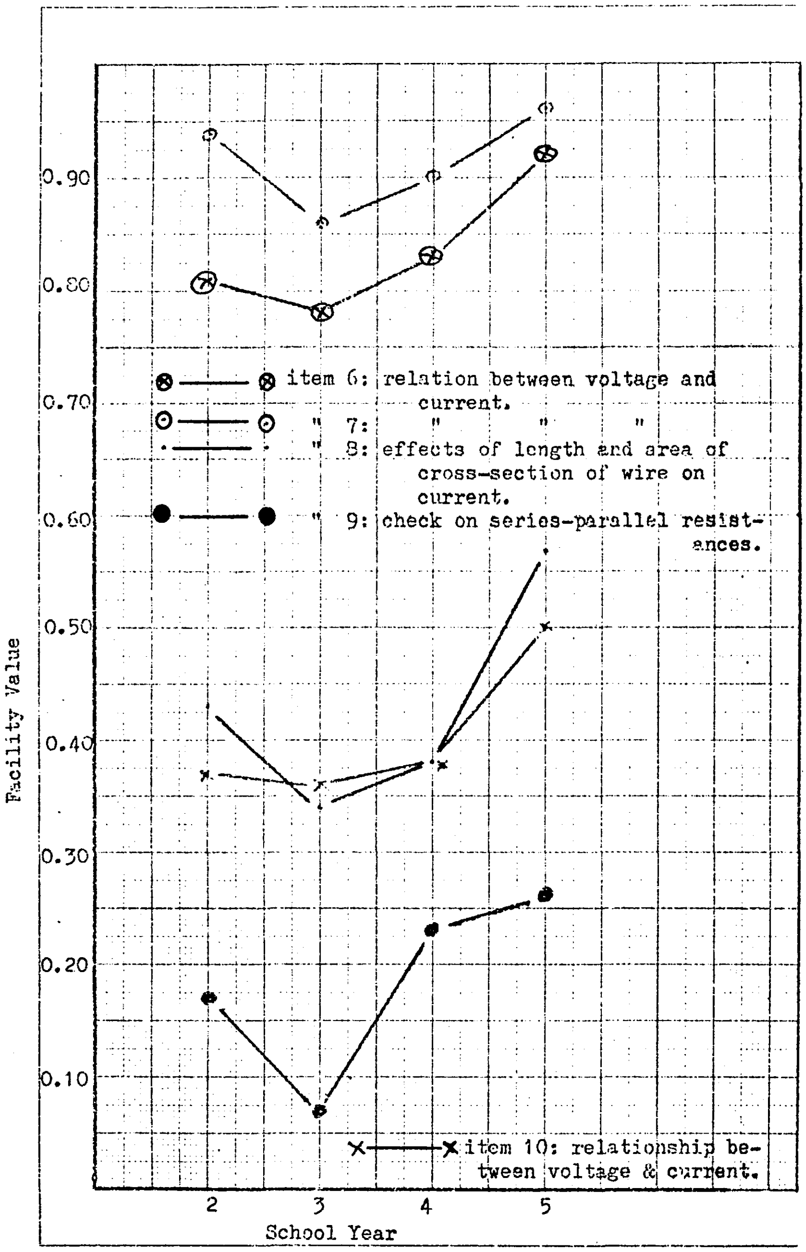
A. R is hotter than the bulb.

B. R has a greater resistance than the resistance of the bulb.

C. the voltage across the bulb in 3 is less than the voltage across the bulb in 5.

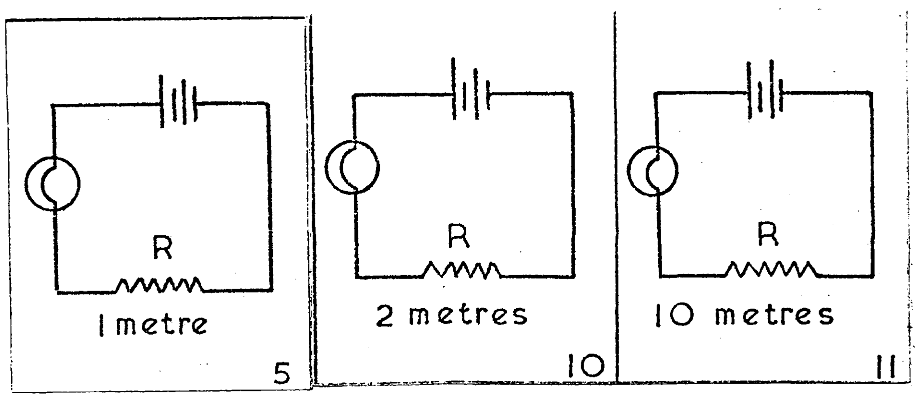
D. the voltage across the bulb in 3 is more than the voltage across the bulb in 5.

This question is a cross-check on questions 6 and 7. This is meant to reveal the pupils' ideas of the relationship between voltage and current. The answer required is choice 'D' which is weak until fifth year and even then it is by no means accepted. However, pupils in second to fourth year classes chose 'B' more than the correct choice, showing some understanding of another relationship, which is between current and resistance. Pupils of fifth year



0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
Facility Value
item 6: relation between voltage and current.
" 7: " " "
" 8: effects of length and area of cross-section of wire on current.
" 9: check on series-parallel resistances.
item 10: relationship between voltage & current.
2
3
4
5
School Year

Figure 18



R
1 metre
5
R
2 metres
10
R
10 metres
11

have marked this choice in second place, revealing the same understanding shown by lower classes.

The results of this part are shown plotted in Figure 18. In this figure, four areas show a gradual and almost linear change, presumably as an experience of every day application in the laboratory. These areas are: relationship between voltage and current and series parallel resistance arrangement. One area shows a marked improvement with age and with reappearance of formal teaching in fifth form. This is area of "effects of length and cross-sectional area of conductor (wire) on current".

Part III.

11. Compare pictures 5, 10 and 11. In all of them, the resistors are made of the same wire but the wire is not of the same length. Which one of the following statements is correct?

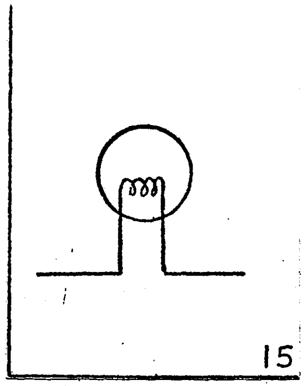
A. Of the three, the bulb in 5 will glow brightest.

B. Of the three, the bulb in 11 will glow brightest.

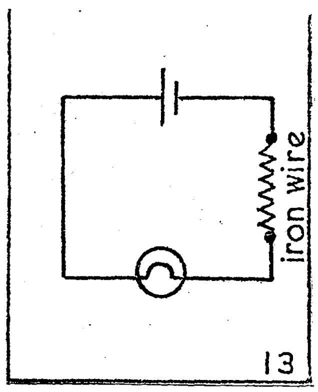
C. The bulb in 11 will be brighter than the one in 10.

D. The bulb in 10 will be twice as bright as the one in 5.

This question is trying to establish if the pupils have an idea about the effect of length of conductor (wire) on resistance. The answer required is choice 'A', which is strong and is seen to increase with age almost linearly. This confirms their knowledge of the direct relationship between length and resistance.



15



13

12. In picture 15, a bulb is shown. The filament of the bulb becomes white hot although the connecting leads to it are cold. Which statement could explain this? The filament

A. is wound into a coil.

B. is thinner than the leads.

C. is of shorter length than the leads.

D. carries a higher current than the leads.

This question was intended to look for the effect of area of cross-section of conductor (wire) on resistance. The choice 'B' was the answer sought but even at fifth year not all pupils were making this choice. However, the majority of pupils in second and third year classes chose 'D' in second place, revealing that they are not clear in the effect of area of cross-section of conductor on current, confirming the result stated in question 8. The pupils of fourth and fifth years placed 'A' in second place, revealing that the shape of the conductor is interfering with area of cross-section.

13. In picture 13, there is a length of iron wire connected in the circuit. If this wire is replaced by a copper wire having the same length and area of cross-section, how well would the bulb light?

A. It will light equally well.

B. With iron wire, it will light brighter.

C. With copper wire, it will light brighter.

This question is trying to establish if the pupils have any idea about the nature of material of the conductor (wire) on resistance. The choice 'C' was the answer sought but even at fifth year not all pupils were

Table 6.2.2

Showing general summary of interview information and test results of concept of resistance

School 2: Interview Results

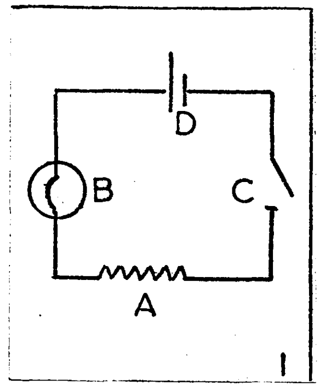
Class	Concept of charge	Idea about nature of material	Effect of length of conductor on current	Effect of area of cross-section of conductor on current	Concept of current	Concept of voltage	Current-voltage relationship	Effect of length of conductor on resistance	Effect of area of cross-section on resistance	Concept of resistance
2nd Year	Not clear	Clear	Clear	Clear to half of the pupils	Clear to one-sixth of the pupils	Clear to one-sixth of the pupils	Clear	Clear	Clear to one-sixth of pupils	Clear to one-sixth of pupils
3rd "	Clear to one-third of the pupils	"	"	Clear to two-thirds of the pupils	Clear to half of the pupils	Clear to one-third of the pupils	"	"	Clear to one-third of the pupils	"
School 1										
3rd Year	"	"	"	"	Clear to half of the pupils	"	"	"	Clear to half of the pupils	"
4th "	"	"	"	"	Clear to two-thirds of the pupils	Clear to half of the pupils	"	"	"	Clear to half of the pupils

Table 6.2.2 (continued)

Test Results

Class	Concept of charge	Idea about nature of material	Effect of length of conductor on current	Effect of area of cross-section of conductor on current	Concept of current	Concept of voltage	Current-voltage relationship	Effect of length of conductor on resistance	Effect of area of cross-section on resistance	Concept of resistance
		Q.13	Q.8	Q.8*		Q.3	Q.7	Q.11	Q.12	Q.9
2nd Year	-	0.68	0.43	0.43	-	0.29	0.94	0.75	0.25	0.17
3rd "	-	0.60	0.34	0.34	-	0.21	0.86	0.72	0.35	0.07
4th "	-	0.64	0.38	0.38	-	0.40	0.90	0.87	0.47	0.23
5th "	-	0.72	0.57	0.57	-	0.65	0.96	0.91	0.69	0.26

*Note: Although these results are low, a confusion is arising over cross-sectional area and not length.


D
B
C
A
1

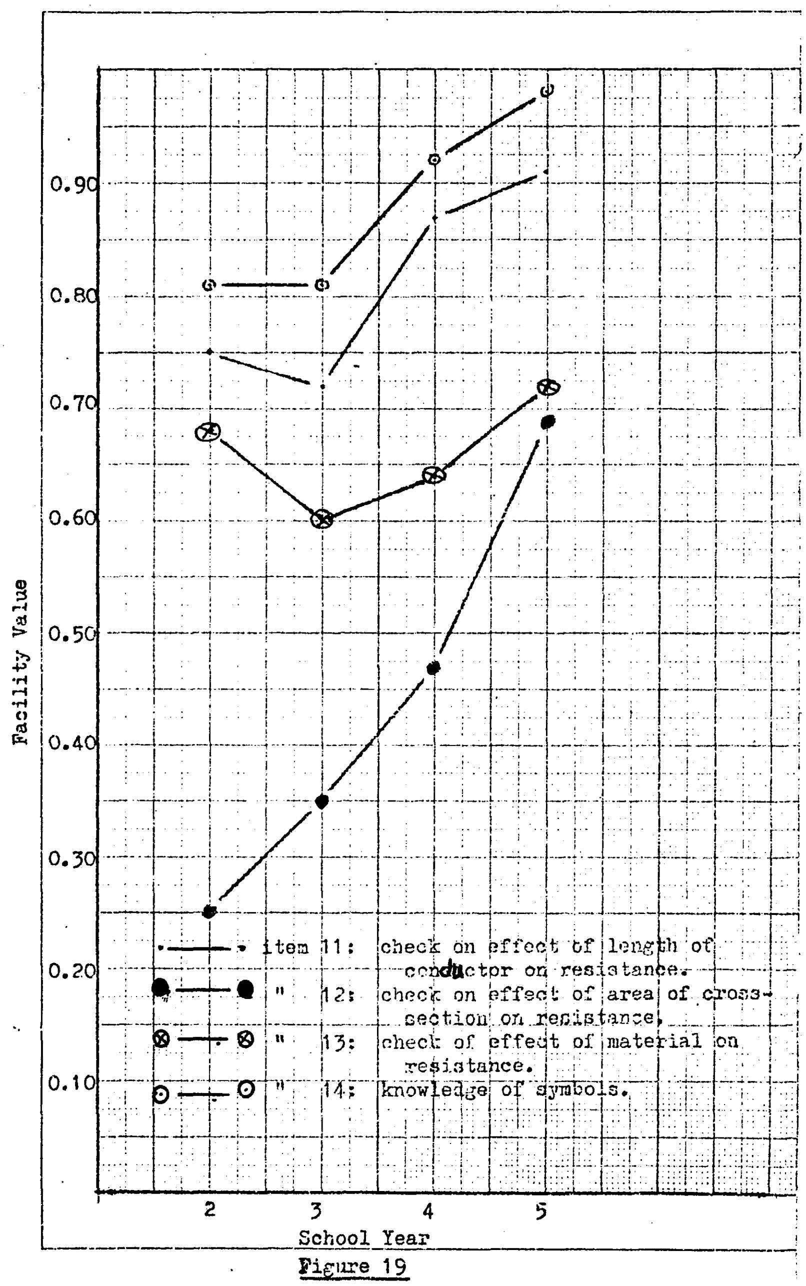

0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
Facility Value
item 11: check on effect of length of conductor on resistance.
" 12: check on effect of area of cross-section on resistance.
" 13: check of effect of material on resistance.
" 14: knowledge of symbols.
2
3
4
5
School Year

Figure 19

making this choice. One would have expected experience to improve scores here more rapidly.

14. Look at the diagram in box 1. Which object in the circuit diagram is the cell (battery) ?

This question is meant to check on the knowledge of symbols. The answer required is choice 'D' which is strong and is seen to increase with age almost linearly.

The results of this part are shown plotted in Figure 19. In this figure, three areas show a gradual and almost linear change, presumably as a result of experience of every day application. These areas are: effect of the length of a conductor on resistance, effect of material on resistance and knowledge of symbols. One area shows a marked improvement with age and reappearance of formal teaching in fifth form. This area is "effect of area of cross-section on resistance".

A general summary showing the results of the interview and the test is given in Table 6.2.2. Comparing both the results we find that there is a good agreement between the results about the nature of material, i.e. conductors and insulators.

There are no direct questions asked about charge and current in the test.

Regarding the effect of length of conductor on current, there is no separate question asked in the test. However, the popular choices were 'A' and 'B' in question 8. In both cases the short conductor has been chosen but the confusion arises with cross-sectional areas.

For the effect of area of cross-section of conductor on current, there seems a good agreement between the results.

Regarding the concept of voltage, there is good agreement between test results and interview results.

Both of the results show the best agreement for current-voltage relationship.

The results also show very good agreement regarding the effect of length of conductor on resistance.

Regarding the effect of area of cross-section on resistance, there seems a good agreement between the results.

For the concept of resistance, there is a little agreement between the results. To the researcher, it seems that this is due to the format of the question. If the question were modified to test resistance alone without the interference of parallel and series arrangements, the scores would almost certainly improve.

6.4. Conclusion

After going through the discussion, the researcher has arrived at the following conclusions.

1. Pupils have complete knowledge about electrical symbols.

2. They have clear ideas about circuits.

3. The concept of voltage is not completely clear to the pupils of all classes. They are mixing it with power.

4. The practical difference between e.m.f. and p.d. is clear to the pupils to a large extent although they may not understand the theoretical differences.

5. Pupils are very clear about the relationship between voltage and current.

6. Pupils are clear about the effect of length of conductor (wire) on current and resistance.

7. Pupils are not clear about the effect of area of cross-section of conductor (wire) on current and resistance.

8. To some extent, pupils are clear about the nature of electrical conducting materials and their effect on resistance.

9. The concept of resistance is not clear to the pupils even at fifth year level.

10. After comparing the test results with the interview information, it is concluded that there is a good agreement between both the techniques and to a large extent, the test has worked effectively and is valid. However, due to a possible fault in format of question 9, there is little agreement seen in the results. This could be improved by changing the format of the question, as mentioned earlier.

APPENDIX 6.1.(a)

Interview schedule for the concept of resistance.

1. (Rubbing the polythene rod with cloth) What has happened to rod?
2. What is an electric charge?
3. How does the electric charge move from one body to another?
4. There are two different kinds of materials as far as carrying current is concerned. What are they?
5. What is a conductor?
6. What is an insulator?
7. What would you mean by electric current?
8. (Showing pieces of thin and thick wire) In which will a current pass most easily?
9. (Showing long and short pieces of wire) In which will a current pass most easily?
10. What makes a current pass through a conductor?
11. What do you mean by potential difference?
12. Why does no current pass through an insulator?
13. What would you mean by resistance?
14. There are two pieces of wire, A and B. For wire A, large p.d. is needed to make the current flow. For wire B, small p.d. produces the same current. Which wire is offering more resistance?
15. (Showing the thick and thin pieces of carbon rod of the same length) Which piece of rod will offer less resistance?
16. (Showing the large and short pieces of copper wire of same cross-section) Which piece of wire will offer more resistance?

(Showing pieces of wire of different materials, but having the same length and cross-section, e.g. eureka, iron and copper)

17. Which piece of wire will offer most resistance?

18. Which piece of wire will offer least resistance?

(Showing four pairs of wire of different length and cross-section)

19. Which pairs are likely to offer the same resistance?

APPENDIX 6.1.(b)

Showing list of pupils, their years in schools, chronological age, I.Q., and mental age.

School 1

Year	Code letter used for pupil	Rank in class	C.A. Years	C.A. Months	I.Q.	M.A.
2nd Year	A	Top	14	4	140+	16+
" "	B	"	15	4	-	-
" "	C	Middle	14	3	129	16+
" "	D	"	14	2	127	16+
" "	E	Lower	14	1	115	16+
" "	F	"	14	7	112	16+
3rd Year	A	Top	14	10	140+	16+
" "	B	"	14	8	140+	16+
" "	C	Middle	15	8	139	16+
" "	D	"	15	6	121	16+
" "	E	Lower	15	8	115	16+
" "	F	"	15	4	112	16+
School 2 3rd Year	A	Top	14	10	140+	16+
" "	B	"	14	4	140+	16+
" "	C	Middle	14	8	130	16+
" "	D	"	16	6	-	-
" "	E	Lower	17	4	-	-
" "	F	"	15	7	89	14
4th Year	A	Top	16	4	140	16+
" "	B	"	16	4	140	16+
" "	C	Middle	16	3	140	16+
" "	D	"	16	7	125	16+
" "	E	Lower	16	8	-	-
" "	F	"	16	1	117	16+

APPENDIX 6.1.(c)

Showing details of interview conducted with third year pupils in one school.

T: (Showing polythene rod rubbed with a piece of cloth) What has happened to this rod?

A: It has become electrified.

C: It has become charged.

T: What do you mean by an electric charge?

F: It has got energy in it.

C: It attracts certain particles.

T: What sort of particles?

C: Positive and negative.

A: It is electrons which make charge.

T: What sort of charge has an electron got?

F: Negative.

T: What other type of charge is there?

B: Positive.

T: In what way does charge move from one object to another?

A: Negative to positive.

T: (Showing different conductors and insulators and pointing towards copper) Will that allow electrons to move?

All: Yes.

T: Glass?

All: No.

T: Plastic?

All: No.

T: Piece of iron?

All: Yes.

T: Wood?

All: No.

T: Polythene?

All: No.

T: Aluminium?

All: Yes.

T: Carbon rod?

All: Yes.

T: Can you tell me the name of the things which allow the charge to pass through them?

F: Good conductors.

T: What is the name we give to glass, wood, plastic, etc.?

D: Non-conductors.

E: Poor conductors.

T: (Showing pieces of wires of the same material - one thick and one thin) Which one will allow current to pass the best?

A,D,E & F: Thick one.

B & C: Thin one.

T: (Showing different lengths of wire of same material) Which one allows a better current?

D & E: Long one.

A,B,C & F: Short one.

T: What is making the current flow?

A: Battery.

T: What will happen if there is no battery?

D & E: Bulb will not glow.

T: What is the name for the push or drive which we get from battery or cell?

A: Energy.

C: Potential energy.

T: What is the common name for such energy?

B: Power.

D: Electricity.

A: Voltage.

T: What happens if I use more voltage?

A: The current is bigger.

T: If I use here a piece of plastic, would there be a current?

All: No.

T: What is electric current?

C: It is flow of electrons.

T: Does anybody know the word which we use for a wire which allows big current or small current?

B: Resistance.

T: What do you mean by resistance?

A: How much amperage we need for wire breaking.

T: (Showing thick wire and thin wire) Which one has the bigger resistance?

F: Thin wire.

T: (Showing short wire and long wire) Which offers bigger resistance?

All: Long wire.

T: (Showing two pieces of carbon rods having different areas of cross-sections) Which will have the bigger resistance?

D: Thin one.

T: (Showing two pieces of copper wire having different lengths) Which one will have the bigger resistance?

B: Small one.

T: What is resistance?

B: Electricity does not pass easily.

APPENDIX 6.1.(d)

Analysis of interviews of the various pupils in two schools.

School 2

Second Year

I. Charge.

The pupils knew "how to charge a body".

They knew about the kinds of charge.

They did not know completely "what is an electric charge".

II. Nature of electrical material.

The pupils knew about conductors and insulators.

III. Current.

One-sixth of the pupils knew about "what is current".

The effect of length of wire on current was clear to the pupils.

Half of the pupils knew about the effect of area of cross-sections of wire on current.

IV. Voltage.

One-sixth of the pupils knew about voltage.

V. Current-voltage relationship.

The pupils were clear about this relationship.

VI. Resistance.

One-sixth of the pupils knew about resistance.

The effect of length of wire on resistance was clear to the pupils.

The effect of area of cross-section of wire on resistance was clear to one-sixth of the pupils.

VII. Current-resistance relationship.

The pupils were not clear about this relationship.

Third Year

I. Charge.

The pupils knew "how to charge a body".

They knew about the kinds of charge.

One-third of the pupils knew about "what is charge".

II. Nature of electrical material.

The pupils knew about conductors and insulators.

III. Current

Half of the pupils knew about "what is current".

The effect of length of wire on current was clear to the pupils.

The effect of area of cross-section of wire was clear to two-thirds of the pupils.

IV. Voltage.

One-third of the pupils knew about voltage.

V. Current-voltage relationship.

The pupils were clear about this relationship.

VI. Resistance.

One-sixth of the pupils knew about resistance.

The effect of length of wire on resistance was clear to the pupils.

The effect of cross-sectional area of wire on resistance was clear to one-third of the pupils.

VII. Current-resistance relationship.

The pupils were not clear about this relationship.

School 1

Third Year

I. Charge

The pupils knew "how to charge a body".

They knew about the kinds of charge.

One-third of the pupils knew about "what is charge".

II. Nature of electrical material.

The pupils knew about conductors and insulators.

III. Current.

The concept of current was clear to half of the pupils.

The effect of length of wire was clear to the pupils.

The effect of area of cross-section of wire was clear to two-thirds of the pupils.

IV. Voltage.

One-third of the pupils knew about voltage.

V. Current-voltage relationship.

The pupils were clear about this relationship.

VI. Resistance.

One-sixth of the pupils knew about resistance.

The effect of length of wire on resistance was clear to the pupils.

The effect of area of cross-section of wire on resistance was clear to half of the pupils.

VII. Current-resistance relationship.

The pupils were not clear about this relationship.

Fourth Year

I. Charge.

The pupils knew "how to charge a body".

They knew about the kinds of charge.

One-third of the pupils knew about "what is charge".

II. Nature of electrical material.

The pupils knew about conductors and insulators.

III. Current

Two-thirds of the pupils were clear about current.

The effect of length of wire on current was clear to the pupils.

The effect of cross-sectional area of wire was clear to two-thirds of the pupils.

IV. Voltage.

Half of the pupils knew about voltage.

V. Current-voltage relationship.

The pupils were clear about this relationship.

VI. Resistance.

Half of the pupils knew about resistance.

The effect of length of wire on resistance was clear to the pupils.

The effect of area of cross-section of wire on resistance was clear to half of the pupils.

VII. Current-resistance relationship.

This relationship was clear to half of the pupils.

APPENDIX 6.2.(a)

Showing Bloom's levels, key and explanation of questions of Test Three.

Question No.	Bloom's level	Key	Explanation
1	B1	A	Knowledge of symbols.
2	B1	B	Knowledge of circuits.
3	B2	C	Check on voltage. If any of A, B and D, mising voltage with current and power, so idea not clear.
4	B3	A	If B and D, don't know about the difference between e.m.f. and p.d.
5	B3	C	If B and D, missed the significance of double cell.
6	B2	B	Relationship between voltage and current. If any of A, C and D, the idea is mixed with power, current and the resistance, respectively.
7	B3	C	Relationship between voltage and current. If A, B and D, missing the significance of voltage.
8	B3	A	Check on effects of length and cross-sectional area of conductor on current. If any of B, C and D, the effects are not clear.
9	B3	D	Check on series parallel resistance arrangement.
10	B2	D	Relationship between voltage and current. If A, relationship is not clear. If C, relationship between voltage and resistance is

			not clear. If B, the inverse relationship between current and resistance is clear.
11	B3	A	Check on effect of length of conductor on resistance. If B, C or D, the effect is not clear.
12	B2	B	Check on effect of area of cross-section of conductor on resistance. If A, shape of the conductor is interfering. If C, length is interfering and if D, current, so effect not clear.
13	B3	C	Check on effect of material of conductor on resistance. If A and B, effect is not clear.
14	B1	D	Knowledge of symbols.

Note: B1 = Knowledge.

B2 = Comprehension.

B3 = Application.

APPENDIX 6.2.(b)

SCIENCE EDUCATION DEPARTMENT

UNIVERSITY OF GLASGOW.

Test Three

Resistance

1. Look at the diagram in box 1.

   (a) Which object in the circuit diagram is the resistor?

   (b) Which object in the circuit diagram is the cell (battery)?

2. In picture 1 the bulb is not glowing. To find out why, the first thing you would check would be

   A. the e.m.f. of the cell.
   B. that the switch is closed.
   C. the filament of the bulb.
   D. the resistance of the resistor.

3. The two appliances in picture 14 are wired to the mains parallel with each other so that they may have the same

   A. current in them.
   B. operating temperature.
   C. voltage across them.
   D. power supplied to them.

4. In pictures 6, 7 and 9, which voltmeter (V) would have the highest reading?

   (Please fill in boxes on the card, the letter written over (V).)

5. In pictures 7, 8 and 9, which voltmeter (V) would have the highest reading?

   (Please fill in boxes on the card, the letter written over (V).)

6. Look at pictures 2 and 3. In picture 2, the bulb is not lit but in picture 3, it is lit fairly brightly. This is because there

A. is more power in 2 than in 3.
B. is more voltage in 3 than in 2.
C. are more electrons flowing in 2 than in 3.
D. is more resistance in 3 than in 2.

7. Compare the circuit in picture 4 with the circuits in pictures 2 and 3. How would you expect the brightness of the bulb in picture 4 to appear?

A. Same as the bulb in 2.
B. Same as the bulb in 3.
C. Brighter than the bulb in 3.
D. Dimmer than the bulb in 2.

8. In picture 12, a pupil wishes to bridge the gap between x and y so that the lamp may glow as brightly as possible. He should use a

A. short thick conductor.
B. short thin conductor.
C. long thick conductor.
D. long thin conductor.

9. In picture 16, each resistor has the same resistance. The resistance measured between the terminals x and y will be

A. 3R.
B. 2R.
C. R.
D. R/2.

10. Look at the circuits in pictures 3 and 5. In picture 3, the bulb is well lit but in 5, it is not lit so brightly. This is because

A. R is hotter than the bulb.
B. R has a greater resistance than the resistance of the bulb.
C. the voltage across the bulb in 3 is less than the voltage across the bulb in 5.
D. the voltage across the bulb in 3 is more than the voltage across the bulb in 5.

11. Compare pictures 5, 10 and 11. In all of them, the resistors are made of the same wire but the wire is not of the same length. Which one of the following

statements is correct?

A. Of the three, the bulb in 5 will glow brightest.
B. Of the three, the bulb in 11 will glow brightest.
C. The bulb in 11 will be brighter than the one in 10.
D. The bulb in 10 will be twice as bright as the one in 5.

12. In picture 15, a bulb is shown. The filament of the bulb becomes white hot although the connecting leads to it are cold. Which statement could explain this? The filament

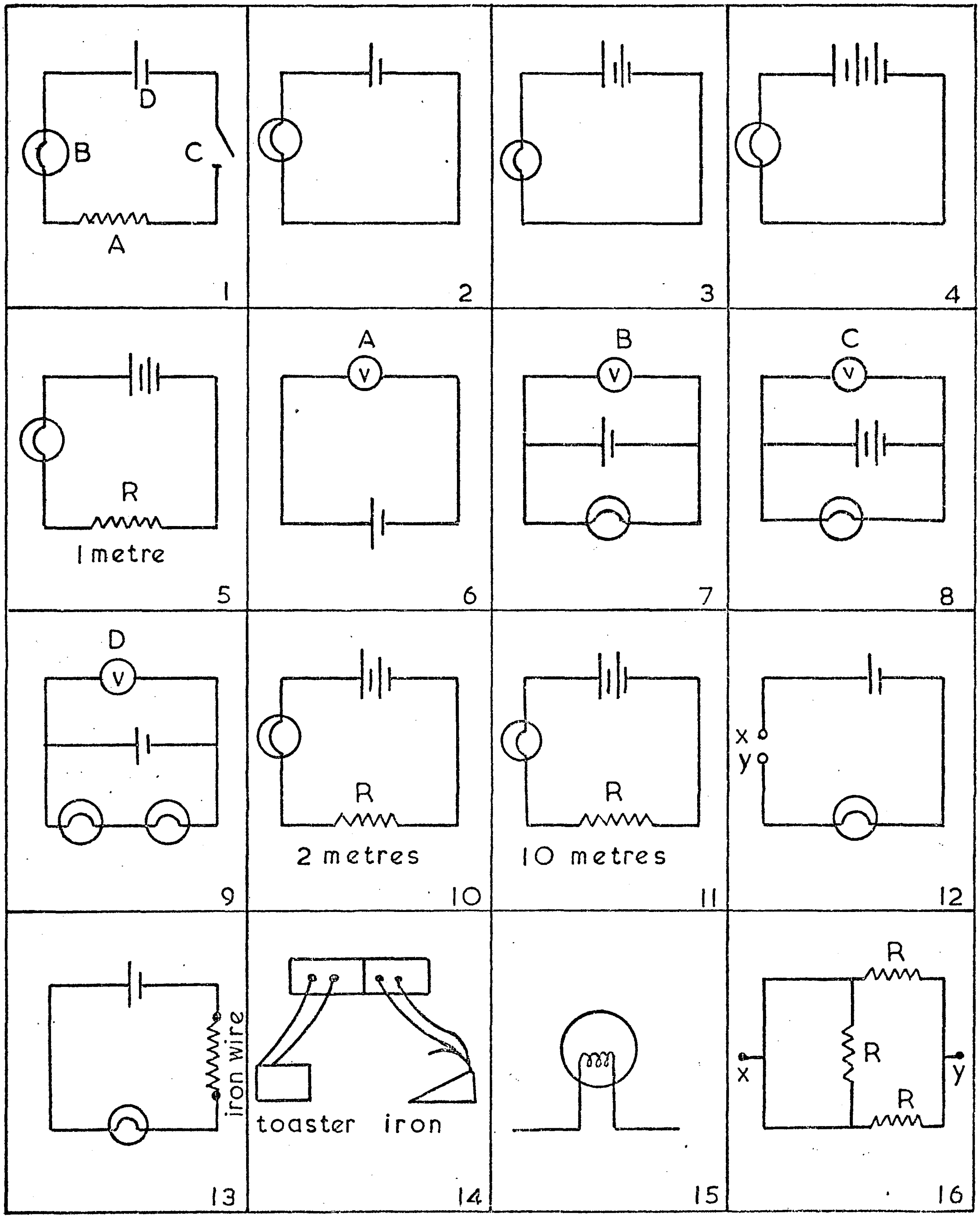
A. is wound into a coil.
B. is thinner than the leads.
C. is of shorter length than the leads.
D. carries a higher current than the leads.

13. In picture 13, there is a length of iron wire connected in the circuit. If this wire is replaced by a copper wire having the same length and area of cross-section, how well would the bulb light?

A. It will light equally well.
B. With iron wire, it will light brighter.
C. With copper wire, it will light brighter.

Note: Please treat question 1(b) as question 14.

Resistance



D
B
C
A
1
2
3
4
R
1 metre
5
A
V
6
B
V
7
C
V
8
D
V
9
R
2 metres
10
R
10 metres
11
x
y
12
iron wire
13
toaster
iron
14
15
R
R
R
x
y
16

APPENDIX 6.2.(c)

Sheet of instructions for subject teachers.

INSTRUCTIONS TO BE GIVEN TO PUPILS

1. This test is printed on both sides of the paper.
2. Answers for this test will be recorded on PINK computer cards by shading in the appropriate oval using a soft pencil (preferably 2B).
3. In the right-hand portion of every card, only the date will be written; no need of the name.
4. There are 6 columns in the left-hand portion of every card. The ovals in the columns will be shaded as follows:-

   (i) 1st Column: "No. of School" - which your teacher will tell you.

   (ii) 2nd Column: Your Year (e.g. 3 = 3rd Year)

   (iii) 3rd Column: No. of test.

   (iv) 4th)
   5th)
   6th Columns) Your number, which your teacher will give you. (e.g. if you are No. 3 - shade in 003; of if you are No. 37, shade in 037).

APPENDIX 6.2.(d)

Showing question analysis, F.V., and frequency of answers of second year pupils.

(No. of pupils - 102)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	0.94	0.76	0.50	0.74	0.18	0.26	0.44	75*	19	6	0
2	0.71	0.68	0.41	0.60	0.03	0.25	0.30	6	61*	15	19
3	0.32	0.26	0.21	0.26	0.06	0.06	0.11	14	8	27*	53
4	0.76	0.21	0.26	0.41	0.56	-0.06	0.50	42*	13	19	28
5	0.82	0.71	0.41	0.65	0.12	0.29	0.41	4	16	66*	16
6	0.94	0.68	0.44	0.69	0.26	0.24	0.50	9	70*	10	11
7	0.97	0.91	0.47	0.78	0.06	0.44	0.50	7	7	80*	8
8	0.41	0.44	0.21	0.35	-0.03	0.23	0.20	36*	37	17	11
9	0.18	0.15	0.21	0.18	0.03	-0.06	-0.03	32	26	25	18*
10	0.44	0.29	0.29	0.34	0.15	0.00	0.15	11	36	15	35*
11	1.00	0.50	0.18	0.56	0.50	0.32	0.82	57*	15	13	13
12	0.44	0.06	0.15	0.22	0.38	-0.09	0.29	20	22*	13	43
13	0.82	0.53	0.12	0.49	0.29	0.41	0.71	12	30	50*	6
14	0.94	0.68	0.62	0.75	0.26	0.06	0.32	0	11	14	76*

* denotes correct answer

APPENDIX 6.2.(e)

Showing question analysis, F.V., and frequency of answers of third year pupils.

(No. of pupils - 236)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	0.91	0.90	0.69	0.83	0.01	0.21	0.22	196*	30	9	0
2	0.88	0.74	0.36	0.66	0.14	0.38	0.52	19	156*	45	12
3	0.37	0.14	0.13	0.21	0.23	0.02	0.25	43	19	50*	116
4	0.85	0.64	0.40	0.63	0.21	0.24	0.45	148*	20	27	37
5	0.94	0.77	0.55	0.75	0.17	0.22	0.39	4	33	177*	17
6	0.96	0.85	0.52	0.78	0.12	0.32	0.44	16	183*	12	18
7	0.97	0.96	0.66	0.86	0.01	0.30	0.31	5	5	204*	19
8	0.44	0.29	0.29	0.34	0.14	0.01	0.15	80*	112	16	18
9	0.10	0.05	0.05	0.07	0.05	0.00	0.05	73	76	64	16*
10	0.54	0.36	0.20	0.36	0.18	0.16	0.34	16	95	31	86*
11	0.96	0.81	0.39	0.72	0.15	0.42	0.57	169*	19	19	24
12	0.64	0.29	0.13	0.35	0.35	0.17	0.52	31	83*	37	78
13	0.85	0.62	0.34	0.60	0.23	0.28	0.51	27	55	141*	7
14	1.00	0.87	0.55	0.81	0.13	0.32	0.45	0	15	26	190*

* denotes correct answer

A P P E N D I X 6.2.(f)

Showing question analysis, F.V. and frequency of answer of <u>fourth year</u> pupils.

(No. of pupils - 283)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	1.00	0.98	0.92	0.96	0.02	0.06	0.08	273*	8	1	0
2	0.96	0.84	0.59	0.80	0.12	0.25	0.37	10	225*	28	20
3	0.71	0.28	0.21	0.40	0.44	0.07	0.50	62	10	113*	94
4	0.87	0.83	0.52	0.74	0.04	0.31	0.36	209*	15	20	35
5	0.95	0.90	0.66	0.84	0.04	0.24	0.28	3	24	237*	14
6	0.95	0.90	0.64	0.83	0.04	0.26	0.30	14	235*	13	15
7	0.99	1.00	0.73	0.90	-0.01	0.27	0.26	6	17	256*	4
8	0.56	0.41	0.17	0.38	0.15	0.25	0.40	108*	134	17	24
9	0.40	0.18	0.11	0.23	0.22	0.08	0.30	76	78	61	65*
10	0.60	0.34	0.20	0.38	0.26	0.14	0.40	7	145	21	107*
11	0.99	0.94	0.69	0.87	0.05	0.24	0.29	247*	12	14	10
12	0.76	0.51	0.14	0.47	0.24	0.37	0.62	64	132*	27	57
13	0.90	0.63	0.39	0.64	0.28	0.24	0.51	33	58	181*	11
14	0.98	0.95	0.83	0.92	0.03	0.12	0.15	0	11	8	260*

* denotes correct answer

APPENDIX 6.2.(g)

Showing question analysis, F.V., and frequency of answers of <u>fifth year</u> pupils.

(No. of pupils - 247)

Question No.	Question Analysis							Frequency of Answers			
	T_1	T_2	T_3	F.V.	T_1-T_2	T_2-T_3	T_1-T_3	A	B	C	D
1	1.00	1.00	1.00	1.00	0.00	0.00	0.00	247*	0	0	0
2	0.95	0.91	0.81	0.89	0.04	0.11	0.14	1	220*	21	4
3	0.85	0.61	0.48	0.65	0.24	0.13	0.37	29	3	160*	54
4	0.88	0.71	0.64	0.74	0.17	0.07	0.24	183*	13	14	34
5	0.98	0.91	0.83	0.91	0.06	0.08	0.14	4	6	224*	13
6	0.96	0.96	0.83	0.92	0.00	0.13	0.13	6	227*	6	4
7	0.99	0.98	0.92	0.96	0.01	0.06	0.07	2	4	237*	3
8	0.90	0.56	0.25	0.57	0.34	0.31	0.65	141*	85	14	6
9	0.48	0.18	0.11	0.26	0.29	0.07	0.37	50	74	57	63*
10	0.88	0.40	0.22	0.50	0.48	0.19	0.66	1	96	22	123*
11	1.00	0.99	0.73	0.91	0.01	0.25	0.27	224*	10	4	7
12	0.94	0.72	0.42	0.69	0.22	0.30	0.52	34	171*	17	21
13	0.88	0.78	0.49	0.72	0.10	0.29	0.38	36	33	177*	0
14	1.00	0.98	0.95	0.98	0.02	0.02	0.05	0	2	2	241*

* denotes correct answer

CHAPTER 7

CONCLUSION AND SUGGESTIONS

CHAPTER 7

CONCLUSION AND SUGGESTIONS

To achieve the objectives of the research, the general survey of the areas of difficulties was made subjectively and objectively. The difficult topics/concepts fall into three main areas: (i) motion, (ii) energy and (iii) electricity. The fact that these appeared in undergraduates, 'H' and 'O' with increasing intensity suggests that they are real phenomena and that the problems encountered far down in school persist into undergraduate study and may form the basis of continued misconceptions.

Three small parts of these areas were investigated in some depth. They were chosen to give examples of each of three types.

(i) Density:- Here little formal teaching except in integrated science and later assumed. Any growth in this must be caused by general natural experience of the physical world in which density comes to be an attribute of a 'material' and not of a given 'object' so natural growth could be observed.

(ii) The distinction between heat and temperature:- This was taught more than once in the cyclic physics course but normal language usage often equates 'heat' and 'temperature' and would tend to undo the teaching.

(iii) Electrical resistance:- The growth in this concept must be almost entirely due to formal teaching since it does not enter into normal every day conversation and experience.

These give us three situations for concept growth: (i) natural with little formal teaching, (ii) formal teaching and natural 'learning' in conflict (iii) formal teaching.

To investigate these, two methods were adopted - interview and structured test. Both were based on nets - not hierarchical Gagne's teaching nets, but guides to the structure of the concept to ensure that all parts of this were tested.

Since the interview was slow, but probably the most valid method, an attempt was made to devise picture tests which would give comparable results and with a large and more representative population of pupils.

The tests were applied at successive levels in a group of schools and the facility values of the test items gave some indication of the growth of the ideas with age. In some cases the growth was slow and still incomplete by the end of 'H' grade while others grew rapidly with age or with the onset of formal teaching or with both.

There is a danger of accepting Piagetian ideas as a veto to teaching e.g. if a concept is judged to be at 3B level - there is no point in teaching it at age 14. Since the age of change over from one Piaget level to another is indistinct (even with mental age) and since school classes are based on chronological age anyway, it is dangerous to follow Piagetian theory. A second problem is that children may be thinking mainly in the concrete level and in some areas of their thought, may be operating at a formal level. A third snag is that the influence of formal teaching may to some extent circumvent the "natural Piagetian growth". The only

Table 7.1.

Showing summary of the concept growth.

Clear	0
Clear to one-third of the pupils	Δ
Clear to two-thirds of the pupils	ΔΔ
Clear to half of the pupils	Δ0
Clear to one-sixth of the pupils	ΔX
Not completely clear	XX
Not clear	XXX

	Mass	Volume	Density	Energy	Temp.	Heat	Current	Voltage	Resistance
5th Year	0	0	0	Δ0	0	ΔΔ	ΔΔ	ΔΔ	Δ0
4th Year	0	0	ΔΔ	ΔX	0	ΔΔ	ΔΔ	Δ0	Δ0
3rd Year	0	0	ΔΔ	ΔX	Δ0	Δ	Δ0	Δ	ΔX
2nd Year	0	0	Δ	XXX	XXX	XXX	ΔX	ΔX	ΔX
1st Year	XX	0	Δ	-	-	-	-	-	-

way to find out when a group is in a state of readiness for a new concept is by empirical measurement.

If an untutored group is tested to give a 'base line' and then given formal teaching, a retesting will reveal one of three happenings: (a) no change in performance, (b) a rapid improvement in performance, (c) deterioration in performance because of Ausubelian phenomena of wrong connections being made. By using different groups of different ages, it would be possible to find the age beyond which (b) always occurs.

This would be a large study, but with a number of workers operating in a team, some valuable empirical findings could be made rapidly enough to influence future curriculum planning.

In the end, the summary of the growth of the different concepts is shown in Table 7.1. Here it is easily seen that the growth and difficulty of the concepts in various classes varies with age. In the same class for example, in 3rd year, concepts of mass and volume are clear and there is fast growth for these concepts, but other concepts are at various levels of growth. In this way the curriculum planners can see the growth of the various concepts at a glance and in an 'easy to see' manner.

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