"AN EXPERIMENTAL STUDY IN DIAGNOSTIC TESTING AND CONCEPT DEVELOPMENT IN SECONDARY SCHOOL BIOLOGY"

by

NABEEL ALI MAHMOUD

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(This volume is accompanied by a copy
of a 16mm colour film produced by the
researcher, entitled 'Osmosis', with
a running time of 14 minutes.)

CONTENTS

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SUMMARY

Through a survey on the role of concepts in the field of science learning and teaching, the researcher pointed out that the teaching of biology should be made towards concept attainment and development.

To fulfil this objective, the course designer as well as teachers should be able to know when a pupil, or a group of pupils, are 'ready' to learn a given concept meaningfully.

To recall what has been written about the issue of cognitive 'readiness' for learning concepts, the researcher surveyed three of the most distinguished and contemporary theories in the field. The theories are the 'Piagetian theory of intellectual development', 'Gagné's model of the learning hierarchy' and 'Ausubel's cognitive theory of meaningful verbal learning'. From that survey, the researcher established the main points which should be regarded by course designers and teachers to ensure that the learning of concepts will be meaningful and not just by rote.

The researcher surveyed the situation in the learning and teaching of biology in Scottish Secondary Schools, and was able to highlight its major elements, as well as the possible sources of trouble in the learning of biology.

To spot the topics which were causing difficulty in the biology courses, the researcher employed several tools. He distributed two questionnaires among teachers, another among secondary school pupils and first year University students. He also surveyed the annual reports issued by the Scottish Certificate of Education Examination Board, and held consultations with some school biology inspectors and University lecturers. He also made several observations in biology classes during which he gathered relevant data. In addition, he constructed and administered objective tests

among the fourth and fifth year pupils in nine selected schools. At the end of that stage, he was able to provide a list of the most difficult topics in secondary school biology courses.

The researcher found it of great importance to investigate the reasons behind those difficulties in learning. He believed that a formative type of evaluation through a criterion-referenced assessment would be the most suitable technique to follow for this purpose. Concentrating on the topics of diffusion, osmosis and water potential, he started by analysing those topics into their elementary scientific ideas. Those ideas were arranged to form a proposed hierarchy for the meaningful learning of the topics.

It was hypothesised that, under the current situation of biology teaching and learning, the reason for difficulty was in the superficial learning of those topics, i.e. pupils may learn the top ideas without sufficient learning of the basic or intermediate ones. To check the validity of that hypothesis, the researcher carried out a diagnostic study through which he assessed the pupils' level of understanding in respect of the specified topics. First he held eight group interviews with stratified samples of pupils from eight of the selected schools. Each interviewed group included six pupils representing three levels of biology learning ability. The interviews were held around concrete objects with several tasks assigned for the testees. The Piagetian type of clinical interviews were taken as a guide through the interviews. The data obtained was double checked with the help of a biologist, who participated in the interviews, and a preliminary report was prepared. To improve the validity of this diagnostic assessment, the researcher took one further step. Guided by the data obtained during the interviews, as well as the proposed learning hierarchy, the researcher constructed two criterion-referenced tests. One test was on diffusion and osmosis, the other on water potential.

The first was distributed among both fourth and fifth year pupils, the second among the fifth year pupils only, all of which were in mixed ability classes in the same eight selected schools. The results obtained from that assessment showed that pupils could learn the topics only superficially if the relevant subsumers were missing from their cognitive structures. Thus the hypothesis raised earlier was found to be valid. Detailed discussion of the underlying ideas of the topics revealed that the majority of them were 'mental models' at a molecular level and were dynamic in nature.

Once again it was hypothesised that if a kit of new learning materials was designed in the light of the results obtained during the diagnostic study, pupils who learned through it could develop better understanding of the topics. For this reason the researcher constructed written and diagrammatic material to provide pupils with the ideas subsuming the topics and essential for its meaningful learning. He also constructed a fourteen-minute animated film to accompany the printed material in order to enable pupils to visualise, at a molecular level, what is going on in the macro phenomena.

The new materials were used by pupils in the same eight schools in the following year, and the same diagnostic tests as before were administered among them. Ensuring the similarity between the 'original' group (of the diagnostic study), and the 'new materials' group (of the remedial study), several comparisons were held. The results showed that the new learning materials evidently filled the gaps and made for meaningful rather than rote learning. Thus the second hypothesis was proved to be valid as well. Correlations between the test scores and other scores obtained on two external criteria were computed, as well as the test reliability and standard error. All were shown to be within the accepted limits.

CHAPTER ONE

INTRODUCTION

Concept Development Through the Learning of Science

The emphasis on concept development in science has been important and is becoming increasingly important with the rapid growth of knowledge. It is the one way known to provide the maximum coverage of knowledge because it is a kind of classification or summarizing system which results in the conservation of human intelligence.[(1)]

1.1 Definition of the Term "Concept"

In spite of the large amount of research done on concepts from different points of attack, the definition of the very word is still not the same to all writers. In 1952, Serra mentioned that "the attempts to define the word "concept" have been many but as yet there has been little agreement on an adequate definition."[(2)] In 1978, Novak reported that the case was still as before by saying, "Concepts are very much discussed in education but seldom defined."[(3)] To Archer (1966), a concept is "the label of a set of things that have something in common."[(4)] To Gagné (1970), it is "a class of observable objects or object qualities."[(5)] Beard (1971), as well as Mussen (1973) implied these two notions in their definition of a concept. Beard looked at the concept as an idea of a class of objects or relations normally expressed by words.[(6)] Mussen suggests that the term refers to a response made to a class of objects or phenomena that have certain common characteristics, usually - but not always - these responses are verbal "labels."[(7)] Rogers (1960) says: "In ordinary discussion, a 'concept' is a highbrow word for an idea or general notion."[(8)] Much the same, Lovell (1961) says: "A concept may be defined as a generalization about data which are related."[(9)] Fensham (1975) is of the same opinion when he talks about a concept in the sense in which it means a generalization of one sort or another.[(10)] Novak (1965) gave consideration to the effects of the learner's emotions when they are reflected on the concepts he forms since 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."(11)

Novak (1978) agreed with the view that concepts are "regularities in facts designated by some culturally agreed upon sign or symbol," and they are "inventions of man to describe observed regularities in events."(3) Realizing that "there is no general agreement on what constitutes a concept in science," Bloom (1971) takes the term 'concept' in science 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."(12)

Schaefer (1979) went a different way in this theme. He started first by analysing the concept into its components, and defining each of them second. To him, a concept has three main features, a 'logic core,' a 'name' and an 'associative framework.' The logic core is the invariant structure representative of a certain class of things or events. The name is a denoted verbal symbol which serves both as a vehicle for communication between individuals and as a label for effective memorization within the individual. The associative framework is attached to the logic core as a network additional to the associated name and can serve as attaching points for certain situations of life. The three components are intercorrelated as they give additional value to each other. A mere name without an associated logic core is then regarded as meaningless, the logic core being the meaning. On the other hand, a logic core describing part of reality but without designation by a word, is sometimes regarded as a non-verbal concept. Also it is the associative framework that makes a concept applicable and memorizable in different contexts. A concept is never isolated in our memory, but embedded in a network of associations which colour the concept with sensory attributes, emotions and with other concepts. Figure No. (1.1.A) illustrates this idea which is called the "Bur model of concept."[13]

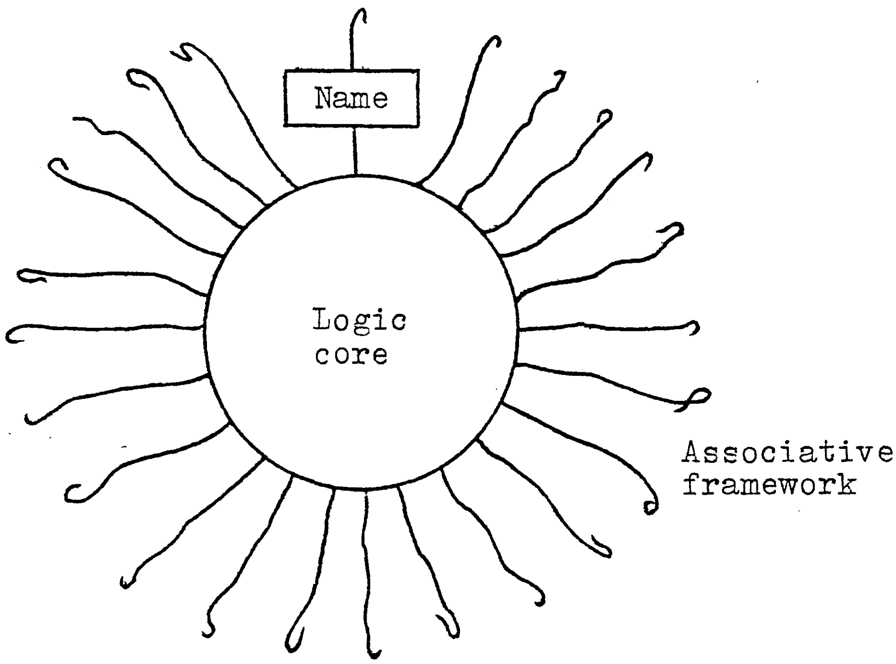


Figure (1.1.A): "The Bur Model of Concepts"

The writer of the present study finds it is useful to adopt the definition suggested by Johnstone (1972) as it is precise and compromises with most of the above mentioned ones. Johnstone's definition reads, "The concept is a unifying idea which makes relational sense of a variety of observations.[41]

1.2 Types of Concepts

Having seen such variety in the definitions of a concept, an important question may have to be raised, "Are concepts all the same?" The survey of literature shows that concepts could be classified into different groups according to the criteria one might hold in mind. Thus occurs the variation in definitions.

One of the most common types of concept is the 'class' concept. Class concepts are those which are denoted by class nouns, such as vehicles, plants, animals and furniture. These examples cover one of the two subclasses of this category, i.e. the 'concrete concepts.' To Gagné

(1970), "things which can be observed are called concrete concepts." His reason is that: "since they can be denoted by pointing to them, so they depend upon direct observation."(5) However, concepts like 'beauty,' 'potential' and 'conservation' can be easily sorted out into another subclass, i.e. the 'abstract concepts.' "Concepts that are abstract in the sense that they involve relations, these are concepts by definitions," Gagné continued. To Smith (1966), concepts, by definition, are abstractions. But he pointed out that, "... yet abstractions occur at many levels." From the discipline of science he gave the following illustration of this notion: "... the levels of abstraction shift dramatically when one moves from simple concepts such as 'red' to 'primate' and 'vector', and then to such concepts as 'homeostasis' and 'entropy'."(15) This would draw our attention, when dealing with concepts, that those which are based on direct experience with material entities are of relatively lower level of abstraction, whereas those in which a direct physical referent cannot be identified are of higher levels of abstraction. The latter group are inherently more difficult to acquire since they are known only by their effects or through a process of abstraction, which is not easily reached by all individuals.

In addition to this classification, Mussen et al (1973) recognised another two types, viz. the fundamental and derived concepts. Derived concepts are those which are formed or constructed out of concepts already in the subject's repertoire. The concept of 'speed' is derived from the combination of the concepts of 'time' and 'distance'. The lower order concepts from which the higher order concepts are derived have been called 'fundamental' concepts.(7) Similarly, the concepts of 'volume' and 'mass' are fundamental to the concept of 'density'. The concept of 'osmosis' is derived from the concept of 'diffusion'. But the distinction between derived and fundamental concepts seems to be relative, because "concepts which are derived themselves can be fundamental to other concepts."(7) 'Volume', though fundamental to 'density', is in turn derived from 'length' and 'breadth'. By the same argument, 'diffusion' is derived from 'concentration' and 'concentration gradient' and so forth. The so-called 'fundamental concepts' of science are a small handful, yet they are the building blocks from which all other concepts are constructed or derived. It might be this group of concepts to which Holton (1973) is referring when he says: "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."(16)

Rogers (1960) says that concepts are of six types which can be classified into two main groups, minor and major. The 'minor' group of concepts includes:

(i) mathematical concepts, which are useful tool ideas, such as the idea of direct proportionality or variation, and

(ii) name concepts, which are ideas in some descriptive names which help us to classify and discuss, such as 'metals', and

(iii) definition concepts, which are ideas that we invent and define for our own laboratory use and may be manufactured from simple measurement such as 'pressure'.

To him, the 'major' concepts would include:

(i) scientific concepts, which are useful ideas developed from experiments, and

(ii) conceptual schemes, which are more general scientific ideas that act as cores of thinking, and

(iii) grand conceptual schemes, which are the examples such as conservation of energy, conservation of momentum, etc.(8)

Mussen (1973) referred to three types of concepts named the 'conjunctive', the 'disjunctive' and the 'relational'.[7] The conjunctive concept is defined by the joint presence of several attributes; all examples of the concept have one or more attributes in common. The concept 'osmosis' can be a representative of this type. Figure No. 1.2.A illustrates this notion. The 'disjunctive' concepts are derived by combining fundamental concepts which have no common members, that is, examples of the concepts have any one (or more) of several characteristics rather than all of them. The concept 'plant' can be one of this type. Figure No. 1.2.B illustrates this group.

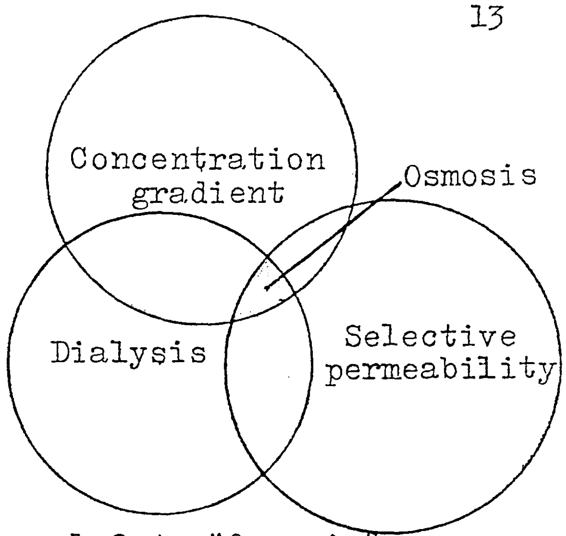


Figure 1.2.A: "Osmosis" as a conjunctive concept.

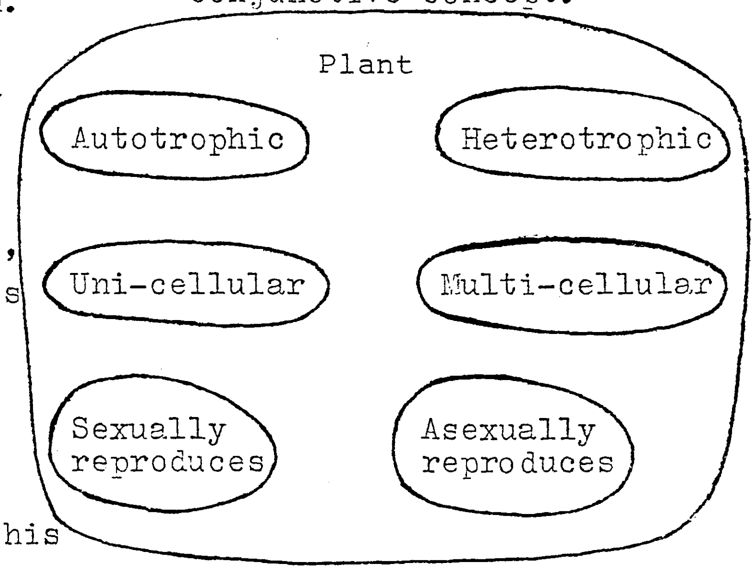


Figure 1.2.B: "Plant" as a disjunctive concept.

The 'relational' type of concept is concerned with the relation between attributes of objects and events rather than the attributes themselves. The relationships of two positions on a map, the similarity of two triangles, the difference in osmotic pressure caused by two different solutions are examples which could illustrate this type of concept. Hunt and Hovland (1960) have summed up the differences between these three types of concepts as follows: "In the conjunction 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."[17] Science concepts, in the main, fall in the 'relational' group.[18]

The second type is more difficult to attain than the first, whereas the third is the most difficult of them all.[7] No doubt a certain effectiveness in brain functioning is necessary before the third type of concepts can be mastered. Some pupils may never have the necessary machinery in their nervous systems for doing this.[19]

Glancer et al (1963) have supported this trichotomy classification, but added a constructive notion to it. 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.[20] The phenomena of the movement of water particles from one side to the other in a solution which is being formed is a positive instance to the pupils if they are learning the concept of diffusion. But the same instance is not necessarily a positive one in the context of the concept of osmosis. Their attention should be drawn to the absence of the semi-permeable membranes, and so that particular phenomenon carries a negative instance within itself towards the latter concept.

Other scholars apply psychological criteria in classifying concepts. Johnson et al (1971) recognized the presence of 'relational' and 'operational' groups of concepts. However, "the distinction between them 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 equivalent to $f = m \times a$."[21] Applying this to the field of biology, one can deal with the concept 'water potential' either in its relational definition, i.e. Ψ_{cell} = cell wall potential pressure + cell sap osmotic potential, or in its operational definition, i.e. the possibility and rate of water movement into or out of a cell.

Kegan's (1970) contribution to the classification of concepts was based on psychological grounds. He grouped concepts as follows: (i) analytic-descriptive, (ii) relational and (iii) inferential-categorical concepts. The first includes concepts that are based on similarity in objective elements with a stimulus complex that were part of the total stimulus. Relational concepts, to him, include concepts that are based on a functional relationship between or among the stimuli grouped together. Inferential-categorical type includes concepts that are not directly based on a partial objective attribute of a stimuli but involve an inference about the stimuli grouped together.[22]

Other researchers have classified concepts according to still newer criteria. Mascolo (1969), categorized them according to the role they play in the learning process. To him, there are the 'key' concepts which guide the learner to the structure of the discipline, whereas those which guide him how to learn the discipline are given the name 'process' concepts.[23] Lovell (1975) referred to the dichotomy which has been suggested by Vygotsky when he had distinguished the child's 'spontaneous' concepts as being developed mainly through his own mental efforts, and the 'non-spontaneous' ones as being decisively influenced by adults.[24] The latter group of concepts, with which the biology courses at the secondary school level are stuffed, should receive the greatest care from both teachers and text book writers since they are usually new to the pupils, and, thus very liable to be twisted or misunderstood completely by many of them. Banks (1970) highlighted the troubles which arise in the teaching of the 'energy conversion' concept. She said: "It is always easier to teach a subject to an intelligent but uninformed student than to try to correct earlier mis-teaching.[25]

Similarly, the introduction of a concept beyond the reach of the pupils or from a relatively complex information area would add more troubles to the teaching-learning situations in the classroom. This will be the concern of a later part of this review.

1.3 Concepts and the Learner

Concepts are powerful intellectual tools which enable their possessor to cope efficiently and easily with the continuing flow of life's problems.(15) Brandwein (1962) considered a concept as the simplest pattern which helps an individual to order the events around himself.(26) Gagné (1970) realised that "the effect of concept learning is to free the individual from control by specific stimuli."(5) Lovell (1961) had highlighted the role of concepts by saying: "Concepts enable words to stand for a whole class of objects, qualities or events and are of enormous help to us in thinking."(9)

To be of real help to the learner, concepts and the labels they carry must be clearly defined. A lot of the scientific terms and concepts used in science are either completely new to the school pupils or have been used in their common life situations with a different meaning.(27) If textbooks and teachers want to guide the learner, through different activities, to reach clear definitions of the concepts which he is studying, he would be benefitted in several ways. Gardner (1972) listed the following expected benefits:

(1) Increase of the pupil's vocabulary.
(2) Elimination of ambiguity.
(3) Clarification of the meaning (by elimination of vagueness).
(4) Provision with theoretical explanations.
(5) Influencing his attitudes.(28)

Thomson (1974) agreed with Vinacke (1952) on the idea that a concept is basically a system of learned responses, the purpose of which is to organise and interpret the data provided by sense-perception. Past experience is automatically applied to present contingencies through the use of concepts.[29][30] One restriction should be considered here, namely, that past experience is of no real help to the individual unless he scans it, and picks out the item(s) correctly relevant to the present situation. Bruner et al (1956) pointed out the mental satisfaction which the learner would gain by applying his knowledge of class concepts. When learning in a new situation, classification reduces the complexity of our environment and thus makes it easier to deal with. This enables us to identify objects and events by placing them quickly into preconceived categories, thus reducing the strain on our nervous system by rendering recognition or identification automatic and by reducing the amount of learning we have to tackle. If we did not categorize or classify automatically we would be faced with the exhausting and complicated task of relating every particular item in our experience to every other item in the context of their occurrence.[31]

Learning with the aid of concepts, rather than memorizing facts, would help also in solving problems whenever they face the pupil in his study. In his attempts to interpret the data or the events, he looks for the concepts he knows already. The learned concepts facilitate the transfer of training as well.[32] However, it is necessary to bear in mind that the concepts in terms of which the problem or the new situation is described to the learner, or interpreted by him, have a considerable effect on success or failure. Teachers have to verbalize the problem in such a way that their pupils can conceptualize it most clearly. From their investigative research on learning the concept of electrical resistance, Johnstone and Mughol (1978) reported that: "if it is desirable to introduce electricity to junior forms, would it help if, at the initial stages, 'resistance' were to be replaced by 'conductance', so that the cross-sectional area problem would be overcome? The length of conductor, although now the inverse relationship, would probably be easier to explain as the 'current having a longer way to go'."[33]

Thomson (1974) praised a useful piece of advice given earlier by Wertheimer (1945) which suggests that the learner has to verbalize freely when examining the problem situation. This means that he can better use alternative terms, then analysing the meanings of what he says when abstract notions are involved in interpreting the problem he is facing. By shifting the meanings, a fixated concept which may happen to block his insight will become weakened and removed.[29][34] Until being able to achieve this, the learner will be carrying the concept in a 'premature' form. Some individuals may use a word accurately with little or no 'conceptual' understanding still. An example of this state is the young child who may use the term 'brother' for his but no one else's brother.[7] Similar to that, the pupil may hold the concept diffusion, but with no reference to the phenomenon of water transpiration in the plant leaves. Moreover, as Smith (1966) pointed out, some concepts may be held already by pupils in an erroneous way. Such concepts could have been distorted from their correct meaning in their repertoire for several reasons, such as:

(1) Limited opportunity for experience,
(2) Inadequate perception,
(3) Incorrect prior assumptions,
(4) Incorrect deductions, or
(5) The individual's set and affective state.[15]

Bloom (1956) has been aware of the fact that comprehending an abstract concept does not certify that the learner is spontaneously able to apply it correctly. He classified this as a higher objective to be achieved.[32] Without the full understanding of a concept, the pupil will not be benefiting from the learning facilities usually offered by that concept, simply because he cannot proceed successfully into a higher level of learning in that field of study. This fact was rediscovered through an enormous number of research projects.

Arnold and Simpson (1978) reported a wide misconception of the term 'food' in the context of the study of plants among a sample of Scottish pupils and students at stages varying from Primary VII to post-graduate Biology.[35] Mughol (1977) reported misconceptions of density, resistance, heat and temperature among the second, third and fourth year pupils in the Scottish Secondary schools. The main reason for the misconceptions was the lack of the basic concepts from the pupils' knowledge.[14] Archenhold (1975) uncovered similar misunderstanding of the concept of potential in physics among sixth formers in England.[36] Dow et all (1978) reported the presence of a vague, and even completely wrong, conception of the particulate nature of matter widely spread among secondary school pupils and student-teachers of science in Dundee.[37] Gower has done the same when revealing the conceptual difficulty faced by the Ordinary level candidates in England while learning about the mole concept in chemistry.[38] Okeke (1976) observed a lot of misunderstanding of some biological concepts among the Nigerian secondary school pupils.[39] Nussbaum (1976) in his assessment of children's concepts of the earth revealed at least five different notions held by a sample of 26 young American children of eight years old.[40] Johnstone (1972) pioneered the investigation of the understanding held by a sample of Scottish secondary school pupils in some concepts of chemistry and reported several misconceptions in that field.[41] More details will be the concern of a later chapter in this review.

Three points could be drawn from what has been reviewed so far:

(1) Learning with the aid of concepts can facilitate the learning process, and extends its help to future situations.

(2) Learning a concept is entirely an individualized activity, i.e. a given concept could be grasped at different levels by different learners.

(3) The mere reference to the label of a concept by a pupil does not necessarily indicate that he understands it completely.

1.4 Importance of Concepts in the Learning of Science

To the layman, science would seem to be a huge amount of knowledge and inventions. However, to the more thoughtful individual science is much more than that. Tyler (1969) refers to science as "a structured discipline rather than a miscellaneous collection of facts and generalizations."[42] It is clear that 'structuring' is a function of the tight grouping of its elements. Conant (1951) had put it more explicitly when he said, "Science is an inter-connected series of concepts and conceptual schemes that have developed as a result of experimentation and observation and are fruitful for further experimentation and observations."[43] Conceptual schemes are those concepts of high complexity. To Brandwein (1962), conceptual schemes relate what we call the body of scientific knowledge. Without an ordering in conceptual schemes, the science curriculum becomes a 'pot-pourri'.[26] Holton (1973) suggested how the conceptual schemes are important, not only in communication, but also in understanding the discipline science as well as others. He said: "It is a conceptual scheme which we invent or postulate in order to explain to 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."[16] Our model of the atom, the kinetic theory of matter, the theory of evolution are exemplars of common conceptual schemes which are dealt with in the school science courses.[44]

Learning of science concepts seems to be important nowadays to everybody. Klopfer hits this point when he says: "One component of scientific literacy is 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."[45]

Having realised the importance of concepts in the discipline of science, designers of syllabuses and courses which emerged in the 1950's and 1960's shifted the emphasis from the rote learning and remembering of factual material, to the formation of concepts and the development of thinking skills.[44] Educators, such as Bernard (1963) have boosted that shift by hints like: "... 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."[46]

In Scotland, the development of new curriculii gave room for the application of the new trend. In one of the most influential curriculum paper concerned with science courses for the first two years of the secondary school, the writers mentioned: "The approach to science envisaged in this report is, however, not designed to require the learning of many unassociated facts. Instead, it teaches some fundamental concepts and the ways of scientific thought by means of pupil investigation and participation."[132] For the biology teachers of the third and fourth years in the secondary school, an advisory board on science education ranked the 'acquisition of the ability to recall concepts in biology' within the first objective on a list of ten.[47] The examiners of biology courses showed their concern with concepts by the statement: "The emphasis in the syllabus is on the establishment of concepts and principles which are common to all life."[48]

This would reveal to us that one important aspect in science education is to know more about concept learning.

1.5 The Learning of Concepts

Gagné (1972) remarked that to study and improve education through methods of research it is inevitable to be concerned with the human activity of learning.[50] Tyler (1969) in his criticism of the ongoing research in science education persuaded researchers in the field to be knowledgeable in the psychology of learning.[42] When studying the learning of school subjects, one has to recognize the learning of concepts as one of the major elements in the situation. Human learning differs fundamentally from the learning of other animals in its extensive use of concepts.[49] For those reasons, concept learning (i.e. attainment, formation and development) is central to the entire process of education, as well as to the domains of educational and developmental psychology.

The place of concepts as the essential link between fundamental physiological processes of the senses and all higher processes of thought has made investigation of their learning difficult.[51] The level to which a concept can be attained and developed is thought to be intricately related to the pupil's total development and readiness.[52] For both the teacher and the curriculum designer, the knowledge of what time is suitable for introducing each group of pupils to a new concept is of extreme importance for the success of the teaching-learning situations. As concepts differ widely in their level of difficulty and complexity, they also differ widely in their learnability for the different pupils. In science, as well as other school subjects, the presence of a 'trouble area' would probably indicate the presence of unsuccessful efforts being made to teach a group of concepts to pupils who are not yet ready to learn them. Mughol (1977) from his research on the learning of physics throughout successive years at the secondary school reported that due to the teaching of density at a premature stage, the first and second year pupils were seen to be unable to grasp the concept meaningfully. However, he recorded that the improvement in understanding the same concept begins at the third year, and improves markedly at even higher levels.(14) Ignoring the message carries the risk of causing widespread teaching and learning problems in classrooms. Ormerod (1977) reported, "Difficulty is probably the most well founded and serious incident of science teaching, it is a long standing defect which curriculum reform has done little to amend." The consequences are not simple. He continued to say, "The seriousness is so great because, not only does the pupil fail to learn matter which is too difficult, but the premature presentation induces mental 'blocks' so that the pupil fails to grasp the material involved when it is met again at a more suitable age."(53)

Garforth (1975) in her experimental work on the learning of ionic equations, reported two findings:

(1) The difficulty in understanding the concepts relevant to the topic decreases with age from 15 through 17 years old.

(2) The pupils who had met those concepts at ages 15, 16 and 17 performed significantly worse, on a test built on the concepts, than another sample of pupils who had met the same concepts for the first time at 17.

She stated clearly that, "teaching atomic structure and ionic theory early in a chemistry course is a positive handicap to later understanding or ease of learning ionic equations.(54)

Johnstone (1972), after investigating the learning of some chemical concepts, reported that pupils seem to memorize facts which are beyond their understanding. Memorization could not have been counted as a real learning of chemical reactions and chemical equations.(41) Most of the other scientific concepts cannot be suitably learned by rote. Novak (1978) has remarked, "Knowledge acquired by rote is soon lost, and even before it is forgotten, this knowledge cannot be used effectively in problem solving."[3] Though learning by concept formation could face some degree of forgetting, residual concepts that remain after subordinate concepts or details are lost still serve to facilitate new relevant meaningful learning. For this, the student who is equipped with a reasonable repertoire of fundamental concepts in science is well equipped to enter more advanced studies, or to begin his life work with some reasonable understanding of his scientific-technical society. He is also equipped to communicate successfully with his intellectual peers.[15] What makes learning meaningful is going to be discussed later when reviewing the work of Ausubel.

To learn a concept, the senses have to be stimulated first. Thus, the process of intelligent perception is essential, as Stones (1966) stated, "until one perceives an object as a thing in itself it is impossible to develop a concept of a class of such things."[49] Wilkinson (1973) reported the same notion, but backwards, "a concept refers to the contingency in which a common response is evolved by a class of stimuli."[55] However, the production of such common response requires, and indicates, a mental action from the learner's side. Urquhart (1975) supports this when he says: "A concept is defined to be an inferred mental process."[56]

Garone (1960) had also realized that: "Concepts are integrations and organizations of percepts and interpretations."[52] This would highlight the importance of the individual's past experience in the attainment of new concepts, as it governs his interpretations of the perceived objects and events. Beard (1960) referred to this in the following statements: "Concepts are not direct sensory data but result from a mental representation of successive data of the same kind and establishment of relationships between representations. Their acquisition depends on having repeated experiences of the same sort and on the ability to form mental representations, which can be recalled and compared with the data from new experiences."[51]

From childhood, the individual interacts with his surroundings. With the help of his queries, comments, or surprise and subsequent checking on meeting a case contrary to previous observations,the child forms new concepts and reforms older ones. This would indicate that the individual is always postulating hypotheses in his efforts to form a new concept. Next to that, he evaluates those hypotheses, and eventually may confirm, modify, or reject them completely. Urquhart (1975) summarised the child's activity in forming a new concept in three successive stages, viz;

(1) Play state, 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.[56]

This would mean that the formation of a concept is largely a discovery process for the child. For the secondary school pupil, who has established a considerable repertoire of concepts, a new concept development would not only serve to acquire meanings of that one, but also in 'polishing up' his conception of older ones and in motivating him to seek further information. This process takes place throughout reception learning and concept assimilation.[3] This meets the idea expressed by Brandwine (1972) which reads, "We derive our generalizations inductively from an analysis and synthesis of data; analysis and synthesis of generelizations build concepts which again become the primer upon which further inquiry is based."[26] This draws our attention to the importance of the inclusion of sufficient practical experiences in the science courses. Concrete examples of objects and events are, if not necessary, at least enormously helpful for 'correct' concept formation. Shapiro et al (1972) showed appreciation of Dewey's teachings in this respect when they say: "In this country (the U.S.A.), John Dewey by developing the concept that children learn through experience, gave status to the role of experience in cognitive development."[57] Ormerod (1977) stated that, "... one of the strengths of curriculum reform in science education has been the emphasis on practical work."[53]

Having passed through several experience situations, the pupil either forms a picture of the common features which might stand out strongly from the elements involved (Beard: 1960),[51] or he may draw his new concept by means of an abstraction from these series of experiences (Gagné: 1966).[58] It is important still that teachers of science should guide their pupils while they are forming their concepts. A pupil who undergoes an educational experience may end up with non-valuable concepts. Cawthorn et al (1978) said that the pupil's response to learning situations is determined not simply by sensory stimuli but by how he views his world, or how he processes or programmes stimuli from the world. His data is not something 'out there' to which he has conscious access; facts are not theory free.[59]

In the study of concept learning, one cannot ignore the role played by language in their formation and development. On the one hand, concepts usually carry labels in the verbal form. (Whether they are labelled first and identified second, or the other way round, is a contentious matter and it does not make a great difference in this present argument.) On the other hand, concepts are the products of thoughtful activities, such as, examining, selective sorting, selective recall, abstracting and reasoning. Thought, in turn, is highly connected with language. Mussen et al (1973) have mapped out this triple relation by the following statements: "closely related to thinking are the processes of symbolization known as language. Thought as it has been typically studied by psychologists could be defined as the acquisition and manipulation of symbols and ideas. Studies of concept formation, for example, are designed to investigate the acquisition of verbal symbols or concepts."(7) One of the most significant pieces of work done in this field is Vygotsky's experiments. Examining the relation between language development and the ability to conceptualize, Vygotsky was able to conclude that the more the child could master the language the better he is able to form true concepts.(60) This along with other investigations clarifies the role of language as a medium for concept formation, and the role of concepts as mediators to the thoughtful activities. Science teachers understand that the more abstract a concept is, the more difficult it is to form by younger pupils. Much of science learning in the secondary school is concerned with complex structures of ideas, many of them include relation between simpler ideas. Cellular respiration, energy conversion, transpiration and internal co-ordination are some examples. At this level, one has to rely on both highly developed language and thought to be able to grasp this kind of phenomenon, as the class teacher can no longer point to simple concrete exemplars. Needless to say, it is risky to assume, while writing a syllabus, that all pupils have already developed their linguistic abilities and their intellectual abilities up to the level required to acquire such concepts.

Inspired by this notion, several researchers have devoted their efforts to investigate the vocabulary used in science textbooks. Evans (1977), after performing such an investigation, reported that many of those books are unnecessarily overburdening the pupils. To avoid the hindering effect of language difficulty on concept learning, Evans suggested that textbook writers and teachers should consider questions such as: "how many terms to use, and of what kind, how best to explain those terms; which of them to emphasize as key expressions; and whether the most frequently occurring terms are invariably the most important."(61) Evans also recommended the following points to be recognized by the science teacher in his communication with the pupils:

(1) To limit the total size of the technical vocabulary.

(2) To explain every term carefully at its first occurrence by using definition, discussion and visual aids.

(3) To provide a glossary of terms for constant reference, enriched with notes on pronunciation and with indication of the elements from which a group of terms has been constructed.[61]

Rayman (1974), while assessing the understanding of concepts relevant to the classification of plant and animal kingdoms, reported that the 12-year-old pupils experienced difficulties in this respect. The majority of them was not able to develop reliable class concepts, as revealed by their inability to recognise instances and non-instances of the concepts. Some terms were shown to be used indiscriminately by them on his illustration test. Investigating the reasons showed him that this was due to "inadequate concept formation and language problems." Thus, he concluded that the topic of plant classification includes concepts which require a certain degree of abstraction, which would be possibly beyond that age group.[62]

Considering examinations as part of the educational process, wording and phrasing of their items are also of similar concern. Cassels (1976) investigated the effect of different types of wording the questions on the candidate's ability to understand them. He provided us with the following list of the most common factors which cause difficulty in understanding:

(1) The level of difficulty or abstraction attached to words, such as the use of 'diatomic' instead of 'two atoms'.

(2) The presence of negative expressions.

(3) The presence of ambiguous expressions.

(4) The way in which clauses and sentences are put together.[27]

Teachers of science have appealed for the examination of textbooks for their 'readability' properties using the methods suggested for this purpose, such as the Dale-Chall formula, the Fry Readability Graph, or the Cloze procedure.[63]

At this point a reservation should be raised. One must not take the findings of this research to restrict the development of the scientific vocabulary of the pupils. They are intended to caution against the widespread practice of using more than the necessary terminology with pupils, irrespective of their abilities to understand and accommodate them. Course designers, textbook writers and teachers all must know where pupils stand in the language domain before starting to guide them to the required linguistic levels.

From the previous discussion it is clear that, introducing the pupil to any new concept should be undertaken only when he is 'ready' to acquire it. Thus, an important aspect of teaching for real concept learning is in knowing when a given group of pupils are ready to learn it.[44] 'Readiness' can be considered under three headings:

(1) Readiness in the sense of motivation: This would appear to be an obvious necessity for successful concept learning, and it is the responsibility of the curriculum designer, the subject teacher, the society and the parents to boost the pupil's attitudes towards the need for such learning.

(2) Readiness in terms of the pupil's previous learning:

This is a vital factor in deciding the order in which to present the concept along with others. For the 'target' concept to be achieved, certain pre-requisite ideas and concepts would be essential, and have to be consolidated and developed earlier in the teaching sequence. Mastery of certain skills and terminology is also required.

(3) Psychological readiness: The mental abilities of the child have to be developed prior to teaching him concepts. This would guarantee that he can perform the type of thought at the level required.

Piaget, Gagné and Ausubel, among others, have already investigated the field of the development of child readiness to learn concepts. In the next part of this study the major elements of their researches and theories will be reviewed.

CHAPTER TWO

SOME CONTEMPORARY THEORIES ON THE LEARNING OF CONCEPTS

2.1 The Piagetian Theory of Intellectual Development

Jean Piaget, the Swiss psychologist, is one of scholars who have studied extensively the intellectual development of the child.

During his schooldays, Piaget became a keen student of zoology, while in adolescence and early adulthood he became drawn to epistemology. His study of the writings of the French philosopher Bergson led him to believe that biology could serve his interests in epistemology, although he also realized that he needed a mediator between the two. Eventually he chose intelligence to play this role, and a series of studies on the growth of epistemology was the outcome. In their efforts to bridge the gap between biology and epistemology, Piaget and his colleagues provided a volume of information and a wealth of detail of great value to teachers.[64]

Piaget and his colleagues have been concerned with the qualitative changes which take place in the individual mental make-up between birth and maturity.[65] Tens of studies have been undertaken by the 'Genevan school' which is concerned with the following points:

(1) The origin of play and imitation in children as symbolic ways of representing the world.

(2) The development of language and thought in children.

(3) Judgment and reasoning in children with regard to moral concepts.

(4) The children's understanding of physical causality.

(5) The children's understanding of phenomena in the

world.

(6) The development of cognitive concepts in children, such as: numbers, time, quantity, space, classification, conservation of properties, speed and movement.

Most of their writings were initially in French, but many were translated into several languages, making their influence felt in many countries of the world.

Piaget (1971), speaking to a conference held to discuss his theory, outlined his work as follows: "I must confess that the problem of ordinal succession, not in general development, but in the development of the individual which belong to the realm of differential psychology, is a problem I have unfortunately never studied because I have no interest whatever in the individual. I am very interested in general mechanisms, intelligence and cognitive functions, but what makes one individual different from another seems to me far less instructive as regards the study of the human mind in general."[66] Adopting this line in his work, Piaget stresses the role of development over that of learning in the child's life (c.f. Gagné). He wrote (1961), "I would like to make clear the difference between two problems: the problems of development in general and those of learning. 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. Development is the essential process and each element of the learning occurs as a function of total development."[6]

Piaget starts from the point of view that as all organisms adapt to their environment, they must possess some form of structure or 'organisation' which makes the 'adaptation' possible at all. Thus he views 'organisation' and 'adaptation' as the basic invariants of functioning.

Moreover, since Piaget considers intellectual functioning as only a special case of general biological functioning, he regards organisation and adaptation as essential to the former as well. Furthermore, adaptation can be subdivided into two closely interwoven components, 'assimilation' and 'accommodation'.[64] In assimilation every newly established connection is filtered, modified and integrated into an existing 'schematism', i.e. the actual structure and repertoire of the child (c.f. Ausubel). The child may have also to modify his internal scheme to fit reality. This latter process is called accommodation.[68]

As the child interacts with his environment he builds up sequences of actions, or patterns of behaviour which have definite structure, called 'schemas'. Thus in the first days of life, Piaget speaks, for example, of the schema of sucking; in adolescence of the schema of proportion. Once new experience is assimilated the child's schemas become more complex, and because of this, accommodations of even greater complexity are possible. It is because one of the essential properties of a schema is its need for further interaction with the environment, thereby perfecting the schema itself or allowing it to become incorporated within a wider schema, that the main source of motivation comes from within the young child. But when schemas required for the solution to some problem are not too far removed in complexity from those available to the child, the inadequacies of existing schemas force him to accommodate to the conditions of the problem, thereby extending the capacity for further learning. In Piaget's view, schemas do not remain unchanged even in the absence of environmental stimulation; they are constantly reorganised and linked with others, so that meanings become linked with wider meanings. Even so the growth of intelligence is slow. Nevertheless, changes in the schemas brought about by attempts at accommodation, and reorganisations brought about independent of external stimulation, together ensure schemas of greater complexity and hence intellectual growth.[64] To Piaget and his colleagues, the knowledge which the child is able to gain is derived from his own actions (which organize or combine) rather than from the objects surrounding him.[68] The child performs the mental actions of assimilation and accommodation in order to fulfil better equilibrium with his environment. 'Equilibrium' here, as Piaget pointed out (1969), is the sense of self-regulation. This in turn refers to the series of active compensations on the child's part in response to external disturbances and an adjustment that is both retroactive (loops systems or feedbacks) and anticipatory, constituting a permanent system of compensation.[68] Throughout their extensive investigations, Piaget and his associates were able to infer the developing mental organisation of the child from the constellation of his deliberate movements and conceptual behaviour or functioning. From their work, they suggested that the child's cognitive growth undergoes a consistent course of development, which can be, for purpose of study, divided into several successive stages. However, Piaget (1972) highlighted that "... the rate at which a child progresses through the developmental succession may vary, especially from one culture to another."[69] The main stages of child development are as follows:

(1) The period of preoperational thought: (from birth to seven years).

This period starts with the 'sensori-motor' stage during which the mental operations of the child lack the symbolic functions as he does not have representations by which he can evoke persons or objects in their absence. In spite of this lack, mental development during the first eighteen months of life is particularly important, for it is during that time he constructs all the cognitive structures that will serve as a point of departure for his later perceptive and intellectual development.[68] The infant develops his actions from reflex-like actions to some acquired habits and from the latter to a sensori-motor type of intelligence. This could be reflected by three levels of reactions, viz.; 'Primary, Secondary and Tertiary Circular' reactions, as Piaget called them.[68] By the end of the sensory-motor stage, at the age of one and a half, the child develops his symbolic functions and gets better command of 'symbol signifiers', which are private in nature. This gives way to the development of 'sign signifiers', such as language, which are socially shared by other members of his community. For Piaget, thought comes before language. The latter is fitted on the former, and while a socially shared language may play some part in the growth of thought, it is quite inadequate to explain the origins of the latter. The child at this stage of 'preconceptualization' can dissociate objects and their properties on the basis of their behaviour.(64) He is said to be at the first level of abstraction. However, his thought is egocentric still, as he is unable to view a problem from any perspective other than his own.(70) Between four and seven years of age the child develops and depends on intuitive type of thought, in which conceptualization begins. His thought is pre-logical still as his logical mental operations are not functional, and his perceptions dominate his thinking. At that stage, Piaget found the children unable to understand conservation of mass when the form of a clay ball was altered for being incapable of mentally reversing the action to restore its original appearance. The same deficiency covers their ability to conserve numbers.(51)

(2) The period of concrete operational thought: (from seven to twelve years).

By the age of seven, the intuitive stage ends, and the child's thought starts to be rather systematised, logical and internally consistent.(64) Reaching this stage, the child has at his command a coherent and integrated cognitive system with which he organises and manipulates the world around him.(71) The child can apply the principle of reversibility, thus able to conserve qualities such as quantity, volume weight and the like. He can classify objects according to several particular characteristics and to build these classifications into complex networks of subordinate and superordinate categories. He can see the class of 'parents' as a large class which includes the smaller classes of 'mother' and 'father'. He can also understand the concepts of space, time, speed and basic causality.[68] Logical transformations in basic mathematics is possible to him as illustrated by the symbols +, −, x, ÷, =, <, >.[72] The child can look on in his own thinking and monitor it, i.e. he is aware of the sequences of action in his mind. It is also possible for him to distinguish between his experience and the order that he imposes on these experiences. For this, it can be said that the child of this stage has reached the second level of abstraction or dissociation.[64] However, his thought is tied to the concrete situations still.[70] For this again, it can be said that he is still thinking within the limits of the first order operational schemes.

In relevance to science, Karplus (1977) listed the expected performances of the concrete thinker child to be as follows:

(A) Applies classifications and generalizations based on observable criteria (e.g. he consistently distinguishes between acids and bases according to the colour of litmus papers).

(B) Applies a conservation logic in such a way that a quantity remains the same if nothing is added or taken away, and two equal quantities give equal results if they are subjected to equal observable changes.

(C) Applies serial ordering and establishes a one-to-one correspondence between two observable sets.[73]

In spite of his dependence upon concrete objects about which he can think, he can solve problems without actually manipulating those objects on condition that they are easy enough to be represented as images in his mind. For this, he is not able yet to work with the algebraic abstractions. He can only perform calculations with first order abstractions where x and y represent known concrete objects. A pupil thinking only at the concrete level cannot deal meaningfully with biological equations such as those of water potential, since the wall pressure and the osmotic potential symbols and values are not imaginable to him. Nor is he able to set up a hypothesis and systematically test it.(72)

Piaget has identified two substages underlying the concrete operational stage and usually denoted by IIA and IIB for the earlier and the later ones respectively. The difference is that the child shows more flexibility in the operational manipulation of the first order relationships, and that reasoning can be extended to greater areas of his experience when he reaches the later substage.

(3) The period of formal operational thought: (commences in the range 12 to 15 years).(69)

Whereas the concrete thinker can make some extension of the actual in the direction of the possible, the formal thinker can concern himself with potentialities and set up a train of ideas and hypotheses making use of the evidence in front of him. Piaget and Inhelder (1969) reported that the great novelty of this stage is that by means of a differentiation of form and content the subject becomes capable of drawing the necessary conclusions from truths which are merely possible, and reasoning correctly about propositions he does not yet believe. This constitutes the beginning of a hypothetico-deductive or formal thought.(68) Reasoning unrelated to reality can now take place.(70) At this stage, the pupil's thinking becomes possible at the third level of abstraction. The intelligently developed images play an important role at this stage. Hypothetico-deductive reasoning requires imagining what might exist and how it might be acted upon.(72) The pupil at this stage can apply that type of reasoning because he is able to disconnect thought from objects, which makes it possible to establish any relations or classes that are desired by bringing together any elements, singly, in twos or more. This generalization of operations (e.g. of classification) culminates in a 'combinatorial system' (combinations, permutations, etc.). Once established, the pupil can combine among themselves objects with objects or similarly ideas or propositions, which give rise to new logic. He can reason about a reality in terms of some or all possible combinations. This is what considerably reinforces the deductive powers of intelligence.(68) The formal thinker can understand proportionality, or what Piaget called the INRC group (inverse, negation, reciprocal and correlation) of operations.(70) These are all second order relationships.

Piaget has identified two substages underlying the formal operational stage which are usually denoted by IIIA and IIIB for the earlier and the later one respectively. In the earlier substage, the pupil sees the point of making hypotheses but is restricted to relations with one variable. Reaching the later substage, he can deal with a complex system holding some variables constant while dealing with another. A second improvement is that instead of being able to make only simple deductions from a model if it is explained to him, he is able to search for an explanatory model, or to extend one that is given.

Once again, Karplus (1977) recapitulated that the formal thinker is expected to carry out the following performances:

(A) Apply combinatorial reasoning, considering all conceivable combinations (e.g. systematically enumerates the genotypes and phenotypes with respect to characteristics governed by two or more genes).

(B) Apply multiple classification, conservation logic, serial ordering, abstract properties, axioms and theories (e.g. distinguishes between oxidation and reduction reactions, uses the energy conservation principles, arranges lower and higher plants in an evolutionary sequence, etc.).

(C) State and interpret functional relationships in mathematical form (e.g. the rate of diffusion of a molecule through a semipermeable membrane is inversely proportional to the square root of its molecular weight.).

(D) Recognize the necessity of an experimental design that controls all variables but one being investigated (e.g. effect of fertilizers on a plant, or factors influencing the oscillation rate of pendulum).

(E) Reflect upon his own reasoning to look for inconsistencies or contradictions with other known information).[73]

<u>Criticism and subsequent research of the Piagetian stage theory</u>

The stage developmental viewpoint of learning has gained a steadily increasing importance in the thinking of educators and psychologists, as is apparent both from attempts to evaluate it or to construct school curricula fitted to developmental levels and to analyse existing courses, in the same terms.[74] To teachers it is of some importance not only to know the order of stages in thinking, if there is an invariable order, but also to know what misconceptions to expect among children of different ages and at what age the majority of children in a given environment reach each stage. Such information is valuable as a guide to curriculum design, to teaching methods and to the evaluative procedures as well. Many writers and investigators have praised the Piagetian theory. Inhelder (1971) sees it as, "... the only theory which links most basic biological mechanisms to the most superior achievements of human thought, and it does this through its concept of development as a continuous and progressive construction." She considered that, "Not only has this led Piaget to a detailed analysis of the construction of a number of fundamental concepts, but it has also enabled him to link cognitive structures to extremely early functions."(66) She summed up the rationale of the theory in the following statements: "This fundamentally developmental approach leads naturally to an interactionist epistemology, i.e. to interaction between the knower and the known. When one is aware of the fact that the knower changes continuously, then his interactions with known objects must also be seen as changing. In other words, the objects themselves lose their apparent invariance, since for the knower their implications do not remain the same."(66)

Experiments similar to those of Piaget, in Britain appear to confirm, at least roughly, the existence of his major periods of development. However, there appears to be some confusion over whether the ages suggested by Piaget are chronological or mental ages. It seems generally agreed, however, that the ages suggested by Piaget are some two or three years earlier than those obtained with British children. As a result, Gaskell (1973) concluded that,"As children develop at different rates, it would seem obvious to assume that any work concerned with mental development must concern itself with mental age rather than chronological age for the work to be meaningful."(75) Beard (1974) is of the same opinion.(6) In a series of studies, Elkind (1974) replicated Piaget's investigations and confirmed his assertion that conservation of a 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 (the criteria taken by Piaget) until the age of about fifteen.(76) In America, Lawson and Renner (1975) reported that none of their subject pupils who were classified as 'late concrete thinkers' understood any of the examination items classified by the authors as formal. On the other hand, 26% of the 'formal' items were understood by pupils previously assessed as 'early formal thinkers', compared with 46% for those assessed as 'late formal thinkers'. Thus the distinction can be made between 'concrete' and 'formal' subject matter content.(77) Sayre (1975) reported that, experimenting with American science students revealed to him that those who demonstrated formal operational logic on his tests tend to receive higher school academic grades than nonformal operational ones.(78) In 1975, Rowell and Hoffmann made use of the Piagetian theory in constructing a test with the aim of providing the science teacher with an instrument to distinguish formal from concrete thinkers among his pupils. They reported that their test proved valuable in the sense that, above its discriminatory power, it is a group test, easily administered, readily marked and yet retaining many of the attributes of the original Piagetian tasks.(74) For fear that the Piagetian tasks could bear on subject matter rather than intellectual abilities, Lawson and Blake (1976) tested the claim made by Piaget (1972) that such tasks are 'content-free'.(69) For this, they constructed three separate instruments; (1) a battery of Piagetian tasks (the pendulum, bending rods and the balance beam), (2) a biology content examination requiring concrete and formal operations and (3) a non-science content examination requiring the same two operations. All three testing instruments were applied to 68 pupils with a mean age of 15.5 years. Relationships among the classifications were examined to verify the Piagetian claim, and it was found to be true.(79)

In a different line, a number of recent studies have attempted to analyse the factor structure of a variety of Piagetian tasks. The general intention of these studies was to identify the number of underlying cognitive parameters or abilities which determine success on the task, and in so doing, gain some insight into the validity of Piaget's insistence on viewing concrete and formal thought as unified stages of cognition. One of these studies was undertaken by Bart (1971) in which he administered four formal operational tasks to a group of adolescents. He hypothesised, in accordance with Piagetian theory, that the four tasks would have a unifactor structure. This hypothesis was confirmed.[80] Lawson and Renner (1974) also found a single intellectual ability to underlie success on formal tasks involving proportionality, combinatorial reasoning and controlling variables, all of which are at the formal level of thought.[81] Lawson and Nordland (1976) using the technique of principal components analysis revealed that there are two components which contribute to the understanding of the Piagetian tasks at different levels of loading. Conservation of number, and of solid and liquid amounts (Piagetian stage IIA) are loaded on one component, while conservation of volume, separation of variables and equilibrium in the balance (Piagetian stage IIIA) are loaded on another component. Conservation of length, of area and of weight (Piagetian IIB) are loaded moderately on both components, which indicates that the latter group of tasks measure something intermediate between early concrete thought and early formal one. This result, in general, is in support of the Piagetian models.[82]

Robertson and Richardson (1975) not only replicated some of the Piagetian tests of conservation, but also extended the idea into new physics concepts. They measured the conservation of pressure, force, acceleration, work and potential energy, which have not been measured by Piaget. Their data supported the sequential attainment of conservation of quantities by each student, which would indicate a hierarchical attainment of concepts in physics.[83]

Apart from the support given to the Piagetian theory, much opposition is directed against it. Beard (1974) concluded, from the survey of many researches, 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."[6] Mays (1955) pointed out that one of the most frequent objections to Piaget's work is the absence of statistics from it.[84] Commenting on these views, Shayer (1970) said: "For his purposes, increasing the number of children studied would merely have decreased the depth of analysis and attention he could have given them. But when it comes to making use of his work in the context of education, the statistical distribution of the stages he describes cannot be ignored, and it has not been provided by him."(85) Elkind (1971) defended Piaget when he said: "Piaget, for his part, has not employed the experimental method simply because it was not appropriate for the problems he wished to study. In every science, there is a natural history stage of enquiry during which relevant phenomena must be carefully observed and classified. In his studies, Piaget has revealed a wide range of hitherto unknown and unsuspected facts about children's thinking, which have become the starting points for a great deal of experimental investigation."(66)

Beard (1960) also points out other weaknesses in the design of the Piagetian investigations by saying, "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. numbers 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 a stage would be practically meaningless." She added: "Further, there is no attempt to relate the achievement of concepts to innate differences in children or to their environment."(86) Piaget and Inhelder did not ignore the last two factors in mental development as they have said (1969): "Their (the stages of development) order of succession is constant, although the average ages at which they occur may vary with the individual according to his degree of intelligence or with the social milieu."(68)

Lovell (1971) spotted a source of inconsistency in the Piagetian interpretation of the mechanism responsible for mental growth. He said, "Piaget hypothesises that all sensori-motor experience resulting in schema development gives rise to regulations, which he uses to explain the growth of schematisation itself. Thus there is a circular relationship as it were between schema and regulation. The schema makes possible the regulation, while the latter allows the growth of new and more complex schemas."[64]

Another group of researches has taken a different line in investigating the validity of the Piagetian theory. Their intention is to verify its contention that 'the role played in cognitive development by massive, general types of experiences cannot, in general, be replaced by limited specific training.' Studies of the effectiveness of inducing Piagetian conservation capabilities have cast some doubt on Piaget's contention.[87] Schafer (1975) conducted an experiment with kindergarten children to examine the effects of instruction on the acquisition, retention and transformation of the ability to insert objects into ordered sets. He reported that the instruction used in his experiment produced substantial and durable changes in children's abilities to perform specific serial ordering tasks.[87] Linn and Thier (1975),[88] Lawson and Wollman (1976)[89] and Karplus (1977)[90] all have reported that their experiments give support to the idea that the acquisition and development of specific capabilities depends, in part, on learning and not solely on the unfolding of some intellectual development structure or mechanism. Schafer (1975) took such results to imply that the 'American learning theory approach', characterized by the emphasis on corrective feedback, attention to relevant task stimuli, cuing and cue fading, can provide a viable basis for the construction of instructional systems designed to influence the child's acquisition of certain specific cognitive abilities.[87] Beard (1974) remarked that, "Although Piaget's work suggests many new approaches in teaching, this has not been his main concern; his object has been to describe children's thinking, not to improve it."[6]

Learning and teaching concepts according to Piaget

The essential assumption made by the Piagetian theory is that the gradual maturation of the individual's brain enables him to carry out more and more complicated mental tasks. His interaction with the environment motivates him to develop higher and higher schemas during his responsive actions. As Piaget believes that these phenomena occur in several definable stages, one can expect that the process of concept formation goes in parallel lines with these successive stages.

In the early periods of life, forming concepts will be limited as the infant is still unable to dissociate stimuli from their surroundings and has no kind of symbolic representation of things. At the age of two, the development of language enables him to internalise a representation of an object in its absence. He can also distinguish between himself and the objects in his world. His thought is egocentric, which makes it difficult to form clear and true concepts. During the intuitive stage (between 4 - 7 years of age) conceptualization begins. His thinking is limited to handling only one attribute of a stimulus at a time, and these are usually very obvious physical attributes. As a result, he cannot master concepts which depend on the notion of conservation (e.g. number and mass conservation). During the concrete operational period (7 to 11 or 12 years of age) the child can build up concepts of real things. Although he has cognitive representations of reality, he can manipulate relations between these real objects only when they are present. Applying this to concepts of science, he can understand the diffusion of physically detectable particles such as those of coloured ink dropped in clear water, or a smelly odour spread out from a container. On the other hand, he cannot understand the diffusion of air or water particles from one position to another. He can form most of the first-order concepts such as push, pull and length. But his concepts of, say, force, work and energy remain intuitive or tied to concrete references. Moreover, intuitive notions of concepts cannot be related to one another in any precise way.(36) The concept of dichotomous classification of organisms (e.g. hairy and non-hairy, flying and non-flying animals etc.) can be understood. The problem arises when a pupil at this age is given a dichotomous key for identification in which he has to go through a logical progression of several subsets. It is difficult for him to hold in mind the sequence of numerous subsets within a class. He cannot retain an earlier statement while considering a later statement.(39) In short, the pupil is able to form concepts at first order relations, with one variable at a time.

At eleven to twelve years of age in outstandingly able pupils and from fourteen to fifteen in ordinary ones, new thinking skills begin to emerge, which enable them to think less concretely and with more abstraction. They are able to grasp concepts which involve understanding relations between relations. Concepts like momentum, heat, energy, diffusion and osmosis can be handled, though they require analytic understanding of ratios, atomisation and are removed from concrete reality. In general, the pupil at this stage can understand concepts in an analytic rather than in an intuitive sense. But it must be stressed that younger pupils can have an intuitive grasp of many of these third level abstractions.(91) An inappropriate or mishandled concept clearly hinders successful learning and adaptation. This explains why a too ambitious syllabus would yield only a superficial type of learning. To apply this scheme to the school situation, researchers have found it a revealing and somewhat difficult experience to decide the levels of conceptual difficulty at which a concept can be taught and then to decide at which Piagetian level of work each of these approaches operates for the full understanding at that level. Gaskell and his team provided us with an analysis of some of the school science concepts along the lines of the Piagetian levels of concept development. Taking their analysis of the concept of 'photosynthesis' (as illustrated by Fig. 2.1.A) it could be useful to identify how could one concept be grasped at different levels by different school pupils.[75]

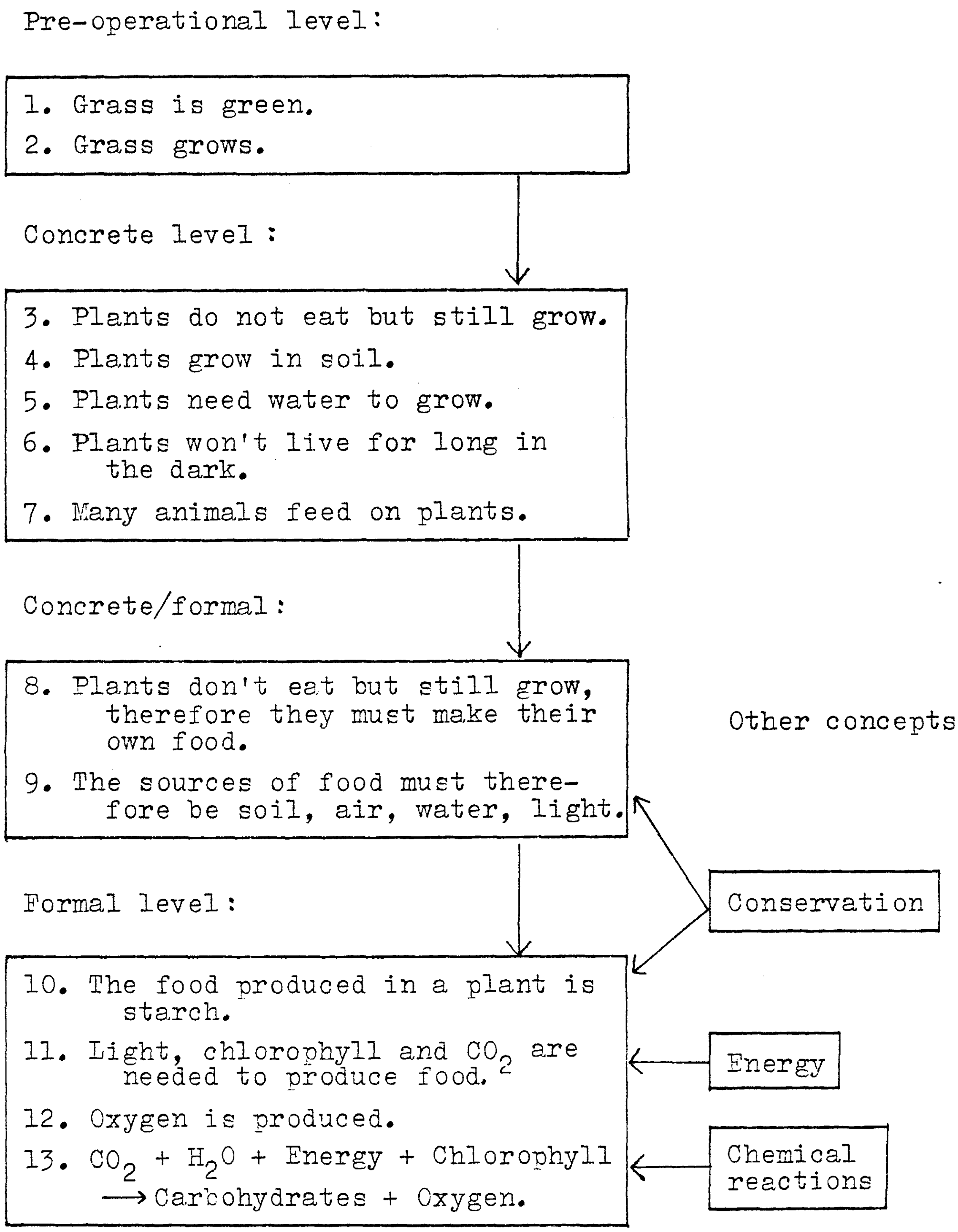


Fig. 2.1.A. The concept 'photosynthesis' at different Piagetian levels of intellectual thought.

A valuable remark about conservation has been made by Turner (1975) when she says: "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."[65] Lovell (1974) made it more precise when he said, "... the age of the 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.[91]

Beard (1974), inspired by the Piagetian model, offers suggestions on how to teach for proper concept formation in the school. In brief, her suggestions are:

(1) When beginning a new topic, learning should be based on concrete experiences. We should be careful not to verbalize where it is unnecessary. It is better initially to 'see' a common property or relationship and only later to describe it.

(2) Teaching methods for the majority of pupils in the first two years in secondary schools should be suited to children who think in concrete terms.

(3) Piaget believes that capacity for thinking in formal operations is initiated by problems raised in attempting to reconcile different viewpoints in discussion and co-operative tasks. Hence, the teacher must present the subject matter as a problem and leave room for discussions to take place.[6]

Karplus (1977) suggested the three following phases for teaching formal concepts:

(1) Exploration, where the pupils gain experience with the environment and learn through their own actions and reactions in a new situation. Minimal guidance is recommended at this stage.

(2) Concept introduction, in which a teacher, a film or a textbook may introduce the definition of the concept,

with relevance to the exploration activities in order to aid pupils in self-regulation processes. This stage would be effective when the concrete definition of the concept is already understood by the pupils.

(3) Concept application, in which familiarization takes place as pupils apply the new concept and/or reasoning pattern to additional situations. In this last phase, physical experience with material and social interactions with teacher and peers play a role. This stage is necessary to extend the range of applicability of the new concept (c.f. Bloom's taxonomy of cognitive objectives). It also provides additional time and experience for self-regulation. Also, it aids slow learners who did not adequately relate the teacher's original explanation to their experience.(90)

Conclusion:

Having surveyed Piaget's theory and the follow-up researches, one can make the following conclusions:

(1) The Piagetian theory adopts an 'age-stage' approach in its attempt to explain how children attain concepts of different levels of abstraction. It assumes that all individuals pass through the same successive, however overlapping they are, stages of mental development, and that each stage is characterised by the ability to perform at certain level of mental operations. An individual cannot deal with a relatively higher level of learning tasks until his growth reaches the corresponding stage. It becomes clear, however, that neither the mental nor the chronological age seems to be more important than the other.

(2) One would expect that the age at which children could acquire certain concepts will vary from one community to another, and from one concept to another since cognitive development depends on

several factors. Organic growth, physical and logico-mathematical experience, social interaction of the individual, social transmission within the population and the complexity of the concept to be learned all are some factors to mention.

(3) It could be possible that there are more intellectual stages in the cognitive development of individuals than those suggested by Piaget, since some gaps have been noticed in the logical model on which the strategies used by him and his associates were based.

(4) Language and thought are highly interwoven in the learning of concepts. The use of difficult terminology hinders the learning process. However, concrete experience is highly required for sound and complete learning of new concepts, particularly for younger pupils.

(5) Teachers need to identify the reasoning patterns of their individual pupils, and should not expect that each of them could be classified entirely as either a concrete or a formal thinker. A younger or older one may operate at one level for one concept and at a higher or lower level for another.

(6) The Piagetian interview method in assessing the pupils understanding and cognitive competencies proved valuable as a diagnostic technique. However, its essence can be adopted in constructing and marking both essay and objective type of questions.

(7) The school science syllabuses, as they are known, often include concepts which can be understood at both concrete and formal levels of thought. Energy, pressure, diffusion and osmosis are some examples of such concepts. According to the Piagetian theory of development, efforts to teach a young pupil one of these basic scientific concepts at formal level could be in vain. On the

other hand, if such a basic concept is learned only at the concrete level it will not be helpful to the learning of another which requires an analytic understanding of the first.

(8) Though it could appear to contradict the point above, the postponement of the teaching of some high-levelled concepts may be undesirable. The increasing abstraction in all sciences calls for more efforts in the development of formal thinking as soon as possible. Several successful studies were reported in respect with the improvement of the subject's rationale. Though the evidence of improved performance relates, in most of these studies, only to tasks that involved specific transfer and not to generalized transfer, better improved approaches of teaching could result in more reliable transfer.

(9) Teachers have to guide their pupils during the suggested steps of learning,(i.e. perception, assimilation, accommodation of knowledge) in order to help them to achieve the best self-regulation, and hence the best concept formation. As Kubli (1979) has remarked, "Concretely-thinking children do reason in a very abstract way, but they lack the physical experience and the ability of discussing topics with an informed person such as a teacher, to become more self-reliant in their conclusions."[92]

(10) Cognitive styles, i.e. the stable attitudes, performances or habitual strategies determining a person's typical modes of perceiving, remembering, thinking and problem solving are important factors in the child's development because their influence extends to almost all human activities that implicate cognition.[93] Piaget has not covered this essential domain in his cognition-based theory. As science teachers, we know from Piaget that our demonstrations in school lessons are assimilated by the children in their own ways, but we know almost nothing about how

they do this in detail. Here, important follow-up investigations are needed.[92]

2.2 Gagné's Model of the Learning Hierarchy

Gagné, the American psychologist, is concerned with the development of human learning and behaviour. He formed a distinguished insight into how the individual progresses from a relatively helpless infant to a marvellously adaptable adult. Like many others, he agrees that such a progress is attributable to growth, development and learning.[5] Though he agreed that the factors that influence growth are to a very large extent genetically based, he argued that the factors that influence learning are chiefly determined by events in the individual's learning environment. Gagné (1970) defines learning as "a change in human disposition or 'capability', which can be retained, and which is not simply ascribable to the process of growth.[5] He (1968) made it clear that his own views "emphasize the influence of learning, rather than growth, on human behavioural development, not because I deny the importance of growth, but rather it is because I wish to come to grips with the problem of what specific contributions learning can make to development, and by inference, what kinds of learned capabilities enter into the process of development."[94] On these grounds, he differs basically from the Piagetian 'cognitive adaptation' theory. Gagné's observation about it is that, "Although the interaction of the child with his environment is given a specific role in that (Piaget's) theory, it is well to recognize that it is in some fundamental sense a theory which assigns only a contributory importance to the factor of learning."[94] He added, "It is my belief that there is an alternative theory of intellectual development.... It is one which emphasizes learning as a major causal factor in development, rather than a factor merely involved in adaptation, as is true in Piaget's theory, or rather than a strictly incidental factor, as in the theory of maturational readiness (that of Gesell and Thomson)."[94]

Gagné also considers learning as an event that happens under certain observable 'conditions'. To him, these conditions can be altered and controlled, and would lead to the possibility of examining the occurrence of learning by means of the methods of science. Also, it would be possible to describe them in objective language, and to detect relations between these conditions and the changes in human behaviour that occurs in learning. Thus, it is possible to make inferences about what has been learned, and to construct scientific 'models' and theories to account for the changes observed, just as it is with other types of natural events.

Types of learning:

Reviewing the different theories of learning, Gagné (1970) remarked that every school of psychologists had created certain typical experimental situations to serve as prototypes for learning. To him, those prototypes represent not only one and the same, but a variety of kinds of learning. It has not been found possible to 'reduce' one variety to another. For example, Dewey, Watson, Thorndike and others set out to study the association between stimulus and responses (S and R). Tolman believed that the essential kind of association in learning was an internal event connecting 'significates' and 'expectations'. Pavlov was studying reflexes. Ebbinghaus studied the memorization of verbal lists. Köhler was studying the solving of problems by animals. By some peculiar semantic process, these examples became prototypes of learning, and thus were considered to represent the domain of learning as a whole, or at least in large part. Nevertheless, there are many instances of learning that these prototypes apparently do not represent. The choice of these prototypes has had considerable influence on the course of learning research. When contrasting predictions are made by theories, it is these prototypes that are appealed to as concrete ways of settling the issue, and it is from these prototypes that experiments are designed to test theoretical predictions. They have become in other words, the concrete models that investigators of learning think about when they set out to study learning experimentally. In addition to that, prototypes came to be placed in opposition to each other: either all learning was insight or all learning was conditioned responses. Noticing that such controversies had continued for years, Gagné concluded that they had been relatively unproductive in advancing our understanding of learning as an event.[5]

In reaction to this, Gagné raised the following question: "How can one determine what learning is?" To find an answer, he planned to classify some everyday observations in which learning occurs. He assumed that once these varieties of learning have been identified, an account can be given of the 'conditions' that govern the learning occurrences. This would lead to a description of the factors that determine learning, derived in so far as possible from available evidence in controlled experiment. By this means it was possible for him to differentiate eight kinds of learning, each requiring a different set of conditions for its occurrence. The eight varieties of learning suggested by Gagné (1970)[5] are as follows: Signal learning, stimulus-response learning, chaining, verbal association, discrimination learning, concept learning, rule learning and problem solving.

By this view, Gagné (1975) said that his intention is "to make a bridge between the findings of investigators who have studied phenomena of learning primarily in the psychology laboratory, and the situations that involve learning in the schools." He emphasized that "it does not intend to describe a theory of learning."[95] Gagné strongly opposed research into learning which began with the premise that 'all learning is the same'. He says: "To equate the responding of an animal to a warning signal with the learning of a child asking for a doll, or the learning of a student to identify a chromosome or the learning to predict inheritance with the laws of genetics is considered to be a matter of gross disregard for some obvious and simple observations."[5] He considered this to be "quite unjustifiable." He also draws the attention to the fact that each type of learning starts from a different 'point' of internal capabilities, and is likely also to demand a different external situation in order to take place effectively.

Hierarchy of cumulative learning:

Gagné assumes that a child who is learning a skill or a subject does not begin this learning from 'scratch', but he already knows something about it (c.f. Ausubel (1973)). He put great emphasis on the notion that the initial capabilities of the learner play an important part in determining the conditions required for subsequent learning. By this, he highlighted the idea of the learning 'pre-requisites' for any teaching-learning situation. To illustrate this, he provided us with a learning hierarchy[5] which accommodates his suggested eight types of learning as illustrated by the flow diagram in Figure No. 2.2.A.

Problem solving (Type 8)

requires as prerequisites:

Rules (Type 7)

which require as prerequisites:

Concepts (Type 6)

which require as prerequisites:

Discriminations (Type 5)

which require as prerequisites:

Verbal associations (Type 4) or other chains (Type 3) — or

Which require as prerequisites:

Stimulus-Response Connections (Type 2)

Fig. 2.2.A Gagné's hierarchy for the learning capabilities.

White and Gagné (1974)[96] described the learning hierarchies as patterns of learning tasks that led up to a terminal skill: each subordinate task would be a pre-requisite for the task above it, and would mediate transfer for that task.

The basic premise underlying learning hierarchies is that failure to learn a particular skill is principally due to lack of essential subordinate skills, and, con-versely, that learning should be easy to induce if all relevant subordinate skills are possessed by the learner.

Gagné (1970) sees that the "developmental readiness for learning any particular new intellectual skill is conceived as the presence of certain specifically relevant subordinate intellectual skills."[5] By this, he intro-duced a new dimension into the meaning of the 'cumulative learning'. Capi and Jones (1971) recapitulated this when they said, "Gagné, 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 Gagné's model, children acquire behaviours in a common sequence where each child passes through the chain in an orderly fashion. A child who fails to master a step cannot skip it and go on, for he is effectively limited in that chain."[97]

Soulsby (1975) pointed out 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."[98]

Gagné (1975) distinguished between two forms of prerequisite hypotheses, i.e. the 'weak' and the 'strong' ones. To him, the 'weak' form states that the recall of a prerequisite (subordinate) skill will make the learning of a given (superordinate) skill more probable, ... the 'strong' one states that if a given (superordinate) skill is learned, the learner must be able to recall the subordinate skill.[95]

Gagné (1974) also distinguished two different forms of transfer for learning hierarchies, vertical and horizontal transfer. Vertical transfer refers to the way in which possession of a subordinate skill affects the acquisition of a relevant higher, or dependent skill. Horizontal transfer is the effect that learning a skill has on another skill that is not hierarchically dependent on it. Horizontal transfer is not so centrally a part of the hierarchy theory as is vertical transfer.[96]

<u>Age and learning</u>:

From what has been said so far, it clearly appears that Gagné does not try to establish any special connection between the ability to learn and the age of the learner. Gagné (1972) attributes the difference between pupils of different ages in their ability to learn to the existing difference in their accumulated capabilities in five suggested domains of learning. When comparing the capabilities of a ten year old school pupil to those of a twenty-four year old graduate student, there will be a noticeable difference between them in the following domains: (a) motor skills, (b) verbal information, (c) intellectual and cognitive skills, (d) cognitive strategies, and (e) attitudes. The older student is a self-learner, as he has acquired much complex highly organized verbal information in his field of study, highly relevant intellectual skills, language uses, and valuable cognitive strategies, all of which the younger pupil has not yet acquired. To Gagné, the existing differences in the process of learning of these two individuals are "not simply because the passage of time has produced a disparity of fourteen years in their ages or stage of biological growth and decay. They exist because of a history of learning, which has left in the older person a residue of increased knowledge, a greater repertoire of intellectual skills, a greatly enhanced collection of cognitive strategies and quite probably a different set of attitudes. All of these capabilities are different in the two instances, and each of them is bound to affect the process of learning, so that a very different problem exists for the design of instruction for these two individuals."[99]

Reaching this point, it is most desirable to point out the main difference between Gagné and Piaget. The latter, while trying to define the structure of the child's mental apparatus which allows him to perceive his surroundings in certain ways, gives weighting to the chronological growth of the child. The intellectual sequence development of the child manifests itself at first through motor action, later through concrete mediation of ideas and still later through complete symbolic representation.[94] On the other hand, Gagné, while trying to study the conditions of learning, gives weighting to the prior knowledge and capabilities of the child as the determinant of what further learning can occur.[100] To Gagné, the child develops his capabilities as he ascends a learning hierarchy by means of positive transfer of learning.[70]

Strauss (1972) pointed out that both Gagné and Piaget seem to agree that (1) a child develops (learns) intellectual capabilities, (2) capabilities are a product of a child's interactions with his environment, (3) capability acquisition is sequential. To Gagné, capabilities are forms of thought which could be arranged in a hierarchical relation, with 'problem solving' as a terminal point. To Piaget the forms of thought are potential organizations of mental structures, which are analogous to logical-mathematical organizations. Regarding the second point, Gagné sees the environment as the crucial focal point, and the child as a relatively passive recipient as the environment becomes internalised through reinforcement. Piaget's organistic viewpoint suggests that a child is an active constructor of his intellectual structures which in turn give rise to potential concepts. About the third point, Gagné would accept that the acquisition order of the capabilities is not necessarily universal, since he defines the hierarchy as a minimally adequate route that a majority of children will take to achieve a final capability. In contrast, universality is basic to the Piagetian sequence of stages. Change in capabilities, to Gagné, is quantitative in nature since he suggests that through the mechanism of transfer newly acquired capabilities are learned in an additive, incremental manner. On the other hand, Piaget hypothesizes that through the equilibrium process structures are transformed in a qualitative, non-addictive manner.

In sum, the differences between Gagné and Piaget are due to their different philosophical views of man. Where the former views man as a problem-solving animal, the latter views the function of man's intellectual structures to fulfil a sort of adaptation to his environment.(70)

Learning of concepts according to Gagné:

To Gagné (1970),(5) the pupil is first able to learn the concrete concepts which depend upon direct observation and implied by names such as colour, shape, heaviness and the like. He called this group the 'concepts by observation'. Their acquisition could happen through trial-and-error, though not typical, or by Ss→R connection (type 2 learning). Next to that level is by verbal associations (type 4 learning), following this by noticing several occurrences in a multiple-discrimination learning (type 5). Requiring the pupil to make distinctions by means of words only is not essential, but might be done. It is important to conduct the discrimination learning within stimulus situations that represent the actual range of the concept being learned, otherwise, the concept that emerges will be in some sense incomplete. Gaining sufficient experience in this stage, all the prerequisite learning would have been accomplished, and the pupil is 'ready' to acquire the concept adequately. A pupil with a relatively good history of cumulative learning is able to acquire abstract concepts, which involve relations. Gagné called this group the 'concepts by definition'. Examples of them are mass, temperature and the like.

To check on the acquisition of a concept, Gagné suggests that a new example of the concept is to be submitted and the learner should be able to classify it correctly, i.e. displays the capability to distinguish the relevant stimuli from others not included in the class, or, in other words, to distinguish the relevant event from the irrelevant one.

How to build a hierarchy:

To build a hierarchy for a subject matter, a 'task analysis' is required. Gagné (1974) says: "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."(101) He adds: "task analysis is a technique which could be brought to bear upon the problem of how to get from known human tasks to design optimal conditions of instructions which would yield competence in these tasks." He further 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."(101)

Second to the task analysis, it is necessary to identify units of previously acquired capabilities which permit the learning of a given unit under a single set of conditions. Gagné and Paradise (1961) claim that this can be done by posing questions of the following type: "What must an individual know or be able to do in order to achieve successful performance of this class of tasks, assuming that he is given only instructions indicating the form of the desired response and stimulus definitions?"(102) The questioning procedure can be repeated with each newly defined behaviour until the level of basic abilities is reached.

White (1974) suggests the following stages to be observed when planning to build a hierarchy:

(1) State the task in behavioural terms.

(2) Derive elements of knowledge subordinate to the first

task by asking of each element in turn, "What would the learner have to be able to do in order to learn this new task, given only instructions?"

(3) Write a learning program to teach the elements of the derived hierarchy.

(4) Have a number of students work through the learning program.

(5) Test the students on their achievement of the elements.

(6) Summarize the results of the test by reporting, for each connection between a pair of elements, the number of students in four categories: those who learned both elements, those who learned neither, those who learned the upper element only and those who learned the lower element only.

(7) Remove from the hierarchy those connections between elements where the numbers of students who learned only the upper element appear to be too large to have arisen by some chance effect.[103]

Criticism and subsequent studies of Gagné's model:

Gagné (1975) stressed that his model does not represent a whole theory of learning. It rather describes the conditions of learning a subject at different levels.[95] Nevertheless, many psychologists and educators paid it a great deal of enthusiastic attention. Deming (1975) says, "It may be, however, that learning hierarchies would provide a more efficient and effective means for selecting, or ordering and teaching curriculum than any other approach presently used." "Through the use of learning hierarchies, we can trace the step by step growth of learning by requiring the student to exhibit the performances specified in each succeeding objective" he added.[104] White (1974) referred to the hypothesis behind the learning hierarchies as attractive "because of the promise it holds for providing a powerful instructional tool through its use in identifying optimum sequences of presentation of subject matter, and subsequently in diagnostic testing and remedial teaching."(96) Gower (1977) in building up his own learning hierarchies for the 'mole concept' wrote: "The (Gagné-type) flow diagram is a model in the scientific sense of the term. It represents not only essential steps in solving problems requiring the use of the 'mole', but also shows the information needed by the student and the concepts required if he is to understand what he is doing instead of just manipulating numbers."(105) White (1974) supported this idea when he says: "Of all the existing learning theories, this (the basic premise of Gagné's theory) seems to have the potential of being most direct in its application to classroom learning."(106) Deming (1975) stated that the hierarchy approach has been demonstrated most successfully within relatively short components of curricula such as a single lesson.(104)

Other writers have had reservations on Gagné's model. Soulsby's (1975) reservation was, "particular examples of learning were generalized (in Gagné's theory) to become prototypes representing (or rather misrepresenting) the domain of learning as a whole." He also pointed out that "Gagné's 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."(98) In reply to this criticism, Gagné (1975) said "... I continue to be impressed with what appears to be a fact: many of the desirable 'higher cognitive' and 'affective' outcomes cannot be achieved unless students have learned basic intellectual skills."(95) White remarks that "intellectual skills appear to be more difficult to identify and define in subjects other than mathematics and physical sciences, and so at present, the theory (of Gagné) is of little use outside mathematics and physical sciences."(107) Gagné (1968) himself stated that "a learning hierarchy does not represent everything that can be learned, nor even everything that is learned within the domain it attempts to describe."(108) Howe

(1974) carried out an experiment to check on the validity of one of Gagné's hypotheses as compared to a parallel one of Bruner's, both concerning the acquisition of the concept of conservation of liquid. Three area and volume tasks, derived from a cumulative learning sequence proposed by Gagné, and two versions of a liquid conservation task were presented to seven to ten year old children. Results did not support the proposed sequence built on Gagné's assumption that knowledge of compensation of differences in dimension (a concrete-type knowledge) is prerequisite to the attainment of the concept of conservation of liquid. The data got by that experiment supports Bruner's view that the transition from non-conservation to conservation is attained through a recognition of identity (a logical-type process) and that the understanding of the principle of compensation is a later acquisition.[109]

Gagné with the help of several associates investigated the validity of hierarchies in different topics in science and mathematics. In his overall survey, White (1973)[110] outlined three major investigations done by Gagné. In the first, he and Paradise (1961) used a programmed book to teach 118 students a hierarchy of twenty-two elements which led up to the element 'solving linear equations'. At the end of the instruction the students were tested on achievement of the final element, on transfer of this skill to equations with unfamiliar letters, and on achievement of the twenty-two subordinate elements. They sorted out the pupils according to their success or failure to answer the questions on the final element as well as the subordinate ones. They reported the presence of exceptions to the hierarchical connections. They also invented an index called 'proportion positive transfer' to judge the validity of hierarchies, but found to be misleading. In his second major investigations, Gagné with others (1962) avoided the previous mistakes by using more than one question per element. The index was again used as evidence for the accuracy of the hierarchy by comparing the ratios

$$\frac{\text{No. of Ss with all relevant subordinate elements who achieved the new element}}{\text{Total no. of Ss with all relevant subordinate elements}}$$

and

$$\frac{\text{No. of Ss lacking a relevant subordinate element who achieved the new element}}{\text{Total no. of Ss lacking a relevant subordinate element}}$$

Ideally, for every connection, the first fraction must be significantly greater than the second, which in turn should be ideally zero. Although they got some good results, they reported some exceptions, which they attributed to errors of measurement. On the other hand, it was suspected that even positive results could not prove fully the validity of the hierarchy since other factors, such as general abilities, are in operation.

In the third major investigation Gagné and Staff of Maryland University (1965) wrote and investigated the validity of a mathematics hierarchy. Few exceptions were also reported. White (1974) realized that the most common pitfalls in the construction of hierarchies could be summarized as follows:

(1) Several studies used only one question for each element in the post-program test. This prevents any estimate of the reliability of the assessment of the students.

(2) Many elements were either loosely defined, or defined to include more than one skill.

(3) Some studies used too few students.

(4) Delaying questions to the end of the learning program can lead to incorrect decisions about the validity of the postulated connections of the hierarchy. Learners could forget lower elements while retaining higher ones though they had acquired all of them in the order postulated.

(5) Some studies included facts which could be rote-learned

among the elements of their hierarchies. Elements of that type are not learned hierarchically, thus they make the validation more complex for no purpose, and can obscure valid hierarchical connections between other elements.[103]

Conclusion:

Having carried on this review, the present researcher can submit the following conclusions about the idea of learning hierarchies:

(1) It is not a theory of learning, but rather a technique to make an intelligent and scientific guess about the most logical prerequisites for learning a subject matter unit.

(2) It does not permit the inclusion of everything that is required for learning a school subject nor the assessment of everything that is learned.

(3) It does not tell about the external conditions of learning situations.

(4) The present method for its validation is long, time consuming and difficult. Moreover, it does not take into account the learning effect of facts and skills other than those included in the recognized elements of the hierarchy, nor the general abilities of the examined individuals.

(5) It can be most useful in planning for teaching a single topic, for diagnostic investigations and for remedial studies.

(6) Teaching for concept formation necessitates the provision of the learner with all prerequisites needed as basic and intermediate elements. On the other hand, when assessing the level of concept learning, one must not interpret the mere repetition of some associated verbal statements or a definition as an indication of a real mastery of the concept.

(7) Although a pupil may be taught via the hierarchy, he does not necessarily have to recall it to perform a task at the top of the hierarchy thereafter. He may commit the results to memory and thereafter extrapolate from it. Having once satisfied himself that there is a logical basis for the fact he is accepting, he may well dispense with the basis. Educated adults do the same when they use Pythagorus' Theorem easily without being able to recall the proof on which it was based and by which they were taught it.

(8) From the previous point, we could expect that the recall and use of hierarchy by individuals would soon prove to be a gross memory overload, and so people need chunking strategies to keep the learning of a relatively complex area under control.

2.3 Ausubel's Cognitive Theory of Meaningful Verbal Learning

Ausubel, the American psychologist, has been working extensively on the learning process since the 1940's. His theory, which appeared in 1963 on his book 'The Psychology of Meaningful Verbal Learning',[111] is a learning theory and deals specifically with events during the contemporaneous acts of learning, as well as development aspects of cognitive differentiation.[3] It refers to the part played by the prior knowledge in organizing new learning and building it into the cognitive structure of the learner, which is a psychological issue.[100] Because Ausubel is concerned with the cognitive process of learning complex verbal material, his theory has considerable relevance to the teachers in their most common classroom situations.

Ausubel's theory, in some sense, is a reaction to the widespread movement of the 1960's in reforming science curricula on the basis of a discovery-learning approach. He viewed this type of learning to be: time-consuming, unnecessary in some occasions, inefficient in others where it is liable to result in misleading notions as a result of learners' exaggerated tendency to jump to conclusions or to overgeneralize on the basis of limited experience.(112) He remarked that, "... Merely because potential meanings are presented (during discovery learning), we cannot assume that they are necessarily acquired."(113)

Ausubel does not deny that there is a value in 'discovery' learning, but since the 'reception-type' of learning is far more common in schools, he argues that we should enquire as to how the latter type can be made more efficient. He pointed out that much of the criticism levelled at reception learning applies only because reception teaching has been badly done. The critical distinction Ausubel elucidates is between 'rote reception learning' and 'meaningful reception learning'. He stressed that the task for effective reception teaching is to plan instruction so that material can be learned meaningfully, and it is to this end that he directs his attention.(115) To him, learning in general refers to "the process of acquiring meanings from the potential meanings presented in the learning material" and "once these new meanings are acquired, they are, of course, available to the learner for subsequent additional learning or for recall and utilization at some later point."(113) He sees the tremendous efficacy of meaningful learning being as an information processing and storing mechanism - with which the school should be primarily interested. This can be largely attributed to its two distinctive characteristics, i.e. the non-arbitrariness and substantiveness of the learning task's relatability to cognitive structure.

Fekner (1975) suggested that an individual's 'cognitive structure' is represented by his organizational framework which, in turn, is dependent on his past experience with an area, and provides a basis for interpreting or decoding impinging messages.(114) By the aid of the nonarbitrariness of meaningful learning, the learner is able effectively to exploit his existing knowledge as an ideational and organizational matrix for the incorporation, understanding and fixation of large bodies of new ideas. It aids him also to use his previously acquired knowledge as a veritable touchstone, for internalizing and making understandable vast quantities of new meanings, concepts and propositions, with relatively little effort and few repetitions. The new ideas, which become meaningful in turn, also expand the base of the learning matrix. On the other hand, the substantive (or nonverbatim) nature of relating new material to and incorporating it within cognitive structure circumvents the drastic limitations imposed by the short item and time spans of rote memory on the storage of information. Much more can obviously be apprehended and retained if the learner is required to assimilate and retain only the substance of the ideas rather than the precise words used in expressing them.[113]

As it might be clear from above, Ausubel distinguishes between two main types of learning, i.e. meaningful and rote learning. The first involves a conscious effort on the part of the learner - even if acquired through a well-planned reception learning - to relate new knowledge in a substantive, non-arbitrary way to relevant existing concepts or propositions in the learner's cognitive structure. On the contrary, rote learning results in arbitrary, verbatim incorporation of new knowledge into cognitive structure, and must occur when no relevant concepts are available in the learner's cognitive structure or when he fails to recognize or recall them, or when precise verbatim recall is essential.

Ausubel sees the rote learning characterization is not a dichotomy but a continuum, along which reside several degrees of meaningfulness of a learning task. The latter property is influenced by the learning set and the relevant cognitive differentiation of the learner.[3]

For meaningful learning to take place, Ausubel suggested that these three conditions must hold:

(a) The material itself must be relatable to some hypothetical cognitive structure in a non-arbitrary and substantive fashion.

(b) The learner must possess relevant ideas (subsumers) to which to relate the material.

(c) The learner must possess the intent to relate these ideas to cognitive structure in a non-arbitrary and substantive fashion (motivation and readiness).

Remembering that rote learning and meaningful learning is not a true dichotomy, we can say that learning will be increasingly rote to the extent that one or more of the above conditions is not fulfilled.

<u>How can meaningful learning occur</u>?

Like most theorists of learning, Ausubel has built his special terminology which are the keys to understanding his proposition on how meaningful learning takes place. Through close examinations of his terms, we can develop an understanding of his theory.

1. Subsumption: Ausubel emphasized that meaningful learning does not result in a kind of accretion with new knowledge added to concepts like snow added to a rolled snowball. Instead, the new knowledge interacts with existing relevant concepts and is assimilated into these concepts, thus altering the form of both the anchoring element (subsumer) and the new piece of knowledge being assimilated.(3) A subsumer is any concept, principle or generalizing idea that the learner already knows that can provide association or anchorage for the various components of the new knowledge.(100) So, the process of meaningful learning results in subsumption of new knowledge.

2. Organizers: The learning of specific new propositions will be facilitated by the presentation of organizers, that indicate the relevance of the knowledge to be learned to the pre-existing cognitive structure.(5)

Advance organizers are those more complex and deliberately prepared sets of ideas which are presented to the learner in advance of the body of (meaningful) material to be learned, in order to insure that relevantly anchoring ideas will be available. Generally speaking, advance organizers would be used by teachers when either of two circumstances prevails. In the first instance, if specifically relevant ideas are not available in cognitive structure when new, potentially meaningful material is presented to the learner, then the likely consequences would seem to be rote learning, or that tangential or less specifically relevant ideas would be pressed into service. In a second situation, appropriately or specifically relevant ideas are available, but their relevance is not recognized by the learner. Using advance organizers in such cases is much better than relying on the spontaneous availability or use of less appropriate anchoring ideas in cognitive structure.[(113)] Advance organizers can, in practice, take many forms. Examples of these are: verbal statements used as introductory discussions, clarification of difficult abstractions, a reminder of the significant aspects of prior learning and reorganization of the order of presenting the content of the lesson so that the major themes are developed in parallel rather than in the normal linear way.[(100)] No need to say that the advance organizer to be used should be, in itself, meaningful to the learner.

3. Progressive differentiation: As new knowledge is acquired in meaningful learning, concepts and propositions become more elaborated and new linkages form between concepts, thus modifying in part the whole matrix of interconnected concepts into which new knowledge is subsumed.[(3)] It follows that when subject matter is programmed in accordance with principles of progressive differentiation, the most general and inclusive ideas of the discipline are presented first and are then progressively differentiated in terms of detail and specifity. This order of presentation presumably corresponds to the natural sequence of acquiring cognitive

awareness and sophistication when human beings are spontaneously exposed either to an entirely unfamiliar field of knowledge or to an unfamiliar branch of a familiar body of knowledge. It also corresponds to the postulated way in which this knowledge is represented, organized and stored in the human cognitive system.(113)

4. Superordinate learning: In classroom situations, new concepts are occasionally introduced to the students. Such concepts usually bear a superordinate relationship to previously acquired ones. In science, this takes place when pupils have to learn that osmosis is a particular case of diffusion, and osmotic pressure is one form of the general concept of pressure. Here the less stable (and more specific) meaning of a combinatorial idea is incorporated within or reduced to the more stable (and more generalized) meanings of the wider, less specifically relevant body of ideas in cognitive structure to which it is related.(113) Superordinate learning results in progressive differentiation of the learner's cognitive structure, since subordinate concepts (of diffusion and pressure for instance) acquire new meanings. To Ausubel, the result of a meaningful learning is a 'differentiated cognitive content'.

5. Integrative reconciliation: This occurs whenever superordinate learning takes place during the forming of new developed concepts. It refers to the explicit attempt to point out significant similarities and differences and to reconcile real or apparent inconsistencies between successive ideas presented in a sequential arrangement. In biology, for example, a pupil may become confused when he learns that water tends to travel more from a solution with relatively lower osmotic potential to another with a relatively higher one. To him, this would seem to be going against his previous knowledge obtained from the natural science lessons, i.e. objects and energy tend to move from systems with relatively higher potentials to others with relatively lower ones. Perhaps, subsequent realization that the concentration gradient of water

goes opposite to that of the substance dissolved in the solution, would resolve at least the source of the confusion. When integrative reconciliation does not take place, considerable cognitive strain and confusion will occur. Moreover, artificial barriers are erected between related topics, obscuring important common features and thus rendering impossible the acquisition of insights dependent upon the recognition of these commonalities. Further, adequate use is not made of relevant, previously learned ideas as a basis for subsuming and incorporating related, new information.(113)

Concept learning according to Ausubel:

Ausubel placed concept learning as one of four types into which meaningful learning is classified, viz; representational (naming an object or a class of objects), propositional (apprehension of the meaning of a composite idea as word order rules and factual statements) and discovery learnings. For a pupil to learn the concept of living organism for instance, he has to think of the critical attributes of this class of organisms to which he is exposed. It is clear that at any stage in the individual's development there may be a considerable discrepancy between the critical attributes that he has discovered, and which give psychological meaning to his concepts, and the critical attributes that define the logical meaning of a concept. But as a result of experience and feedback, his psychological meaning becomes progressively more similar to the logical one. Ausubel refers to the process of inductively discovering the critical attributes of a class of stimuli as the process of 'concept formation'. This is different from another one, which he calls 'concept assimilation'. The former is typical of the learning of young children where they discover the critical attributes of a concept, whereas the latter is typical of the learning of older school pupils where they learn those attributes by definition or by being encountered in appropriate contexts.(113)

In this respect, Ausubel's theory differs from

Piaget's in the following points:

(1) In acquiring new concept, the new pieces of knowledge are linked to specifically relevant concepts or propositions.

(2) The changes in the quality of meaningful learning acquired by the growing individual happen gradually, not as a result of 'general stages' of cognitive development or as a result of merely being older, but rather because of the growing differentiation and integration of specifically relevant concepts in cognitive structure. Novak (1978) took it to explain why many adults fail to solve some kinds of problems or to perform some Piagetian tasks while some younger children may succeed with these tasks. It also explains why experts in one discipline may display such incredible mental obtuseness when they try to reason in another discipline, whereas some children 'think like adults' in some instances.[3] So, the extent of variation among individuals in the degree of prior knowledge and differentiation of specifically relevant segments of cognitive structure is considered, by Ausubel, as indication of the variation in 'readiness' to learn a new concept.

It may be useful also to contrast Ausubel's theory with Gagné's model of learning concepts. Though they both agree on the notion that 'prior knowledge can influence learning', they differ on the nature of such influence. Where Ausubel believes that prior knowledge influences the 'process' whereby this learning occurs, Gagné believes that prior knowledge is a determinant of what further learning can occur.[100] Ausubel explains how prior knowledge determines the quality of learning a new piece of knowledge. Fensham (1975) remarks, "... if Gagné's emphasis is on what is to be learned, Ausubel's concern is with the process of learning, and his theory suggests how the concepts which the learner has already formed interact with new ones.[10]

<u>Follow-up researches of Ausubel's theory</u>:

In a comprehensive study done by Novak, Ring and Tamir (1971), the reported conclusions of 156 science education researches were taken as external criteria to check on the validity of several hypotheses drawn from the most important parameters in Ausubel's theory. Since the majority of the researches reviewed were not designed with reference to that theory, the reinterpretation of them was fraught with difficulties. In general, they reported that the data available so far could be interpreted as consistent with expectations from Ausubel's theory. However, such a conclusion is hardly more than conjecture which ought to be researched further.[115]

Johnstone (1972) and Johnstone, McDonald and Webb (1977) during their investigations into the nature and origin of the conceptual difficulties experienced by pupils studying some concepts of chemistry, realized that many of those students, failing to anchor the new pieces of knowledge to the correct relevant subsumers in their existing cognitive structures, have modified the new concepts to make them fit the irrelevant subsumers they had recalled. Misconceptions (i.e. failure to perform correctly the integrated reconciliation step) and rote learning (i.e. failure to perform the subsumption and progressive differentiation steps) were the results of such situations. Thus, it appears that the negative side of Ausubel's theory of meaningful learning was confirmed.[41][116]

Ring and Novak (1971) investigated the relative effect of existing features of learners' cognitive structures on the learning of new material, and concluded that "the presence of subsumers (e.g. concepts) without facts increased achievement, whereas having facts without subsumers did not.[117] This would lend support to Ausubel's notion about the contribution of prior knowledge subsumers to the learning process. West and Fensham (1976) after examining successive postulations of a predictive nature, reported that advance organizers are incorporated in the learning material during a meaningful learning process. Moreover, the remedial teaching of relevant prior knowledge tends to remove the facilitating effect of advance organizers for subjects initially low on relevant prior knowledge.(118)

Pella and Trienzenburg (1969) studied the comparable effects of different types of organizers, and reported that pictorial, graphic and manipulative materials were more effective than verbal, expository advance organizers.(119)

On the contrary to Ausubel, Kahle and Nordland reported that no function was performed by an advanced organizer presented to their sample pupils before going through an individualized learning programme in science. Possible reasons for this was the relatively shorter time (ten minutes) spent on the advanced organizer and the longer time (four weeks) spent on the main study.(120) Commenting on researches which had reached similar ends, West and Fensham (1974) said, "The failure of an advance organizer treatment to show a significant advantage over a control treatment may result not because advance organizers do not assist learning, but because most of the learners possessed sufficient prior knowledge subsumers for meaningful learning of the particular task involved".(100)

Fekner (1975) tried to determine the cognitive maps of some students at the end of a learning period, but he found it unfeasible as their understanding of the concepts was not at its best. But when different groups of students were instructed to give special attention to learn a list of additional concepts (i.e. advance organizers), which were relevant to the main concepts, they developed much clearer and identifiable cognitive maps.(114) This would lend support to Ausubel's idea of subsumption and progressive differentiation.

Conclusion:

Having gone through the theory and the follow-up studies, one can reach the following conclusions:

(1) Since the reception-type of learning is the most commonly prevailing method in schools, it is worthy of research by educators and psychologists.

(2) Reception-learning is not as inferior as it is sometimes thought to be. One should not confuse the rote-meaningful continuum for learning with the reception-discovery continuum for presentation of school subject material.

(3) A concept could be taught effectively through a reception learning approach, provided that it is made meaningful to the learner.

(4) Meaningful reception learning involves more than the simple cataloguing of ready-made concepts within existing cognitive structure of the learner. It could involve several constructive activities on the part of the learner. Some of these activities are:
   (a) Making implicit judgment of relevance to decide which established ideas in his cognitive structure are most relatable to the new concept.
   (b) Establishing reconciliation between the new concept and similar established data and concepts in order to differentiate between them specially if there are discrepancies or conflicts.
   (c) Reformation of new propositions in order to blend them into the learner's personal frame of reference, such as his vocabulary and structure of ideas.
   (d) Synthesis or reorganization of the learner's existing knowledge under more inclusive and broadly explanatory principles, particularly if he cannot find an acceptable basis for reconciling what seems to him a contradictory idea.[113]

Curriculum planners, as well as teachers, have to make it easy, persuade and guide the pupils to perform successfully those activities to ensure meaningful learning.

(5) While writing a syllabus for a group of pupils, the level of sophistication should be carefully adjusted to their real cognitive structures in that specific field. A syllabus with comparable higher level of sophistication would lead into despair, generation of unfavourable attitudes toward the subject or to rote memorization of the content. It is much better, specially with beginners and while dealing with new topics, to concentrate more on establishing a general ideational framework than in putting a great deal of flesh on the skeleton.[(121)]

(6) The learnability of a given curriculum material should not be assessed by conventional tests of achievement, since these often give misleading impressions of genuine learnability. Most adequately motivated students can learn, for examination purposes, large quantities of materials that they do not really understand. Such conventional retention measures often fail to distinguish between the individual who merely retains factual knowledge, and another whose understanding and retention are sufficient to serve as a springboard for learning new, sequentially related material. Assessment must be concerned with all relevant elements in the cognitive structure of the pupil.

(7) When preparing for teaching a difficult new concept, the teacher is advised to start with testing his pupils to determine whether each of them possesses the prerequisites (the subsumers) for that concept, and to provide each with those prerequisites he does not possess. Hence, diagnostic testing is highly recommended in classroom practice, especially when teaching for a concept in a problem area of the syllabus.

(8) A teaching topic must be first analysed into its various elements, and their sequence of difficulty has to be identified. Learning must start with the easiest of them, followed by the less easy, and so on. This practice would ensure a good tying-up of the first to the relevant subsumers in the pupils' repertoire, and a good level of superordinate learning of the next ones to be taught.

(9) Animated drawings, illustrations, verbal statements, whether printed or spoken should precede, accompany or follow the presentation of the new concepts in order to help visualizing and assimilating the unfamiliar events and properties. It would ensure also a good progressive differentiation of the previously learned concepts as well as the new ones.

(10) When forgetting the detailed facts over the years, the concepts that remain with a pupil from such meaningful learning would still serve to facilitate any new relevent meaningful learning.

General conclusion:

From the above review of the theories on the psychology of learning, one can summarize some of the contemporary notions with regard to the learning of school concepts:

(1) The syllabus should not include abstract concepts to be learnt by younger pupils, since they may not be able to grasp them. If it is necessary to go against this rule, syllabus designers as well as teachers should be sure that the pupils have been previously introduced to the same concepts at a concrete level, with enriched practical experiences. When reaching the abstract study of the higher

concept, they must devote relatively more effort and time for training the pupils in that particular field.

(2) Syllabuses and teachers should not try to teach a new concept until the pupils have developed successfully the lower level capabilities. Some of these are the development of appropriate understanding of the verbal definition of the concept, i.e. the intelligent acquisition of the concept label, and the discrimination of what is relevant to that concept from what is irrelevant to it. On the other hand, when a pupil shows good recall of the label of a concept, this must not be taken for granted as a good learning of the concept. It could be just a mastery of a relatively inferior level of the concept learning.

(3) Syllabuses and teachers should be keen on providing pupils with all the required bits of knowledge and subordinate concepts before teaching a relatively superordinate concept. They have also to guide them to recognize and to recall successfully the relevant bits of knowledge and concepts while learning that new concept. By doing this, pupils can visualize all the incidents surrounding the new concept, and be able to fit it within a confusion-free and a well structured cognitive repertoire of their own.

CHAPTER THREE

THE MAIN STUDY

3.1 Purpose of the Study

. From a previous review of the literature, it has been clear that a successful secondary school biology course must satisfy the following criteria:

(1) Is built to teach for relatively high intellectual goals, such as concept and conceptual scheme formation, rather than for the sheer acquisition of separate bits of knowledge or for a superficial learning which depends on the memorization of rules.

(2) Presents the subject matter in a hierarchical order according to the developing capabilities of the learners. In doing so, it adopts a sequence which ensures that no concept is introduced until the teacher is sure that all the pupils have already learned successfully all the subordinate concepts and ideas required for that superordinate concept.

(3) It helps the pupils to identify and recall all the relevant subordinate knowledge from their existing cognitive structure, and to tie them to the new concept to be taught in a proper integrated manner, where no confusion is likely to occur.

The researcher believed, through his preliminary investigations, that one or more of the above mentioned criteria have not been fulfilled by the biology courses in Scottish Secondary Schools. The intention of this study is to examine closely these courses as they are conventionally taught and learnt in order to identify the points of discrepancy and the areas which were causing difficulties in learning to the pupils. A consequent aim of the study was to construct and to evaluate a remedy for the improvement of the learning process.

3.2 Statement of the Problem

The researcher has attempted to find answers to the following questions:

(1) What is the situation in biology teaching and learning in the Scottish Secondary School?

(2) What are the concept areas causing most difficulties in secondary school biology?

(3) What level of understanding of these concepts have the pupils reached?

(4) Is there any significant difference between the performance of pupils who studied biology only and those who studied other branches of science besides biology?

(5) Is there any significant difference between the performance of boys and that of girls?

(6) Why are these concepts difficult to learn?

(7) What could be the most suitable remedy to offer in order to help pupils to develop better understanding of these concepts?

(8) To what extent has such a remedy proved to be efficient?

3.3 Scope and Broad Design of the Study

To fulfil the aims of this study, the work was carried out for a period of three continuous years (1976 through 1979) mainly in eight schools in the Greater Glasgow Area, besides an elementary study for a confirmative reason in the University of Glasgow.

The study was conducted in four stages as follows:

1. Stage One: The survey of the biology courses in Scottish Secondary Schools:

The researcher first surveyed the situation in learning and teaching biology in schools, the general opinions of teachers on the courses, and the reports of the examiners on the pupils' performances on the external examinations. Next, the researcher distributed a questionnaire among eighteen secondary school biology teachers in different localities in Scotland seeking their opinions on the different topics of the fourth and fifth year courses. The results were studied and a second questionnaire was made, concentrating on the most outstanding topics in the first one. The new questionnaire was distributed among the biology teachers and the fourth and fifth year pupils in nine secondary schools in the Greater Glasgow Area where the study was planned to take place. The nine schools chosen were recommended by both the Chief Inspector of biology in Scotland and the Director of secondary schools in the Greater Glasgow Area. All were recommended on the basis of their characteristics as good representatives of the most prevailing type of schools in the area. They were believed to fulfil the following characteristics:

(1) All of them were comprehensive and accommodated pupils in mixed ability classes.

(2) All of them were offering a co-education system for both sexes.

(3) Some of them were Roman Catholic schools.

(4) All of them were offering biology courses at both Ordinary and Higher grade standards.

(5) All of them were equipped with facilities for teaching those biology courses at the normal level.

(6) All of them with biology staff and administration who showed readiness to co-operate with the researcher to carry out this study successfully.

The sample of pupils dealt with at this stage numbered 337 from the fourth year, and 166 from the fifth year.

The same questionnaire was distributed, for confirmative reasons, among the first year University students who had studied biology in their secondary schools. This sample numbered 209 students. No more dealing with the University students took place beyond this point.

The researcher constructed an objective test at the 'Ordinary' grade standard, and another at the 'Higher' grade one. Each test was divided into three sub-tests to minimize the burden on the pupils' part and to assess the learning of the topics at as many as possible of the levels suggested by Bloom.[12] The tests were distributed among the pupils in the nine selected schools, and the answer cards were scored through the computer.

From the information gathered through these steps, answers to the first two questions on the statement of the problem were reached.

2. Stage Two: The search for the reasons responsible for the difficulties in learning some school biology topics:

In this stage, the researcher analysed the concepts included in some of the topics which were revealed earlier to be the most difficult ones to the pupils. The chosen topics were: diffusion, osmosis and water potential. In that analysis, the researcher identified the elementary ideas and concepts which are subsumed by those major concepts.

A sample of forty-eight pupils of different abilities from eight schools were interviewed in a diagnostic manner to identify the specific scientific ideas which were responsible for the difficulties they experienced in learning those major concepts. In the light of the results of those diagnostic interviews, the researcher constructed one essay-type question and two objective tests covering the various concepts and ideas on which the two chosen topics are built. The tests were administered in eight of the selected schools and the results were analysed for further and much deeper diagnosis. The sample of the pupils dealt with in this stage was as follows:

1 - The fourth year sample:
N = 348, Age range = 14 yrs. : 2 months to 16 yrs. : 11 months, Mean age = 15 yrs. : 6 months, and SD. age = 2 months.

2 - The fifth year sample:
N = 179, Age range 15 yrs. : 9 months to 18 yrs. : 3 months, Mean age = 16 yrs. : 8 months, and SD. age = 7 months.

By doing this, the researcher hoped to find answers to the questions numbered 3 through 6 on the statement of the problem.

3. Stage Three: The construction and application of new learning materials:

It was hypothesised that, once the weak points in the pupils' cognitive structure were uncovered, the specially designed learning materials could help the pupils to develop better understanding of the concepts. In this stage, the researcher constructed a fourteen-minute animated film with a verbal and diagrammatic printed material to accompany it. He also wrote a guide for the teacher with useful suggestions. The year following that of diagnosis, the film and the printed material were used in the same schools by the same teachers but on a new, but similar batch of pupils. Question number 7 on the statement of the problem was hopefully then answered.

4. Stage Four: The assessment of learning as a result of the new learning materials:

Two weeks after the use of the film and the printed material, the same pupils were asked to sit the same diagnostic tests which were used before with the previous year's pupils. The sample of the pupils dealt with in this stage was as follows:

1 - The fourth year sample:
N = 291, Age range = 14 yrs. : 2 months to 16 yrs. : 10 months, Mean age = 15 yrs. : 6 months, and SD. age = 2 months.

2 - The fifth year sample:
N = 153, Age range = 15 yrs. : 8 months to 18 yrs. : 3 months, Mean age = 16 yrs. : 8 months, and SD. age = 7 months.

An assumption about the similarity between the samples of the two successive years was based on the grounds of the consistency in the intake of those schools, on the selection of the pupils made by their teachers and on the similarity of the scores revealed by the school preliminary examinations and by their performances on marker questions included in the test. The performances of the pupils on the diagnostic tests were analysed and compared to the corresponding performances of the previous year's sample of pupils. The work of this stage gave the answer to the last question on the statement of problem. This in turn, proved the validity of the hypothesis posed earlier at the beginning of the third stage.

CHAPTER FOUR

Stage One: The survey of the situation in learning and teaching biology in Scottish Secondary Schools.

4.1 General Features

Scottish children join the secondary school at the age of twelve for four, five or six years according to their aspirations and abilities. Applying the Piagetian age-stage classification, pupils could be still performing at the concrete level of operational thought at the time when they join that school. As they move up the school years, their intellectual development moves up along the continuum concrete-early formal-late formal levels of operational thought.

With regard to the system adopted in class setting, the majority of secondary schools are adopting the mixed-ability type for the first one or two years. This decision, though it has its social merits, has not completely proved to be the best when we consider its administrative, academic and educational disadvantages.[122] Frost (1978) conducted a well controlled experimental study from which he concluded that the groups of pupils who studied science in streamed classes showed better academic progress during their following two years of study when compared to an equal group who studied the same course by the same teachers but in mixed ability classes. The effect was most marked among the top third of each group, but was imperceptible among the lower one.[123]

In the first two years, all pupils have to learn biology whether as a separate subject or as a part of an integrated science course. In the remaining two years of the compulsory four years of secondary education, a pupil who chooses biology would study it as a separate subject. Each pupil theoretically can study one or two or even three branches of science as separate subjects. The decision to be taken on whether to study science or not, and which branch(es) a pupil can take in the third and fourth years is not completely left to him. His scores on science, as well as his interest and ability would form the grounds for such a decision. If he is able enough and wishes to continue his schooling, a pupil may study biology for another year at the 'Higher Grade' standard.

However, it is the common belief in schools that the least able pupils who desire to study science usually opt for biology, whereas the most able opt for chemistry or physics as a single science, or for a combination of more than one of these three branches. The reports on terminal examinations consistently showed a comparatively low percentage in pass and in the high scores obtained by the pupils studying biology when compared to those studying other branches of science.[124] Appendix No. 4.1.A shows a comparison between the results of different groups of pupils on the terminal examinations of the year 1976.

It seems that the University entry requirements have influenced the school science subjects. Since most of the University faculties do not consider biology as one of their major requirements, the biology community in the secondary schools have tried their best to prove it to be of greater academic respectability. To do this, they have inserted topics of a highly informative nature, which in many cases require a mastery of chemistry and physics. This does not seem to go well with the relatively low abilities of the pupils who usually opt to study biology. The learning of many parts of the courses could not be expected to reach the required levels.

Another phenomenon connected with the biology classes in Scottish Secondary Schools is that the majority of the pupils doing it are girls, which is not the case with the other branches of science. (This could be recognized from Appendix No. 4.1.A.) With regard to the 'Ordinary Grade' candidates, the percentages of girls were 65.4, 38.1, 20.5 in the year 1976 for biology, chemistry and physics respectively. The 'Higher Grade' distributions were similar. This would be worth noting especially when we realize that about 75% of all university science students in Scotland were men in the same year.[(125)]

In Scotland, Alison Kelly (1975) examined a suggested explanation that girls study biology because of their "interest in people."[(126)] She found that this is not the whole story. At least amongst girls reaching University, an interest in people does not differentiate biological and physical scientists (though it does distinguish scientists from arts or social science specialists). To find a more reliable explanation she turned to consideration of career decisions, the early education, the conceptual differences between the three sciences and the nature of girls' fears.

1. On the career decision grounds, Kelly suggested that most girls anticipate motherhood and many consider a nursing career. Biology can offer them adequate satisfaction in preparing themselves for that expected future.[(126)]

2. On the early years of education grounds, Kelly draws attention to the fact that the primary school syllabus is more biased to the study of nature, which is mainly a biological theme, at the expense of physical studies. When proceeding to the secondary education stage, the physical sciences seem to all pupils to be new and uncomfortable. With boys this probably does not matter - they have mechanical toys,

and are more encouraged at home to be interested in how things work. Girls, however, immediately feel at a disadvantage and head for the most secure branch, i.e. biology.

3. On the conceptual differences between the three sciences, Ingle and Shayer (1971), and Shayer (1972) have suggested that the early years of Nuffield chemistry and physics sullabuses are at a conceptual level which is beyond that of most of the pupils studying them.[127][128] It is most likely to be the same with the corresponding Scottish syllabuses as they are similar in nature to the Nuffield ones. Duckworth and Entwistle (1974) showed that pupils, particularly girls, consider chemistry and physics difficult, but biology is less so. With girls, this belief can cause acute anxiety or resentment, or both. They are also made afraid by the fact that chemistry and physics are more mathematical and theoretical, as compared to the descriptive biology in the early years of the secondary schools. Discouraged by difficulties, girls readily abandon the difficult subjects and get along with the most rewarding one.[129]

For the sake of attracting girls towards the study of physical sciences, Kelly suggests that these subjects should be presented in a manner similar to biology - that is introduced into the primary school curriculum, and made easier and more familiar in the early years of the secondary school. To the biological science educators, this suggestion would be welcomed as the attainment of physical science concepts would give a desirable conceptual boost to all boys and girls doing biology at the same time.

In England, Ormerod (1977) suggested another explanation drawn from the affective domain of sexes. His argument rests on the observed phenomenon that the study of biology does not require spatial ability as much as the study of physical sciences. Since most girls, at adolescence, feel that they are not competent in this respect, they prefer the study of biology to chemistry or physics.(53) This belief is supported by a study which showed that girls are more strongly influenced by perceptions of subject difficulty than boys.(130)

Concerning the boys who opt to study biology up to the 'Higher Grade' standard, a relatively high proportion of them study one or two of the other sciences in addition in order to fulfil the requirements for entry to the study of Science or Medicine in the Universities.(131)

4.2 Biology in the First Two Years in Scottish Secondary Schools

In 1969, a Working Party on the Secondary School Science published its major report under the title: "Science for General Education."(132) The report suggested a new science syllabus for the first two years of secondary education, stating that pupils must acquire:

(i) some knowledge of the empirical world around them,
(ii) a little of the vocabulary and grammar of science,
(iii) an ability to observe objectively, and
(iv) an awareness of the culture which is science.

The syllabus designers recommended the 'Integrated Science' approach to be followed by schools while teaching that syllabus for the following reasons:

(1) The children at this stage are still immature. For them, dealing with one science teacher is more desirable than dealing with three. They would benefit most by seeing science as a whole rather than as three separate disciplines.

(2) Teaching science as one integrated form gives the science class teacher relatively longer and uninterrupted sessions which would help him to cover the syllabus and to perform better orientation and assessment. It would help him also to introduce his pupils to science as interwoven ideas and concepts rather than separated sets of observations and principles. This approach helps them to develop well-established concepts on which they can build others at higher level.

(3) It would be easier for the school administration to timetable one science teacher per set, than it would be to co-ordinate the efforts of three.[132]

Applying the views of Hirst on the nature of human knowledge on this situation, some educators would argue that a separate sciences approach is more realistic.[133] They also believe that it could provide pupils with solid scientific background which would be of greater help for further studies in science. Moreover, it is easier to teach separate sciences from the viewpoint of teachers' preparation and satisfaction. In spite of that, a high proportion of Local Authority schools are following the Integrated Science course.[131] But there is a beginning of a trend away from it.

The syllabus designers also recommended the guided discovery method in learning the scientific facts to be arranged for wherever possible. In addition to its merits in introducing the pupils to the scientists' way of reaching facts and forming theories, it could free the teacher from the need to deal with the whole class at once. Accordingly, the science teacher can give his attention to individuals or small groups, who usually work at a different pace. For this reason, an experimental set of worksheets was prepared and provided for teachers.

Again, in 1973 a National Working Party (N.W.P.) was set up by the Scottish Central Committee on Science to reconsider the remit suggested earlier by the 1969 report as there was a changeover from a selective to a comprehensive school system. Besides, a decision had been taken already by many headteachers that classes at least during the first year, should be unstreamed. As a result of this decision, about 64% of Scottish schools distributed their S1 and S2 pupils in mixed ability classes for science at that time. The Working Party was asked to state the aims and objectives of science education for the different groups of children in mixed ability classes. Another duty was to structure the Integrated Science Course (set out in Curriculum Papers 7) to enable the aims and objectives selected for the different groups to be realized. However, it was understood that the findings of and the materials produced by the Working Party would also be useful with streamed classes.(134)

With regard to these duties of the N.W.P., one can consider their exercise as a formative-type of curriculum evaluation, since it was carried out side by side with the development of the teaching material itself.(173) This type of evaluation helped the course designers to alter and improve their successive trials and to criticize the course objectives until they were able to produce an improved version of the teaching materials. With the help of seventy science teachers forming ten local working groups the N.W.P. made an attempt to provide some advice and information of a practical nature for science teachers to help them to devise a more flexible science course for that broad range of pupil abilities. Since it was noticed that the worksheets associated with Curriculum Papers 7 had been (mistakenly) taken to define the course completely, and their whole content was offered to all pupils irrespective of their abilities, there was a need for a new arrangement for the course. The new Working Party took into consideration that most of the problems were associated with the use of the course by pupils at both ends of the ability range. The less able pupils were finding some of the concepts to be very difficult and were experiencing difficulty in reading instructions in the worksheets. On the other hand, the course was deemed to be insufficiently demanding for the most able pupils. The worksheets were criticized for containing insufficient instructions for these pupils to work independently for more than a short time.[135] The N.W.P. took the responsibility of restructuring the Integrated Science Course as described in CP7 for use with the different groups of pupils in mixed ability classes, while being flexible enough for use with any type of class organization. These considerations led them to meet the different educational needs of different groups of pupils of differing ability and hence to adopt the pattern of 'core' worksheets with three levels of 'extension' activities as follows:

(1) The 'Core' sheets represent the principal worksheets as they cover all the units of the syllabus and written to be carried out by all pupils in the first and second year classes. It is assumed that through doing the experiments involved in those sheets, the pupils can attain almost all the skills and knowledge recommended by the course.

(2) The 'Extension' sheets are grouped as a, b and c sets of worksheets. Set 'a' is designed for the less able pupils, i.e. the lowest 20%, who need extra help to understand and grasp the notions associated with the work on the core sheets. Sets 'b' and 'c' are intended for the 'average and above average' and the 'most able' pupils respectively. The flow diagram in Figure 4.2.A is an example of the overall programme of work for a typical section being used with a mixed

ability class.[135]

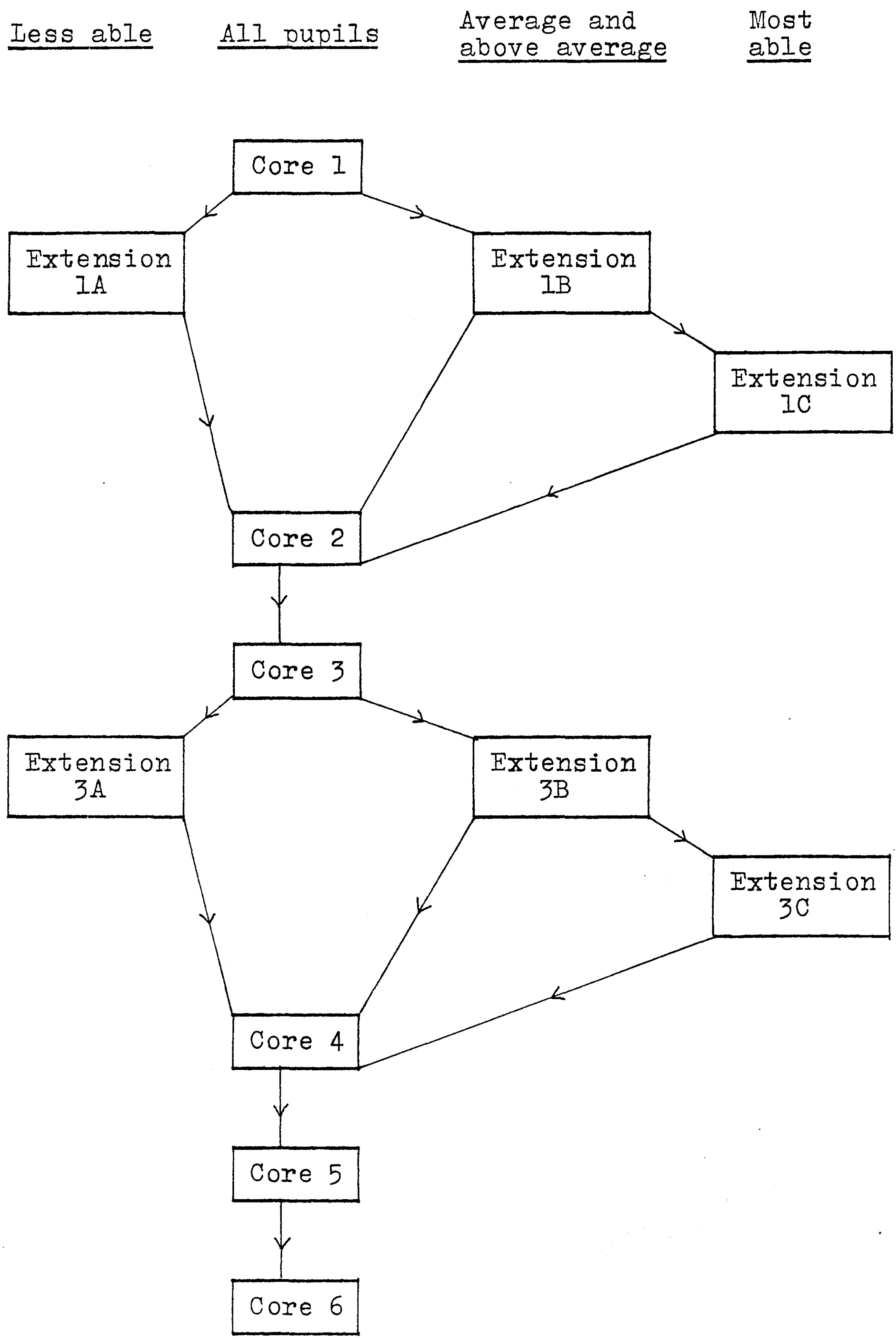


Figure 4.2.A
"An example of the basic flow diagram for a typical section"

It was hoped that every teacher would carry the responsibility of knowing his pupils well enough to identify those with learning difficulties from those who have greater interest with better capabilities for each topic of the course, then distributing the appropriate assignments accordingly. The extent to which such course could be successful depends largely on that preliminary step.

This strategy in facing the individual differences among pupils could be likened to that adopted by the Nuffield group in England when they have provided schools with more than one written text for more than one level.(136) It would also correspond to what has been done by similar groups outside the U.K., such as the Biological Science Curriculum Study in the U.S.A.

After a series of trials in a limited number of schools to test the evaluation procedures and to make an initial tentative assessment of the suitability of the worksheets for the less able pupils, major trials in 50 schools were carried out in the next year. Classroom observation, pupil tests and subjective judgment by teachers were among the tools used, and the necessary alterations were made.

4.3 Biology Courses for the Third, Fourth and Fifth Years

The new syllabuses for Biology were published by the Scottish Certificate of Education Examination Board in 1968.(48) They took into consideration that our understanding of basic principles of biology is growing at a very rapid rate, with new areas of knowledge becoming uncovered and presenting extremely sophisticated problems which are intellectually challenging but directly relevant to almost every aspect of human activities and thought.(48) The designers of the syllabuses intended to show Biology both as a liberal subject of the highest educational value and as an experimentally-based science. For this, the study through the syllabuses demands mental skills, imagination, experimentation and clarity of thought with good ability of expression. The syllabuses reflect an international trend to study both the whole organism, i.e. how it lives and how it is related to other organisisms, on the one hand, and the study of the relatively complicated processes within it on the other hand. This trend is expressed by Weisz (1971) when he says: "The frontiers of biology have been extended down to the chemical level during the last few decades, and while research with larger living units continues as before, the newest biology attempts to interpret living operations in terms of the chemicals out of which living creatures are constructed."[137] The reflection of this in the school biology is the new move towards giving room for the study of the 'micro' instead of totally devoted to the study of the 'macro'. New concepts of chemical and physical origin have been included in the new biology syllabuses. This new trend has introduced a new type of difficulty to the schools for both pupils and teachers, since most of the introduced concepts are highly abstracted in their nature. Topics such as the building up and the release of energy in organisms, and the movement of water and dissolved substances inside the organism and their environment are some examples of this physically and chemically based pattern of knowledge.

In the Scottish Biology syllabuses, it does not seem to be clear what are the valid criteria on which the burden of these newly introduced requirements were distributed among the 'Ordinary' and the 'Higher' grade candidates, nor how they were originally chosen. It seems that it was the logical reasoning of the grown-up people on which the syllabuses were constructed.

Moreover, the decision about the sequence in which the topics, or the concepts, are to be taught is left completely to the teachers.[47][48] Objectives of the courses were stated rather loosely since they lack precise definitions (See Appendix 4.3.A).

Surveying the syllabuses would show clearly that some topics require a prior study of another topic. In addition, the Ordinary Grade syllabus is based on an acceptance of the biology content of the Integrated Science course for S1 and S2,[47] which by nature, may not prepare the pupils to extend their knowledge to link with the new topics in further years. It has been revealed by a survey study that the majority of school biology teachers are not happy with the biology content offered to the first and second year pupils. Their comment was that 'there is no biology taught in S1 and S2 on which to build at S3 and S4.'[131] Before teaching a topic to the third year pupils, the teacher has to think of how to help them to build up their knowledge from that weak level to another much more suitable for the learning of the new topic. Another difficulty that faces the teacher in this respect comes from the nature of biology itself as it deals with living things, and the living process is a unitary system. Concepts and ideas in biology are closely interwoven so that it becomes difficult to place one before the other.[39] For this very reason, some researchers went to indicate the lack of hierarchical order in some current biology courses.[138] In such cases, biology teachers find themselves facing a circular arrangement of biological concepts and have the problem of deciding at which point to break into the circle. Appendix 4.3.B shows several possible sequences of the school biology topics suggested to the teacher by an advisory educational body.[47] Although this does not exhaust all possibilities, it illustrates the interdependent nature of the biological concepts. At whatever points they finally break in, the use of the concentric arrangement of subject matter provides them with the opportunities to tie up the connections.(39)

Some topics of the biology syllabuses require an understanding of physical and/or chemical concepts. Pressure, diffusion of particles and potential are some examples worth a mention. The biology syllabuses assume the presence of sufficient understanding of those fundamental concepts in spite of the fact that not all the pupils who study biology are necessarily following the physics or chemistry courses. However, it does assume the coverage of those concepts in the shallow study of the physics and chemistry topics of the Integrated Science course. In that latter course, the level of treatment applied to them is normally regarded as sufficient for 'Ordinary' and the proceeding 'Higher' grade biology.(139) It could not be completely true in cases such as the study of osmotic pressure which requires a good conceptualization of the term pressure as a necessity for its successful achievement. Among the objectives suggested for the Scottish Biology courses (Appendix No. 4.3.A) one reads: "an awareness of the interdependence of all branches of science and mathematics in scientific progress."(47) This objective cannot be fulfilled unless pupils have been equipped with real understanding of all relevent concepts from the physical sciences.

As a result, it has become the responsibility of every biology teacher to identify the subordinate biological, physical and chemical facts and ideas which should be taught first to his pupils in order to furnish them with the basic requirements for a good level of understanding of the main biological concepts in the course. Knowing that the teaching-learning situations are affected by many factors and subjected to several pressures, it would not be unfair to suggest that some teachers have failed to equip their pupils with such learning prerequisites, whereas others have met the challenge successfully.

With regard to the facilities available in schools for the teaching of biology, it has been reported that they are improving and this subject is generally taught in properly equipped biological laboratories.[131] Most teaching time at the 'Ordinary' Grade is spent in pupil participation practical work, whereas with the 'Higher Grade' pupils it is spent on more theoretical work.

In general, the mean time allocation for biology in most of the schools is three hours and ten minutes per week in both the third and fourth years, while it is three hours and forty-five minutes per week for the fifth year pupils.[131]

4.4 Written Texts for the Third, Fourth and Fifth Years

There are no 'Government' textbooks designated for the school biology as is the case in some other countries. Private authors provide the book market with several texts in which they treat the topics of the syllabus according to their own understanding and approaches. Biology teachers in Scottish Secondary Schools feel free to use one or more of these books according to their own inclinations. Some may prefer a text according to its merits in explaining the facts involved, others may choose the one which goes best with their laboratory facilities. Some teachers, still, give more support to a text because they feel at ease with its explanations and approach to the factual contents of the syllabus.

One of the widely used textbooks displays the facts followed usually by experiments to demonstrate or to support them.[140] On the other hand, another set of texts suggests experiments followed by guide of questions to help pupils to formulate their own conclusions.(141) While the former is spoiling the pleasure and the benefit of tackling the unknown to discover the relations and scientific rules, the latter is taking for granted that all biology teachers will safeguard every individual pupil while reasoning with each experiment not to draw any wrong conclusion. For both reasons, one may wonder how many pupils are learning biological facts by memorization, and how many are holding in their minds vague ideas about some biological concepts. In other places, textbook writers have tried their best to avoid such potential pitfalls. The Nuffield group, for instance, have published the 'laboratory guides' separate from the 'study guides' for the A-level biology candidates.(136) The Biological Science Curriculum Study group in the United States have written the 'laboratory blocks' separate from the main source books with their unique versions. By this strategy, they are offering the pupils a fair chance to experiment with biology, and helping them at the same time to build up their knowledge on a solid and clear basis.

A second point about the textbooks used by biology teachers in Scotland is that they are written for one-level classes. In spite of the fact that the majority of schools have become comprehensive, no biology textbook is offering more than one approach to the topics to be used in those mixed-ability classes. In some parts of England, many biology teachers got together in regional workshops to help produce the necessary resource materials.(142) In Strathclyde, another group of teachers has recently done the same.(143) Being more able to feel the structure of their classes, such groups are more likely to produce well-fitting and oriented textbooks for their pupils, though adopting one single approach still. However, using such books could be expected to suit local pupils better than books written elsewhere outside the region. Some solutions could be reached to remove any conflict between the need for regional-based textbooks and the growing appeal for nationwide examination papers.

Another important point about the biology text-books used in Scottish schools is that they have not been tested for their 'readability'. As teachers, we realize the importance of choosing material which our pupils can read and understand. If the material is too hard, pupils may become frustrated and turn away from the topic.(63) Some of those texts have introduced a great deal of scientific terms, maybe more than the syllabuses have suggested for the required standard of the subject. Other books are using the old terminology side by side with the newly adopted one in an artificial blend. A small number of them have explained the meaning of the different syllables of the terms, or how to pronounce them correctly. On the other hand, the pupils doing biology in Wales seem to be on their way to benefit from a current trend in examining the textbooks for their readability.(61)

One major deficiency, which is unfortunately common among biology books, is that they do not furnish the pupil with the basic chemical or physical facts required for a good quality of understanding of some topics. This drawback is observable in topics such as photosynthesis, respiration and water intake and movement inside the plant. Studying from such books, only a superficial understanding or a rote type of learning could be acquired in most cases. Knowing that there is no 'Head of the Science Department' post in Scottish schools, one could at worst expect that a minimum level of co-operation would take place between the biology teachers and their colleagues in the physical science departments. Even if one assumed the presence of such consultation and co-operative planning, it would appear that it could be beyond the teachers' authority to take remedial action when it comes to the pupils' scientific background and to the course structure in the Secondary School stage. In such cases, it seems that a whole check-up of the course structure is inevitable if real learning is to be made possible for the pupils. The alternative to that is to keep on teaching concepts and whole topics without evaluating their suitability to the pupils, and replacing them by others of the same sort, whenever complaints arise. This certainly could lead to a state of chaos in curriculum reformation.

4.5 Methods Applied in Scottish Secondary Schools for Assessing the Pupils' Learning of Biology

During the first two years, the level of understanding of the biological facts and concepts held by pupils is assessed by the end-of-the-year examinations as well as by the teachers' reports on the pupils' performance. This goes along with what has been recommended by several writings in the field of science education. In this stage, the education authorities advise teachers and examiners to construct their assessment tools to test for skills other than retention of information alone, "so that the school and the pupil himself can obtain the most complete picture possible of his strengths and weaknesses."[(132)(144)] Conscientious teachers are taking guidance in this respect from the literature on assessment such as that of Bloom, which has proved to be the most respectable of all among the science teachers in Scotland for many years.[(32)]

In the beginning of his fourth year of the secondary school, a pupil doing biology may be advised to take the course assigned for the non-certificate group of pupils, or to take the more sophisticated and specialized one leading to the national examination named the 'Ordinary Grade Certificate of Education'. This advice is built on the reports submitted by his science teacher of the previous year and on his scores on the examination of that year. Some schools, however, do not offer such facilities, and pupils who choose to study biology have to undergo the same sophisticated course of biology irrespective of their individual abilities. In the middle of the fourth year, pupils studying biology have to sit a trial examination held by their school called the 'Preliminary Examination'. Its result determines for each pupil whether he is entitled to sit the final Ordinary Grade examination. This final examination is mainly composed of objective-type items which are meant to assess the candidate's learning at several levels. Although it does not include practical testing, it attempts to check on his comprehension of some experimental aspects in the study of biology. The results of this end-of-the-grade examination essentially make the decision of whether he should be entitled to carry on further studies in biology. Little attention is given to his teacher's report on his performance throughout the year. Practically speaking, only when a pupil needs to appeal if he fails the final examination, is his teacher's report examined carefully. This is a safeguard of precautionary nature.

In his fifth year of study, a pupil may continue with chemistry, physics or both besides biology. No regular examinations are necessarily held during the year, except a preliminary one like that of the previous year. Conscientious teachers, believing in the value of continuous assessment, may arrange for some class tests on several occasions throughout the year.

To the knowledge of the researcher, no one has investigated yet the philosophy held by teachers adopting the policy of continuous assessment in their classes. It would be of great importance to reveal whether the majority are bound by the same type of measurement adopted by the end-of-the-grade examinations, i.e. the norm-referenced measurement, or they make better value out of their assessment by giving sufficient room for the criterion-referenced type.(146) At the end of the fifth year, pupils who are successful on the preliminary examination are entitled to sit the final external examination.

Two types of question items are presented to the pupil in that examination. The first group of questions, in an essay form, aim to assess his understanding of the general theme of biology, as well as his language and drawing skills in this respect. The other group of questions, in an objective form, aim to check on his attainment of particular bits of knowledge, as well as his conceptual understanding of the topic. The second group of questions tend also to assess his mastery of some experimental skills such as making hypotheses, interpreting data and reaching reasonable conclusions from a given amount of data. Like the Ordinary Grade examination, no oral or practical tests are held. The final aim of this examination is to provide the Universities and employers with an estimate of the candidate's achievement in the secondary school courses. No kind of diagnosis is deliberately intended by such examinations.

4.6 Teachers' Opinions on the Biology Syllabuses

When the current biology syllabuses were first introduced to schools in 1968 they were welcomed by most of the teachers since they included a higher level of treatment of the topics, and gave some room for individual initiative and innovations from the teachers' side. When put in real classroom situations, the syllabuses were subject to a wide spectrum of interpretations and implementations, and were taught at different levels. This could be one reason for the considerable difference in the standards of candidates' performance on the first examination papers set on the syllabuses. This was attributed to "the failure of some schools to realize the implications of the new approach outlined in the syllabuses."[147] This is not a strange phenomenon with the arrival of new teaching materials, but, has repeated itself occasionally for several years. A questionnaire, which was distributed by the Association of Biology Teachers in Scotland, revealed that they were not happy with the topic on water potential and would like to see other topics trimmed at different levels (Appendix No. 4.6.A).[148][149] A joint working party was set up in 1977 from both the Scottish Certificate of Education Examination Board and the Scottish Central Committee on Science to review the Biology syllabuses.[150] Revision of the report issued by this party showed that the teachers were experiencing difficulties in interpreting, implementing and in sequencing the topics of the syllabuses. Special reference was given to water relations of organisms, the biochemistry details of photosynthesis and respiration, perpetuation of species as the most difficult topics. Teachers stated that because of time limitations they had not been able to provide their pupils with the necessary laboratory experimentation, which in turn led to an inadequate grasp of the ideas and understanding of the higher level concepts.[151] Teachers also showed their natural apprehension with regard to the topics which are time-consuming, and if they are to be covered adequately, this must be done at the expense of other 'examinable' topics. They remarked that the detail asked for in examinations is sometimes unjustified when compared with the lack of stress put on them in the syllabuses. This would highlight the existing conflict between the written syllabuses as an outline document, and the external examinations with their implicit, but unavoidable, commanding influence. Recommendations were submitted by the joint working party, and decisions were taken later by which some topics were modified or omitted altogether.(152)

4.7 Examiners' Reports on the Pupils' Performances on the Terminal Examinations

Though they cannot be taken as a final judgment on the suitability of the courses, the annual reports issued by the Scottish Certificate of Education Board can provide researchers of the field with clues to the general situation. One major inherent defect in them is that they are intended to reveal the level of achievement in view of particular objectives which the examiners have deemed most worthy to be assessed. Knowing that the biology syllabuses do not carry clearly stated objectives (Appendix No. 4.3.A), one can expect that a statement of praise on the report would not necessarily mean a good level of learning has been achieved by the pupils. In fact, it could possibly indicate a good recall of a piece of knowledge memorized easily with little or no real learning behind it. On the other hand, a statement of sorrow on a report could mean a disagreement between the objectives for which teachers have been working and those which the examiners have been assessing for.(145) Examinations also, as they are conventionally constructed, do not reveal reasons behind observed misconceptions.

Reviewing the annual reports issued over the past six years revealed that the following are recurrent patterns in the pupils' performances:

(1) Weakness in the fundamental facts and concepts.
(2) Unfamiliarity with basic biological terms.

(3) Poor ability to reason.
(4) Poor ability to express themselves.
(5) Poor knowledge of practical work.
(6) Shallow understanding of basic biological structure and function.[153]

This could reveal that some parts of the syllabuses are not suitable or not being presented adequately to the pupils.

CHAPTER FIVE

IDENTIFICATION OF THE DIFFICULT TOPICS IN THE BIOLOGY COURSE

The aim of this part of the study was to locate which topics cause the most difficulty to the pupils to learn. It was important to gather the most valid and reliable data through this part in order to proceed to the next stages with complete confidence and certainty. To achieve this, the researcher gathered the data through different channels with the help of different tools of investigation.

5.1 Revision of Examiners' Reports

As mentioned earlier, in spite of their limitations, the annual reports on the pupils' performances on the terminal examinations could provide useful clues to the researchers. Examiners pointed out that candidates of the 'Ordinary' and 'Higher' grades repeatedly showed unsatisfactory understanding of the following topics:

(1) Basic plant anatomy
(2) Central nervous system and co-ordination inside organisms
(3) Ecosystems
(4) Genetics
(5) Water relations of the organisms
(6) Enzymes
(7) Respiration and photosynthesis
(8) Shape and support in plants
(9) Locomotion in animals
(10) Energy storage and conversion
(11) Mechanism of evolution. (153)

5.2 Observation Inside Classrooms

Through arrangements with education authorities, the researcher paid regular weekly visits over a complete school year to different classes in two secondary schools. During those visits, he was able to observe the teaching-learning situations while most of the biology topics were dealt with in the course of the year. He held many discussions with many pupils during their work on experiments, to assess their attitudes to the topics and their understanding of the concepts involved. Great attention was paid to the answers of the pupils on the teachers' evaluative questions whether during or at the end of each lesson. To make these observations directed, systematic and fruitful in this stage of general survey, a simplified check list was used.[154] Short accounts were written on the suitability of the concrete experience, academic knowledge provided to the pupils during each lesson and notes were taken about the evident levels of their understanding. Appendix No. 5.2.A presents the check list used during observation.

Results from the observations:

As an observer, the researcher was convinced that the biology syllabuses are too long for both the 'Ordinary' and the 'Higher' grade standards. Teachers were rushed most of the time to cover the syllabuses, leaving minimum opportunity for pupils' questions and classroom discussions. With the pre-Ordinary classes, most of the time was devoted to teachers' explanations of the factual knowledge, instructions concerning the handling of apparatus, checking on the results from experiments and specification of the homework. An unsatisfactory amount of time and effort was devoted to discussing the need for an experiment, the method by which a ready-made microscope slide or preparation was done, the nature of the chemicals used in the experiment, the reasons for the failure of some experiments. Also the unseen behaviour of particles in experiments was not referred to, though it could have been explained through simple recall of the pupils' knowledge which they had during their study in previous years. The terminology used in many lessons was completely new to the pupils, nevertheless, explained to them in a relatively brief manner with the help of verbal definitive phrases. Evaluation of pupils' understanding was mainly con-concerned with the memorization of the steps included in an experiment and the ideal results expected out of it, or the factual knowledge that describes a phenomenon along with its labelling name. Rules that govern biological phenomena were recited, with superficial explanations. Minimum attention was given to link biology concepts with the corresponding ones in the physical sciences.

By questioning pupils about the experiments on the action of enzymes on food material and the release of energy stored in them, the observer noticed that pupils had only a little, or even a false conceptualization about energy and energy conversion. On experiments on osmosis, pupils were not able to explain how solutions were formed or explain how molecules of water travel between solutions across the membranes. When considering models of gametes, they showed weak understanding of the nature of those hypothetical structures. The same phenomena were present in the fifth year classes, with the additional problem time for experimentation being very limited. The lessons were packed with factual presentations but fewer of the concrete type. During demonstrations on the effect of stem ringing on the movement of sap, pupils were not able to show good reasoning of the relation between the observed results and the function of xylem and of phloem. In the water potential lessons, the majority of pupils faced great difficulty in following their teachers' demonstrations about water potential and the cell wall pressure as opposing factors in determining the net value of (Ψ). Many of them failed to explain what is meant by cell water potential or how the direction of flow could be predicted among several cells with the help of their water potential values. Names of different sea fishes used as examples of water balance problems in marine organisms (i.e. elasmobranchs and teleosts) seemed to mean nothing to them as they were not shown representative specimen. Worked problems on genetics were followed in a cookery-book manner with little understanding. Difficulties seemed to reach their climax with pupils who were studying the 'Ordinary' and the 'Higher' grade biology within a relatively limited time on the so-called 'crash courses'.

In general, the following topics seemed to the observer not to be grasped meaningfully:

(A) The pre-Ordinary grade:

1. Energy storage in plant food
2. Energy conversion in respiration
3. Enzymes action on organic materials
4. Osmosis in plants and animals
5. Mendel's factors

(B) The post-Ordinary grade:

1. Chemical energy and chemical reactions included in respiration and photosynthesis
2. Water potential and osmoregulation within the living organism
3. Genetics.

5.3 Consultation of Some H.M. Inspectors and University Lecturers

The researcher sought the opinions of three secondary school biology inspectors who used to go frequently to schools, as well as four University staff members who used to teach biology to the first year students. From their experience, they were able to identify the areas of common weakness among pupils in schools, and students joining the University recently. Both groups indicated that the topics of water potential and of energy build-up and break-down are at the top of the difficult areas.

5.4 Distribution of Questionnaires Among the Biology Teachers

It has been acknowledged that questionnaires are among the fruitful tools for gathering information about the attitudes and feelings of individuals on specified topics for different purposes.[155] In the field of science education, Reid (1978) used them to assess attitudes of secondary school pupils towards both scientists in general and the application of specific chemical concepts in human affairs.[156] Mughol (1977) used them to identify the relative difficulty of the topics included in the physics courses taught in Scottish secondary schools.[14] Evaluators of the efficiency of the Nuffield project courses used questionnaires to both teachers and pupils to estimate the levels of success reached through the use of these courses.[157] The 'Working Party' on the newly developed Scottish Integrated Science work sheets used questionnaires through the stages of developing that new educational material to gather evidence about their levels of acceptance among teachers and their feasibility in classroom situations.[135] The content and format of questionnaires, though they may appear to vary considerably, follow a relatively limited number of patterns. The commonest patterns of them all are those originated from the work of Thurston, Likert and Osgood. To choose the most useful to the present study, the researcher went through them according to the following brief survey.

(1) Thurston's method:

In his attempt to measure individuals' attitudes towards topics of general concern, Thurston (1929) laid one of the most popular formats ever used for such reason. He presented the testees with a wide range of well defined statements, each of which represent one point of view towards the topic concerned by the questionnaire. Testees were asked to mark all the statements with which they agreed. By matching the marked statements for one individual with the judgments they represent, a profile of his general attitude was available to the examiner.(158)

The construction of a questionnaire in this manner is painstaking and time-consuming as it required a sophisticated procedure in the preparation of those statements.

(2) Likert's method:

Likert (1932) suggested a modification to Thurston's method in order to avoid the cumbersome collating of statements. He suggested the use of a self-explained statement for each trend followed by several judgments on that statement, ranging from strong agreement to strong disagreement. The respondent is asked to state his position on that multi-point scale for each statement.(159) The questionnaire can be scored by giving different rated values for each response according to either one of the following schemes:

"The biology course in the fifth year is difficult to learn."

Rated judgments	Value given
Strongly agree	5 or +2
Agree	4 or +1
Uncertain	3 or 0
Disagree	2 or -1
Strongly disagree	1 or -2.

One major disadvantage to the above mentioned schemes of scoring is that the adding of scores got on each item to those got on the others would result in losing essential details in results interpretation. Moreover, it may not be mathematically meaningful to add numbers which are usually ordinal, and certainly not ratio in nature.(156) However, for a survey study in which an enquirer wishes to explore the general opinion on certain topics, the first apprehension is lifted since he is not concerned with individual differences. With regard to the second, it would be much better to make count of the individuals who marked each judgment for each statement as a replacement of the value-giving procedure.

(3) <u>Osgood's 'Semantic Differential' method</u>:

In his book 'Measurement of Meaning', Osgood (1967) suggested his approach to the identification of the individuals' opinion.(160) According to this approach, a testee is to be presented with an attitude statement on a seven-point scale, such as the following example:

"My opinion about a scientist is that he is

	1	2	3	4	5	6	7	
careful								careless
Valuable to community								Worthless to community

The testee is asked to tick the cell appropriate for his opinion on each bipolar dimension.

In spite of its remarkable brief format, this approach has the drawback of ambiguity. It is very likely that both the inquirer and the testee do not come to agreement on the meaning of each position on that multi-point scale for each bipolar dimension. However, by minimizing the number of the points of the scale and providing the testees with clear instructions and worked examples, more reliable results could be reached.

Being convinced with the merits of the Likert's type, the researcher inspired its pattern while constructing his questionnaires for gathering teachers' and pupils' opinions on the relative difficulty of the school biology topics.

5.4.1 The first general questionnaire to the biology teachers:

In 1976, the researcher distributed a Likert-type questionnaire among the biology departments in eighteen secondary schools at different localities throughout Scotland. On that questionnaire, which was sent through mail, all the topics of the 'Ordinary' and 'Higher' Biology courses were listed. The teachers were asked to rate each topic on a five-point scale of an easy-difficult continuum, viz.; very easy, easy, average, difficult, and very difficult to learn. All eighteen schools replied and the responses were sorted and calculated for each topic. Appendix No. 5.4.1.A shows the questionnaire used in this stage as well as a record of the results obtained.

Results of the first questionnaire:

Number of responses which referred to a topic as 'very difficult' were added to those referred to it as 'difficult', and the total was taken as indication of its relative difficulty as compared to the other topics. Table No. 5.4.1.A below lists the topics which got ten or more responses (out of 18) according to the above mentioned method.

Table No. 5.4.1A - The difficulties according to teachers.

Ser. no.	Topic	Total no. of 'Difficult' and 'V. diff.' which the topic got
1	Chemistry of respiration	15
2	Water potential	15
3	Chemistry of photosynthesis	14
4	Mendel's factors, DNA, RNA, linkage and crossing over and mutation	13
5	Water balance in man and in various animals and plants	12
6	Hormonal and nervous control	12
7	ATP	11
8	Diffusion and osmosis	11
9	Growth and differentiation in embryos	11
10	Gametes as vehicles of inheritance and pattern of inheritance	11
11	Cell division and cell growth	10
12	Respiration and energy release	10
13	Water loss or gain by osmosis	10
14	Role of kidney	10
15	Control of development by hereditary material	10

5.4.2 The Second Concentrated Questionnaire

Being enlightened by the results of the general questionnaire, the researcher constructed another one with the following characteristics:

(1) Presented two separate lists, one for the 'Ordinary' and another for the 'Higher' grade topics.

(2) Incorporated the topics which were shown to be difficult in addition to those which were controversial. Besides, some of the easy-rated ones were listed for confirmation.

(3) Split some of the difficult topics into minor elements in order to get more revealing results.

Appendix No. 5.4.2A shows the format of this questionnaire.

This questionnaire was distributed among the biology teachers at nine secondary schools in the Greater Glasgow Area. Teachers were asked to classify the topics to same categories as on the first questionnaire.

Many writers in the field of science education have urged researchers of the field not to underestimate the importance of questioning the pupils about their feelings towards the topics which they are studying. Tyler (1977) pointed out, in a criticism of the prevailing research studies, that 'we have largely neglected to look at the way learning is viewed by the student himself. We have been greatly preoccupied with investigating learning as commonly perceived by the teacher or curriculum maker'.(161) Ormerod (1977) gave justification for the need for exploring the pupils' opinion when he says: "Simply because the learner, no matter how great his mental powers, has an absolute veto over whether he learns anything at all or not."(53) For this reason, the same version of the above mentioned questionnaire was distributed among the fourth and fifth year pupils in the same schools. A relevant list of topics, a computer card, as well as full instructions on how to express his opinion on the card were provided to each pupil. Teachers were asked to guide them how to fill in the cards and to urge them to be honest in their opinions. Pupils were asked to classify the same topics into four categories defined as follows:

(i) Easy; if they had understood it first time,
(ii) Average; if they had to work at it to understand it,

(iii) Difficult; if they had to struggle with it and still not clear,
(iv) Not yet studied in school.

The pupils' instructions about the questionnaire are shown in Appendix No. 5.4.2.B. Responses on that questionnaire were collected from 337 fourth year and 166 fifth year pupils, as well as from their biology teachers from the chosen schools.

To check on the validity of the method, the following postulate was made: "If the topics referred to as difficult by the secondary school pupils have genuine difficulties, the same questionnaire, given to a sample of first year University students, should give peaks in the same places, but the peaks should be less intense because the University sample is more able than the school sample containing those who will fail the biology examinations."

This postulate was tested using the first year students in the University of Glasgow who had passed the 'Higher Grade' biology (167 students) and with others who had joined the University with 'Ordinary Grade' biology (42 students) as their highest qualification.

<u>Results of the second questionnaire</u>:

The filled-in returns of the teachers' questionnaires were dealt with as with those of the first questionnaire. The filled-in computer cards by both the secondary school pupils and the first year University students were punched and treated by the Computer Centre at the University of Glasgow, and the data was tabulated. The indices of difficulty as percentages were computed for each year group of pupils for each topic. The formula used for the computation was:

Index of difficulty percentage =

$$\frac{\text{Number of pupils who referred to the topic as difficult}}{\text{Total number of pupils in the sample - Number of pupils referred to the topic as not yet studied}} \times 100$$

Since the questionnaires were administered near the very end of the school year, very few pupils fell into the group that referred to a topic as 'not yet studied'.

On Tables 5.4.2.A and 5.4.2.B the data got from the previous sources are shown in a comparative manner.

Table No. 5.4.2.A - The relative difficulty of fourth year topics as revealed by teachers and pupils.

Ser. no.	Topic	% of teachers referring to the topic as diff. or v. diff. N=26	Index of difficulty % for each topic	
			Secondary school pupils N = 337	University students N = 42
1	Plant and animal classification	0.0	9.6	4.8
2	Cell structure and cell division	24.3	14.3	12.0
3	Chemical energy from food	31.9	30.6	26.4
4	Enzymes in general	35.8	39.5	36.0
5	Photosynthesis	23.9	11.6	16.8
6	Respiration	28.0	41.9	38.4
7	Feeding and digestion	7.5	19.9	9.6
8	Breathing and gas exchange	3.7	37.0	19.2
9	Diffusion, osmosis, turgor and plamolysis	56.6	56.2	74.4
10	Control of water content inside living organisms	40.0	35.6	52.8
11	Size, surface area and heat loss in animals	15.9	23.9	7.7
12	Development of insects and birds	8.3	8.4	16.8
13	Central nervous system, hormones and co-ordination inside the human body	28.0	49.1	52.8
14	Gametes	24.1	25.7	24.0
15	Alleles, genes and Mendel's work	48.1	48.6	40.8
16	Different types of soil and the nitrogen cycle	24.0	39.7	16.8

Table No. 5.4.2.B - The relative difficulty of fifth year topics as revealed by teachers and pupils.

Ser. no.	Topic	% of teachers referring to the topic as diff. or v. diff. N = 13	Index of difficulty % for each topic	
			Secondary school pupils N = 166	University students N = 167
1	DNA and RNA	22.5	21.0	22.8
2	Cell structure and cell division	9.5	16.8	13.2
3	Chemical energy	44.8	36.5	24.0
4	Chemistry of photosynthesis	44.8	30.5	28.7
5	Chemistry of respiration	41.5	32.9	25.7
6	Gas exchange between living organisms and their environment	6.8	12.6	6.0
7	Osmosis and water potential	51.5	50.9	47.3
8	Role of the kidney	12.5	16.8	13.2
9	Water balance problems and osmo-regulation in organisms	31.5	35.3	27.5
10	Reproduction and growth in living organisms	9.5	7.8	9.6
11	Hormones	0.0	26.9	19.8
12	Gametes	6.5	25.7	19.8
13	Genes	25.5	29.9	24.6
14	Evidence for evolution	12.7	13.3	13.8
15	Mechanism of evolution	32.0	22.3	29.3

From these two Tables, it is clear that there is a considerable agreement between the three different groups on the relative difficulty of many topics. Figures Nos. 5.4.2.A and 5.4.2.B illustrate this agreement and show how the postulate was valid. The intensity graph for the University students is superimposed on that of the school pupils. For the Higher Grade candidates, the postulate has been well supported. For the Ordinary Grade candidates, the pattern is substantially the same, but the small sample size (N = 42) gives rise to errors which make the intensities less reliable. Nevertheless, the same pattern emerges.

Spearman's rank difference coefficient of correlation (p) was computed between the opinions of the previous groups from Tables Nos. 5.4.2.A and 5.4.2.B using the following equation:

$$p = 1 - \frac{6 \sum D^2}{N(N^2-1)}$$

where D is the difference in ranking order between the different groups and N is the number of topics. Tables Nos. 5.4.2.C and 5.4.2.D show the result of computations.

Table 5.4.2.C - 'Rho' values for the 'Ordinary' grade topics.

Groups	Fourth year pupils	University students
Biology teachers	0.69	0.84
Fourth year pupils	-	0.76

Table 5.4.2.D - 'Rho' values for the 'Higher' grade topics.

Groups	Fifth year pupils	University students
Biology teachers	0.70	0.77
Fifth year pupils	-	0.83

Using the formula $t = p\sqrt{\frac{N-2}{1-p^2}}$ (193)

revealed that all the above (p) values are significant at the 1% level. As a result, one can reject with 99% confidence that such correlations could be due to chance.

A minor and limited discrepancy appears about a small number of topics between teachers and their pupils. Teachers seemed to underestimate or overestimate the relative difficulty of those topics as being conceived by their pupils. It could be an indication of how the logic of the grown-ups could sometimes fail to anticipate the psychological and academic factors that govern the learning process. Garforth (1975) in her study on the learning of ionic equations has reported similar discrepancy.(54) Apart from that, the fairly high values of (p) would suggest the presence of a reliable common agreement on the difficulty faced by pupils when they learn specific topics. This is supported when comparing this conclusion with the examiners' reports on the performance of pupils in the external examinations.

5.5 Objective Assessment of the Pupils' Learning of the Biology Topics

Beside gathering data on a subjective basis, it was decided that a horizontal assessment of the pupils' learning would throw more light on the situation. Nisbet and Entwistle (1970) suggested that an educational survey may include, among other methods, the use of tests on representative samples of pupils.(162)

5.5.1 Possible types of question items:

Questions on subject matter could follow one or more of the following types:

1. Essay-type questions: The most commonly used in the past conventional examination papers. Testee has to interpret the question as closely as possible to what the examiner is intended it to be. Next, he has

to supply the answer in his own words in a manner which displays as clearly as possible his understanding of the theme. The scorer, in turn, has to read and understand from that answer to what extent the testee is knowledgeable in that specified topic. Both answering and scoring an essay item is highly loaded with subjective factors, unless several measures are taken to minimize them. In spite of this major defect, an essay item would allow the scorer to get some good idea about the way in which a pupil reasons in that field, what level of understanding and conceptualization he reached and how mature his skills in reporting and communicating in the sciences.[164]

2. Objective-type questions: These are the most suitable whenever the need arises to test a great number of pupils for their mastery of certain bits of knowledge or how to deal with them in different ways. Yet several formats are in common use by examiners over the last decades. Some of these formats are as follows:

(A) True-false items: where the testee has to decide on the validity of an argument or on a piece of knowledge. The major defect of this type is the relatively high guessing factor included in their answers. However, they can be constructed easily and made to cover as many parts of the course as desired. They require relatively shorter time to answer and to score. If they are carefully structured, they can provide a good tool for assessment.

(B) Selection-type or multiple-choice items: widely used by examiners on which they provide the pupil with: (i) a stem, which represents a problem situation,and (ii) two or more alternatives, which provide possible solutions to the problem. They include the correct answer (i.e. the key) and several plausible wrong answers (i.e. the distractors). Friel (1976) showed that three or four alternatives are the best number to provide the testee with.[163] Gronlund (1968) pointed out that there is no reason why the items in a given test all need to have the same number of alternatives.[164] Following this would pose a problem only if the test were to be corrected for guessing. In all cases, the following rules must be followed when constructing a multiple-choice item:

(i) Each item must aim to measure an important learning outcome.
(ii) The stem must present a single and clearly formulated problem.
(iii) Wording of the stem must be in positive form, negative wording must be avoided, or emphasized if necessarily used.
(iv) Common content in the alternative answers must be moved up to the stem to avoid unnecessary repetition.
(v) Alternatives must include only one correct answer. Other plausibles, though ideally must be attractive to the uninformed pupil, must be either wrong or not as correct as the key answer. Position of the key must be varied with different items.
(vi) All alternatives must be homogeneous in length and grammatically consistent with the stem and parallel in form, verbal clues which might guide the testee to the key answer must be avoided.[164]

In general, the multiple-choice items proved to be the most popular form of objective testing for their several advantages. Firstly, they permit a wide coverage and sampling of the syllabus, and demand at the same time the ability to read and think quickly and to reason accurately. Secondly, they give a more reliable measurement of the performance of the pupil since more samples of their thinking are available, and these can be scored objectively.(165) The only difficulty in them is that they are time-consuming since the incorporation of effective distractors requires great care and precision. A modification has been introduced to this type of item writing to enable the examiner to assess for partial knowledge whenever he finds it of good contribution to his evaluative tools. In the 'best-answer multiple-choice' items, the alternatives are all partially correct but one is clearly better than the others. This type is used where the pupil is needed to identify the best explanation for a phenomenon, the best method for doing an experiment, the best application of a principle or the best solution to a problem. In another modification still, one wrong answer, one completely correct answer and one or more partially correct answers are included in the item. The pupil is asked to identify the wrong and the correct answers separately. According to his degree of precision in the choice,his scores are determined. Several methods of scoring this latter type are under usage, all of which aim to assess his partial knowledge whenever he fails to show complete success on an item.(163)

(C) Matching-type items: which is a modification of the multiple-choice form. A series of stems, called 'premises' is listed in one column and the alternate responses are listed in another. It is preferred when the same alternatives are suitable for several stems, thus bringing all of them together would save repeating the alternatives with each item. This seems to be the only condition under which it is desirable to shift from the multiple-choice format to the matching one. One major difficulty in constructing this type is the necessity for including homogeneous material in each matching item, where all the responses could serve as plausible alternatives for each premise, and each response must be eligible for re-use. In each subject matter area, there are relatively few situations where this condition can be met.[164]

(D) Short-answer-type items: or the restricted-response type, which is somewhere between the essay-type with its extended answer and the objective one which provides a completely structured response. For this it may be considered as a semi-objective type of question. In one format, it requires a completion of a statement by using one word or so, in another it requires a very limited short answer to a very precise question on a specific problem. Correct answers must be within the pupils' repertoire. Sometimes difficulty in scoring arises because of ambiguities in the question and at other times from the way the student has expressed his answer. Failure to deduce the examiners' intention and misspelling of an academically correct answer could be some of factors which bring subjectivity into this type of question. It is most suitable for testing knowledge of vocabulary, names or dates, simple comprehension of concepts and ability to solve quantitative problems. Thorndike (1969) realizing that it is not very flexible, advises teachers to use it but sparingly in classrooms.[154] For researchers, it would be difficult to feed answer cards directly into a computer system.

When writing questions, the classification of educational objectives suggested by Bloom (1956)[32] are usually taken as a guide. On his taxonomy, Bloom illustrates how to proceed from statements of general aims to explicit descriptions of course objectives, thus for an examiner, it proposes a scheme of hierarchical levels which are aligned with development of competence in depth in a given field of intellectual activity.(166) Though criticized on the grounds that it merely provides a taxonomy rather than a hierarchical classification, it would still help examiners to aim for all possible outcomes of achievement.(167)(168) Appendix No. 5.5.1.A shows that taxonomy.

5.5.2 The construction of objective tests

Being convinced with the merits and suitability of the multiple-choice type of questions, the researcher took the following steps in order to construct the needed tests:

(1) The biology syllabuses for the 'O' and 'H') grades were studied carefully and many school textbooks and work-sheets were reviewed. This step was to make the researcher more acquainted with the specific content and levels of treatment of the topics.

(2) The past years examination papers in 'O' and 'H' grades were reviewed as well as books on testing in general and biology in particular. This step aimed to make the researcher more acquainted with the methods of constructing tests of achievement in biology.(12)(154)(164)(165)(166)(169)

(3) The researcher constructed about seventy multiple-choice questions at the 'Ordinary' grade and a similar number at the 'Higher' grade standards covering many different topics from the syllabuses of these two grades. As the intention was to prepare tests for survey and diagnosis, questions were deliberately made at the easy side in order to discover how well the pupils have mastered the subject we expected them to learn.(169) Questions were submitted to examinations by

two groups of school biology teachers for relevancy to syllabuses, wording, coverage of more than one of Bloom's classified educational objectives and level of difficulty. Inappropriate questions were discarded and the useful ones were distributed into three sub-tests for each grade group. Some of the questions were made common in the three sub-tests. Each sub-test covered all the chosen topics at same level of difficulty as the other two sub-tests. The reason for constructing three sub-tests instead of one was to gather more evidence by a relatively large number of questions per topic, yet avoiding fatigue and reducing time needed for answering them to a minimum. (154)

(4) The six sub-tests were all applied randomly to the relevant pupils in every one of the schools used before. The pupils sample was 337 in the fourth year and 166 in the fifth year. They were instructed to mark their answers on computer cards and no limit on the time allowed was made since the purpose was to assess power not the speed.

(5) Answer cards were scored directly through the Computer Centre at Glasgow University according to a suitable ready-made programme. No correction for guessing was applied since there was no limitation imposed on answer time, besides it was acknowledged that in similar situations there would be no gain from applying such correction. (154)(169)(170)(171). Appendix 5.5.2.A shows the six sub-tests, while Appendix 5.5.2.B shows the distribution of the key among the alternate answers for the questions included in the sub-tests. Appendix 5.5.2.C shows the distribution of questions over Bloom's taxonomy.

(6) The Facility Value, as well as the discriminating power were estimated for each item through the

computing system. The formula used for computing the facility value was:

$$F.V. = \frac{\text{Number of pupils who got the item right}}{\text{Total number of pupils who tried the item}} \times 100$$

The higher the F.V. for an item, the easier it was.(172) The formula used for computing the discriminating power of items was:

D.P. = F.V. of top third - F.V. of bottom third.

(7) Questions with F.V. less that 0.25 or greater than 0.85 were disregarded. Similarly, questions with D.P. less than 0.10 were also disregarded. The remaining questions were corresponded to the relevant topics on the second questionnaire list in order to compare the learning levels of the pupils for each topic as indicated by their performances on the corresponding questions. Appendix 5.5.2.C shows the mean F.V. for the questions based on each topic.

Results of the objective assessment:

From the results of the tests, the researcher was able to get some pointers about the relative difficulty of the topics covered by the tests. Below is a list of the areas that seemed to be more difficult than the others:

(A) Fourth year syllabus:
1. Chemical energy, photosynthesis and respiration.
2. Diffusion, osmosis and control of water content inside living organisms.
3. Nervous system, hormones and co-ordination in human body.
4. Alleles, genes and Mendel's work.

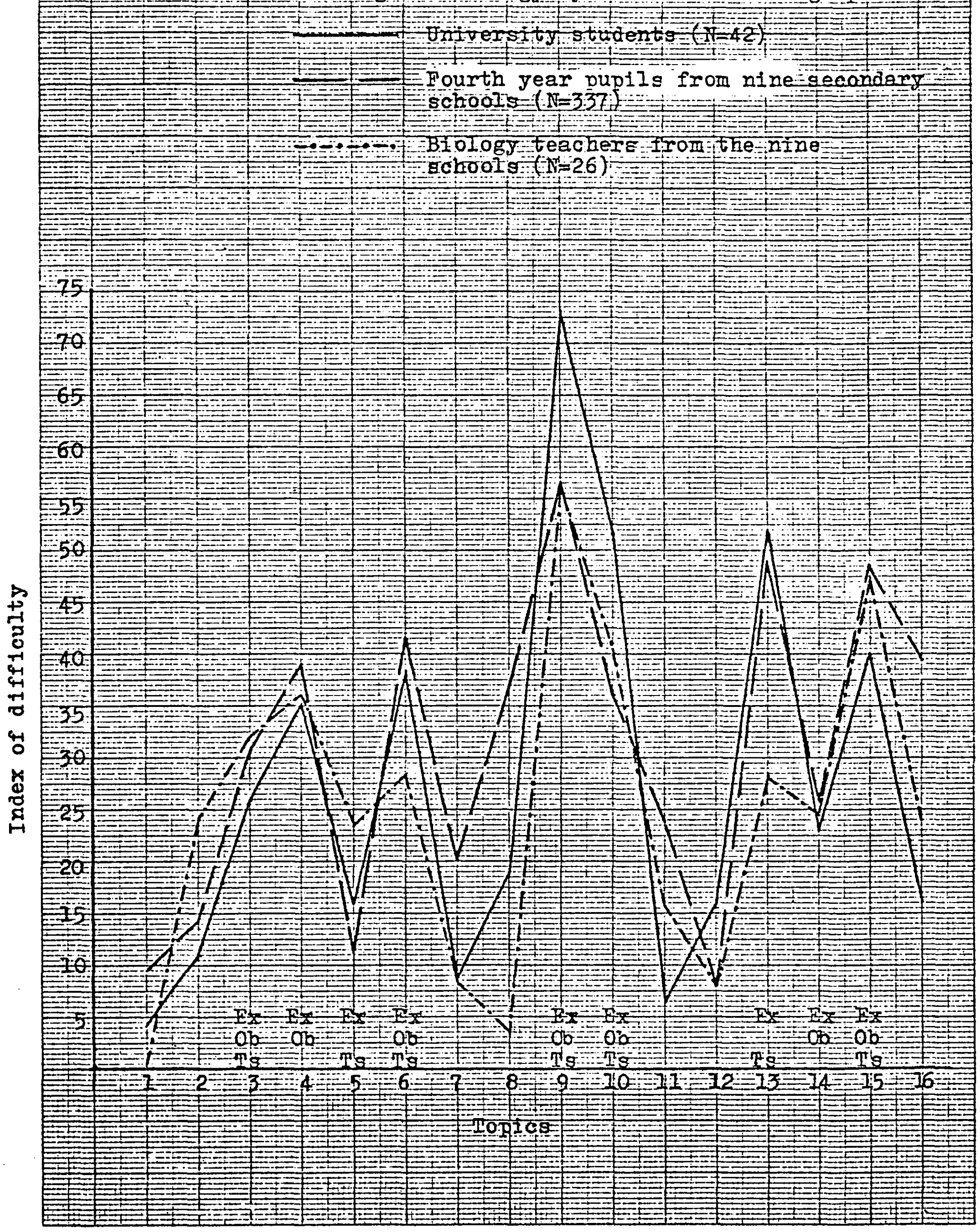
(B) Fifth year syllabus:
1. Osmosis and water potential.
2. Heredity.
3. Evolution.

5.6 General Conclusion of the Survey Stage

Through different channels and using different tools of gathering information, the researcher reached a satisfactory conclusion that there is a common agreement that several topics are difficult to learn by the pupils. Figures Nos. 5.6.A and 5.6.B bring together all data collected for easy recognition. At the top of these topics one sees osmosis and water potential, energy make-up and break-down, and genetics.

Having established 'where' the difficulties lay, it was necessary to find out 'why' they were there. How this was done will be described in the subsequent chapters.

Figure 5.6.A Relative difficulty of the topics drawn from the O-grade biology syllabus - a summing up.



LIST OF TOPICS (Higher Grade)

1. DNA and RNA.
2. Cell structure and cell division.
3. Chemical energy.
4. Chemistry of photosynthesis.
5. Chemistry of respiration.
6. Gas exchange between living organisms and their environment.
7. Osmosis and water potential.
8. Role of the kidney.
9. Water balance problems and osmo-regulation in living organisms.
10. Reproduction and growth in living organisms.
11. Hormones.
12. Gametes.
13. Genes.
14. Evidence for evolution.
15. Mechanism of evolution.

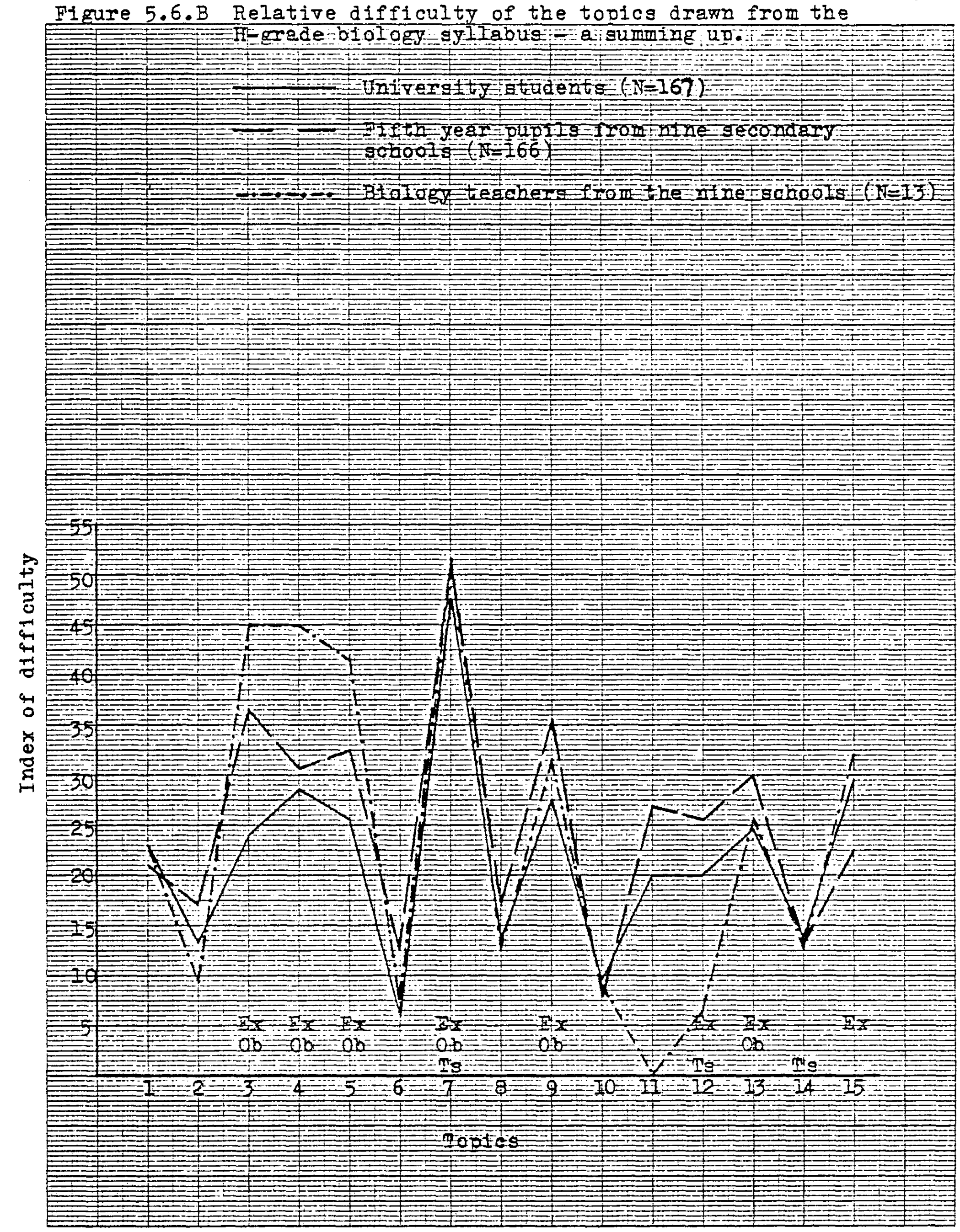
Symbols used on the graph:

Ex denotes a difficult topic according to the examiners' reports.

Ob denotes a difficult topic according to the observations carried out by the researcher.

Ts denotes a difficult topic according to the tests carried out by the researcher (where F.V. < 0.50).

Figure 5.6.B Relative difficulty of the topics drawn from the H-grade biology syllabus - a summing up.



CHAPTER SIX

Stage Two: The search for the reasons responsible for the difficulties in learning some school biology topics.

The researcher found it necessary to start with evaluating the pupils' understanding of some of the topics which were providing trouble in school biology in order to carry out a systematic investigation to establish the cause of difficulty in learning those topics.

6.1 Possible Types of Evaluation

To Cronbach (1963), evaluation means the collection and use of information to make decisions about an educational program.(180) To Thorndike and Hagen (1969) it means the complete process of identifying the objectives of an aspect of education and appraising the extent to which those objectives have been achieved.(154) To Wheeler (1976), evaluation is undertaken to help educators to assess the behavioural changes in individual pupils and groups of pupils, as well as to make decisions about the objectives of the school and the suitability of the learning experiences, the content, organization and teaching methods used to attain them.(145) To Bloom (1971), evaluation of student learning can fall into one of the following three categories:(12)

1. Summative evaluation: This type is directed toward a general assessment of the degree to which the larger outcomes of instruction have been attained over the entire course or some substantial part of it. Assessment under this type of evaluation may serve a variety of functions, some of which are:

(i) Assigning of grades.
(ii) Certification of skills and abilities.

(iii) Prediction of success in subsequent courses.
(iv) Initiation point of instruction in a subsequent course.
(v) Feedback to students.
(vi) Comparisons of outcomes of different groups.

It is usually carried out at the end of a unit, term, or year's work. Emphasis is made on cognition, behaviour, or psychomotor skills.

2. Formative evaluation: This is the type of evaluation which the researcher found useful for the purpose of this study. The main purpose of this type is to determine the degree of mastery of a given learning task and to pinpoint the part of the task not mastered. In addition it is used for the location of errors in terms of the structure of a unit so that remedial alternative instruction techniques can be prescribed. Another purpose of this type of evaluation is to help both the learner and the teacher focus upon the particular learning necessary for movement toward mastery. Bloom (1971) suggested that one useful operating procedure is to break a topic into smaller elements arranged on a learning hierarchy, using some of the ideas of Gagné and Bloom. Next to that is to construct diagnostic tests and use them to determine whether each student has mastered the topic. Tests which are constructed for this purpose usually put emphasis on cognitive behaviours, taking into account specific samples of all elements of the topic. Item difficulty cannot be specified beforehand, and the scoring is a criterion-referenced one.(12) Scriven (1967) points out that formative evaluation should be applied during the construction and tryout of a new curriculum in such a way that revisions of the curriculum can be based on the evidence obtained.(181) In the case of settled courses, formative evaluation can also give feedback to the teacher, since it can help to identify particular

points in the instructions that need modification. Its results can be useful also for pupil learning. For the pupil who has thoroughly mastered the unit, formative tests should reinforce the learning and assure him that his present mode of learning and approach to study are adequate. For the pupil who lacks mastery of the unit, such tests should reveal the particular points of difficulty. It is most useful for both pupil and teacher when the diagnosis shows the elements in a learning hierarchy that the pupil has not yet mastered.

3. Diagnostic evaluation: This can be quite distinct from or closely related to formative evaluation, depending on the function it seeks to fulfil. If several formative units are planned for a year's work in a given subject, diagnostic evaluation can try to place individual pupils at the most appropriate starting point for each. This type of diagnosis takes place prior to instruction and focuses on the pupil's status in relation to prerequisite behaviours, level of mastery of each unit, or some other variable. In this way diagnostic evaluation differs from formative, which has as its function providing the learner and teacher with feedback information as the learner progresses through any one of the several units. Further, diagnosis used for placement does not concern itself, as does formative evaluation, with the relationships or lack of them between elements in a given unit and among the several units themselves. However, diagnostic evaluation can be carried out in conjunction with the formative one to try to determine whether factors unconnected with instruction are the cause of the breakdown in the learning which has been pinpointed by formative testing.

Since the aim of the present study was not to certify pupils nor to guide individual pupils, it was clear to the researcher that the most appropriate approach to the problem was the formative-type of evaluation. He believed that, in line with that type of evaluation, if he breaks the topics down into formative units and builds formative tests for those units, then these tests could be used to diagnose the learning-teaching situation with regard to those topics.

Choice of Topics:

It was decided to concentrate on the topics of diffusion, osmosis, and water potential in this stage of study. The justification for the choice of these topics was as follows:

1. They were at the top of the difficult topics as revealed in the previous stage of the survey.

2. They are highly related to each other, and the research in one contributes to the study of the others.

3. They have as their top concept, water potential, a bold shift in the school biology courses from the descriptive approach at the macro level of treatment to the study of the micro behaviour of water particles, with a mathematical handling of the variables. The outcome of such a new trend is worthy of study.

4. For the reason just mentioned, these topics are causing a continuous debate between teachers, inspectors and academics.

5. These topics are highly connected with other branches of science since they share with them some areas of common interest. A genuine understanding of these topics in biology requires a good understanding of some basic ideas which belong essentially to the fields of chemistry and physics. Some of

those ideas are the particulate nature of matter, the molecular diffusion of substances, the dissolving process, and the nature of pressure. Some other basic ideas, such as the concept of potential and of probabilities, are dependent on intellectual imagination and reasoning. Without good presentation of the course, and co-operation of science teachers, it was thought that a real difficulty in learning them would be the inevitable result.

6. These topics are of basic importance to many other biological themes, such as water balance problems, osmo-regulation, respiration, excretion, food absorption, circulation and the study of marine organisms.

6.2 Statement of the Problem for this Stage

In order to fulfil the aims of this diagnostic part of the study, the researcher considered the following questions:

1. What level of understanding of the concepts involved in these topics had the pupils reached after studying them at school?

2. Did the study of one or more of the physical sciences help pupils to show better understanding of these concepts than without such study? In other words, is there any significant difference between the performance of pupils who studied biology only and that of those who studied either chemistry or physics, along with biology?

3. Is there any significant difference between the performance of boys and that of girls?

4. Why are these concepts reported as difficult to learn?

6.3 Hypotheses for this Stage

From the close observation of biology lessons in classrooms, and the examination of the syllabuses, all in view of relevant contemporary theories of learning and intellectual development, the researcher was able to hypothesise that pupils found it difficult to understand diffusion, osmosis and water potential because of one or more of the following reasons:

1. These topics are high in information content, i.e., they have many subordinate ideas which form together the body of knowledge required to be learnt by pupils, if meaningful learning is to be achieved.

2. These topics are highly abstract and so inherently difficult.

3. The majority of pupils do not possess some or all of the ideas required for achieving the meaningful learning of these topics, thus learning them only at a superficial level.

6.4 Method Used

To check on the validity of these hypotheses, the researcher carried out the following tasks:

1. Analysing the topics being researched into their elementary units and checking their level of abstraction.

2. Evaluating the pupils' level of understanding of these topics using two diagnostic tools, namely, interviews and written tests.

On the following pages a detailed account of these procedures is submitted.

6.5 The Analysis of the Topics being Researched

The close examination and analysis of topics down to their foundations has been considered by many researchers as an essential step for the diagnosis and search for the reasons behind reported difficulty in learning. Bloom (1971),[12] Mughol (1977),[14] Dow (1978),[37] Gower (1975),[38] Okeke (1976)[39] and Johnstone (1972)[41] are more recent workers in this field. The researcher realized that modern and valid explanations of the concepts being researched in his study are founded on principles of physics and thermodynamics. Biological treatment at all levels of those concepts are expected to be compatible and consistent with such foundations in order to achieve meaningful learning,[96] or to avoid the possibility of their having to be unlearned later.

6.5.1 A proposed learning hierarchy

In order to carry out such detailed analysis, the researcher decided to follow the work done by Gagné and his collaborators. Their procedure went as follows: Assuming that the concept submitted to analysis was to be taught for the first time to a pupil, they posed the question "What must the pupil know in order to be able to learn this new concept?" After determining the required sub-concepts, the questioning procedure was repeated with each defined sub-concept, until the level of basic scientific ideas was reached and all the learning prerequisites listed hierarchically.[103]

Following this model, with the guidance of the subject specialists and the help of recommended publications in the field,[182][183][184] the researcher was able to prepare a proposed learning hierarchy of the topics. Table 6.5.A shows this hierarchy, which like others, should be traced upwards from bottom to top. Next to that table, a list of specifications is submitted.

TABLE 6.5.A

(A) Concepts and ideas of diffusion and osmosis on laboratory models (Ordinary Grade Syllabus)

VI. Osmotic Pressure

15. Balanced state between solutions with different concentrations of solute.

14. Pressure of the free particles of water inside solutions.

V. Osmosis

13. Direction of water flow between solutions

12. Probability in the redistribution of water particles.

11. Effect of solute on the free movement of water particles.

IV. Diffusion

10. Rule of diffusion with regard to the water particles.

9. Rule of diffusion with regard to the solute particles.

II. The Dissolving Process

7. Attraction between particles of water and particles of solute inside solutions.

III. Concentration Gradient

8. Concentration of water v. concentration of solute

I. Molecular Movement inside Solutions

6. Combined movement of water and solute particles inside solutions.

5. Dependent movement of solute particles on the movement of water particles.

4. Leading role of water particles in the molecular movement inside solutions.

3. Continuous movement of water particles.

2. Random movement of water particles.

1. Spontaneous movement of water particles.

(Continued)

TABLE 6.5.A (Continued)

(B) Diffusion and osmosis on plant-soil situation.
(Ordinary Grade Syllabus)

7. Manifestations of diffusion and osmosis in the plant and its surroundings.
6. Cell wall pressure and the flow of water from the soil to the plant.
5. Osmotic pressure of the soil and plant solutions.
4. Effect of solute on the flow of water between the soil and the plant.
3. Initial situation of solute in the soil and plant solutions.
2. Initial situation of water in the soil and plant solutions.
1. Initial differences between the soil and plant solutions.

(Continued)

TABLE 6.5.A (Continued)

(C) Concepts and ideas of water potential on laboratory models (Higher Grade Syllabus)

X. Water Potential

31. Direction of water flow between cells, and between cells and pure water.
30. Significance of (Ψ) components as an indication of water gain and loss from cells.
29. Significance of (Ψ) components as an indication of the state of cells.
28. Significance of (Ψ) values as indication of the relative concentration of the free particles of water.
27. Ranking (Ψ) values in order of magnitude to identify the lowest.
26. Ranking (Ψ) values in order of magnitude to identify the highest.
25. Computation of (Ψ) from its components.
24. Effect of the concentration of solute on the direction of water flow between solutions.
23. Effect of the concentration of solute on the water potential of solutions.
22. Effect of the amount of solute on the water potential of a solution .
21. Differences between pure water and solutions in their osmotic properties.

IX. Cell Wall Pressure

20. Effect of water inflow on the cell wall pressure.

VII. Osmotic Pressure

17. Effect of solute concentration on the amount of the free particles of water causing pressure in solutions.
16. Effect of solute concentration on the osmotic pressure of solutions.

VIII. Osmotic Potential

19. Effect of the concentration of solute on the osmotic potential of solutions.
18. Effect of the amount of solute on the osmotic potential of a solution .

(Continued)

TABLE 6.5.A (Continued)

(D) Water potential on plant-soil situation
(Higher Grade Syllabus)

12. Direction of water flow as an indication of the relation between the concentration of free particles of water and the osmotic pressure of the plant and soil solutions.

11. Direction of water flow as an indication of the differences in cell wall pressures between root cells at a given time.

10. Direction of water flow as an indication of the difference in solute concentrations between root cells.

9. Direction of water flow as an indication of the difference in water potential between root cells.

8. Differences in osmotic properties between the soil and plant solutions.

(A) <u>Concepts and ideas of diffusion and osmosis on laboratory models (Ordinary Grade Syllabus)</u>:

I. <u>Molecular movement inside solutions</u>:

Pupils have to be aware of what is going on inside aqueous solutions as a basic step on the way to understand the phenomena of diffusion and beyond. The understanding of the movement of particles in solutions requires, in turn, the understanding of the following ideas:

1. <u>Spontaneous movement of water particles</u>: When water is in its liquid state, its particles can partly overcome the internal forces that keep them pulled together. They can travel from one position to another of their own accord. They do so by making use of the heat energy provided by their surroundings.

2. <u>Random movement of water particles</u>: In their motion, these particles travel in straight lines until they bump into each other or into different kinds of obstacles, and are forced to change their directions. By this kind of random movement, a given particle of water can travel in all directions within the limited volume of the body of water. Applying this to an osmosis situation, particles of water have the chance of travelling both ways across a membrane. This applies to the water particles of all solutions regardless of their concentrations.

3. <u>Continuous movement of water particles</u>: As long as water is in its liquid state, its particles do not cease moving. In diffusion and osmosis situations, this movement does not come to an end even when the complete mixing up, i.e. the state of balance, is reached. This represents a dynamic-type of equilibrium not a static one.

4. Leading role of water particles in the molecular movement inside solutions: Particles of water stick to the particles of solute and pull them everywhere they move in the body of their solutions.

5. Dependent movement of solute particles on the movement of water particles: As long as the dissolved substance is in its solid state its particles cannot travel away from their original places. Though they are permanently on the move, they can only vibrate around fixed points, hence they depend for their diffusion on the spontaneous movement of the water particles.

6. Combined movement of water and solute particles: In a solution, particles of solute are attached to some particles of water and move together into the body of that solution.

II. The dissolving process:

Solutions are the main partners in the cell water relationships. For the pupils to learn meaningfully these relations, they have to build an intelligent understanding of the following seventh idea:

7. Attraction between particles of water and particles of solute: To dissolve in water means to dissociate from the original block of visible solid substance, disperse into the body of solution, and the solid disappears from sight. Possessing the characters of good solvents, particles of water are easily attracted to particles at the outer surface of solutes. Being in continuous movement, the particles of water pull away those particles leaving the next layer of particles exposed to further attraction. As a result of repeated dissociation and displacement, the lump of solute disperses through the solution surrounded by a cloud of solvent molecules.

Ideas Nos. 1 through 7 require the ability to form mental images of particles and to visualise their behaviour in solutions. According to the Piagetian theory, the learning of such ideas would require a late concrete type of thought. Being around fifteen years old, the fourth year pupils are expected to be able to perform at this level.

III. Concentration gradient:

Since this term is being used frequently in the study of the researched topics, it becomes of great importance for the pupils to understand its meaning. Idea number eight below explains this key concept.

8. Concentration of water v. concentration of solute: The more we add a soluble substance to a fixed amount of water, the smaller becomes the ratio of water particles to solute particles in that solution. Thus, the concentration of water particles, which is the main concern of these topics, goes inversely to the concentration of the solute in a given solution.

This idea requires the understanding of ratio, which is a property of the late concrete thinker. Thus, the fourth year pupils are supposed to be able to understand this idea without difficulty. However, difficulty could arise when the terminology itself is not fully explained or supported by concrete experience.

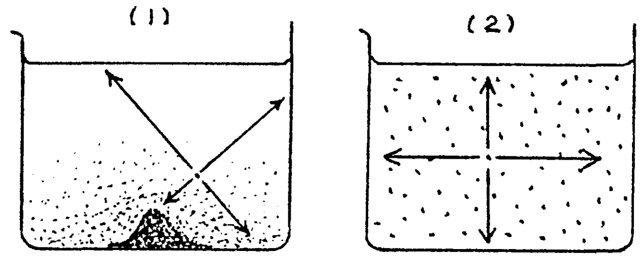
IV. Diffusion:

The term diffusion refers to the migration of particles of a given substance along a decreasing gradient of its concentration. Pupils have to realize that this rule is applicable to both water and solute separately.

9. Rule of diffusion with regard to solute particles: In the initial state, particles of solute are distributed unevenly among water particles. The former being carried

by the latter spread out from where they are initially more concentrated to where they are less so. An adaptation of the schematic illustration given by Weisz (1971) to illustrate this notion is as follows:[137]

A single particle of the solute in the initial state, and after complete mixing.



10. Rule of diffusion with regard to water particles: Particles of water, during their movement, have more freedom to move in the direction of lower concentrations of its own, i.e. to the space initially occupied by the solid substance. This eventually leads to an even distribution of this kind of particles throughout the body of solutions. Pupils have to know that this happens because it is the most probable kind of distribution which can take place.

V. Osmosis:

To learn osmosis meaningfully, pupils must understand the following ideas for the determination of water flow between solutions.

11. Effect of solute on the free movement of water particles: As mentioned earlier, particles of the dissolved substance are attached to a cloud of water particles in a solution. The latter usually circle the former in more than one layer, all of which are bonded to the inner core in one way or another. This causes a decrease in the number of the free-moving particles of water in that solution. Thus the addition of a dissolved substance to water results in a handicap upon the movement of the water particles.[183]

12. Probability in the redistribution of water particles: In view of the above idea, the most likely distribution of the free-moving particles of water in an osmosis situation is to migrate more readily from where they are more concentrated to where they are less so. It is wrong to assume that the solution with higher concentration of dissolved substance "sucks" water across the membrane from the dilute solution.

13. Direction of water flow between two solutions with different concentrations: This direction is determined by the difference in the water-solute ratio on the two sides of the s.p. membrane, not by the difference in absolute volumes of solutions. Pupils must reach this conclusion after being convinced of all the previously mentioned ideas. However, they can predict that direction by merely applying the rule "water flows from where there is more to where there is less." If they do so, they will be lacking the basis on which they can account for this phenomenon, and it will be difficult to understand the relatively higher concepts of osmotic pressure and water potential.

VI. Osmotic pressure:

Pupils have to recall their earlier conception of 'pressure' (force per unit area) and be able to apply it to the osmotic situation. The following two ideas illustrate this view.

14. Pressure of the free particles of water inside solutions: While free particles of water travel in straight lines, they hit the walls of the container as well as the s.p. membrane. This causes pressure. The smaller the concentration of solute particles in a solution, the greater the number of the free-moving particles of water, thus the higher the pressure caused by free water bombardment on the s.p. membrane. Having two solutions with different concentrations on the two

sides of a s.p. membrane, there will be a net flow of the free-moving particles of water from the solution which is less concentrated with respect to the solute. This net flow of water will increase the volume of the receiving solution and create a pressure inside its body. This will develop and support a rising column of the liquid in the receiving solution. This is why we say that the concentrated solution shows higher osmotic pressure than the dilute one. This concept is highly abstracted since it requires the visualisation of what is going inside solutions, how that kind of pressure is caused and how the osmotic pressure of a solution is determined consequently. The concept of osmotic pressure is derived from the earlier concept of osmosis and depends on it for a meaningful learning to be achieved.

15. Balanced state between solutions with different concentrations: As a result of the net flow of water into the concentrated solution, the difference in the concentration of free water particles will decrease gradually. The growth of the rising column of liquid on the top of the concentrated solution will become slower and slower. A state of balance will be reached when the two opposing pressures become equal, i.e. the pressure of the net flow of free water particles at one side and the pressure caused by the weight of the growing column of liquid at the other side. At that point, the free moving particles of water will keep on travelling equally in both directions across the membrane with no net flow into either side. Pupils have to realise that the balanced state in this situation is of dynamic nature and not of static one.

Understanding of ideas Nos. 9 through 15 requires a formal level of thought. Those ideas involve conceptualisation of probabilities, relation between ratios of solvent and solute at two different sides of a s.p. membrane, and making an extension of the actual in the direction of the possible. All of these mental activities depend on reasoning correctly about propositions which pupils have no real experience in their repertoire to support. However, pupils may learn by heart some useful rules to apply in osmosis situations, but this cannot be counted as meaningful learning, nor can it help them to <u>understand</u> higher concepts whenever they are introduced to them.

(B) <u>Diffusion and osmosis on plant-soil situation (Ordinary Grade Syllabus)</u>:

In biology, the ultimate goal of teaching and learning concepts should be directed to enable the pupils to form intelligent understanding of the functioning organism. One main point in this consideration is to develop an analytical understanding of the relation between the organism and its environment. The following seven ideas demonstrate the physical relationship between the plant and soil solutions which lays the grounds for further vital functions of the plant.

1. <u>Initial difference between soil and plant solutions with regard to concentration of water and solutes</u>: Although water forms the main constituent of a living plant, a great number of solutes are found in its sap. Considering equal volumes of plant sap solution and ordinary soil solutions, the former is more concentrated in dissolved substances than the latter. As a result, there are comparatively more free water particles in the soil solutions than in the cell sap solution, considering similar volumes of each.

2. <u>Initial situation of water in soil and plant solutions</u>: Beside being at higher concentration in the soil solutions, the free-moving particles of water cross the root hair walls and membranes both ways. This is due to the spontaneous, random and continuous movement of water particles,

and to the permeability of the root hair walls and membranes.

3. <u>Initial situation of solutes in soil and plant solutions</u>: Particles of solute are more concentrated in the plant sap, thus keeping a considerable ratio of the particles of water linked to them.

4. <u>Effect of solutes on the flow of water from soil to plant and vice versa</u>: By keeping many particles of water attached to them, the particles of solute could be regarded as hindering the free movement of water both ways between soil and root. Since solutes are more concentrated in root cells than in soil, the hindrance effect works higher on the water flow from root to soil.

5. <u>Osmotic pressure of soil and plant solutions</u>: Solutions of the higher parts of the plant exert higher osmotic pressure than those of the lower parts of the same plant, whereas those of the soil exert the lowest of them all. This would guarantee a net flow of water particles from the soil to the plant.

6. <u>Cell wall pressure and the flow of water from soil to plant</u>: Cell wall does not interfere with the movement of water particles until the cell becomes turgid by the excessive inflow of water. At that stage, the cell wall exerts an inward pressure which prevents further net inflow of water.

7. <u>Manifestations of diffusion and osmosis in the plant and its surroundings</u>: The migration of water particles, as well as particles of other substances, from one site to another is governed by the rules of diffusion. Osmosis is a particular case within the general phenomenon of diffusion, and is usually denoted by the migration of water particles across s.p. membranes. Thus, the flow of water from soil to root cells is still a case of

diffusion and the loss of water from the cells of plant leaves to the atmosphere is a case of osmosis.

(C) <u>Concepts and ideas of water potential on laboratory models (Higher Grade Syllabus)</u>:

With regard to the 'Higher' grade syllabus, the following concepts and ideas are a necessary requirement for the learning of the continuum 'Diffusion-Osmosis-Water potential'. For this reason they are listed below in a serial number in line with those concepts and ideas mentioned earlier.

VII. <u>Osmotic pressure as relevant to water potential</u>:

Pupils have to understand that the osmotic pressure of a solution is determined by the solute concentration, as a step towards the determination of the osmotic potential of solutions. The following ideas underlie that conception.

16. <u>Effect of solute concentration on the osmotic pressure of solutions</u>: The lower the concentration of solutes in a solution, the lower becomes its osmotic pressure. From that, solutions exert osmotic pressure while pure water does not.

17. <u>Effect of solute concentration on the amount of free-moving particles of water</u>: The proportion of the free-moving particles goes inversely to the concentration of solute in a solution. This depends on idea No. 11 mentioned earlier.

VIII. <u>Osmotic Potential</u>:

Solutions do not show the property of osmotic pressure when they are not placed in osmometers or any kind of osmosis systems. However, they have the property of generating such a pressure when the osmotic circumstances are present. Traditional writings in the field consider that both osmotic pressure and potential are identical in value for a solution,[140][141][185] whereas another school of writers and researchers advocate that osmotic potential should be the negative value of the osmotic pressure for the solution.[182][183][184][186] The latter trend has an advantage over the former in that it shows the net flow of water particles taking place down an osmotic potential gradient (e.g. from -1 to -2). This is consistent with what is taught in the physical sciences and what is taught about water potential as well. Unfortunately, all the sample schools as well as others are adopting the former scheme in which pupils have to learn that water flows from low to high potentials (e.g. from +1 to +2). As a result, one can expect that pupils are confused when learning this concept. To be fair in the assessment procedure to come, the researcher bound himself to the scheme adopted by the schools, though still seeing the merits of the other scheme. To continue with the analysis of the topics, the next two ideas are included in the learning of osmotic potential:

18. Effect of the amount of solute on the osmotic potential of a solution: If more solute is added to a solution, its osmotic potential rises.

19. Effect of the concentration of solute on the osmotic potential of different solutions: From above, when comparing solutions, the one with the highest solute concentration will have the highest osmotic potential.

IX. Cell Wall Pressure:

20. Effect of water inflow on the cell wall pressure: Pupils have to realise that with the inflow of excess amount of water, the cell wall pressure grows higher and higher, thus avoiding cell rupture.

X. Water Potential:

This is the top concept in the learning hierarchy of the topics being researched. Water potential is to water as temperature is to heat. Water can move from an aqueous system to another at a certain pressure, which is called water potential.[185] This depends upon the rate of motion of the average molecule and the number of molecules of water per unit volume. Pure water has a water potential of zero, and the difference between the water potential of water at any point in the system and that of pure water at the same temperature and one bar pressure, is referred to as the water potential of that system.[184] In other words, water potential is the amount of work required to transport unit quantity of water from a pool of pure free water to a point in aqueous systems at the same elevation. Water potential is expressed in units of energy/volume such as erg cm^{-3}, equivalent to pressure units of dynes cm^{-2} and usually in bars or atmospheres.[183] The water potential of a cell depends on many factors, the main ones being the osmotic potential (OP) of the vacuolar sap, and the cell wall pressure (WP). Again the traditional writings of the field as well as the school sample teachers adopt the following equation for the determination of (Ψ) for a plant cell:

$$\Psi_{cell} = \text{Cell wall pressure} - \text{Cell sap osmotic potential.}$$

The other scholars, who prefer to be consistent with the physical sciences, adopt another version of that equation, viz.

$$\Psi_{cell} = \Psi_p + \Psi_s$$

where Ψ_p is the pressure potential (mainly the cell wall pressure), and Ψ_s is the osmotic potential of the cell sap solutions). Since the osmotic potential is expressed with a positive value in the former equation, while expressed with a negative value in the latter one, algebraic addition used in both equations would give the same result for the same component figures. The following ideas are required for a meaningful learning of the water potential concept at the 'Higher Grade' standard.

21. Differences between pure water and solutions in their osmotic properties: Solutions have higher osmotic potential but lower water potential if compared to pure water.

22. Effect of the amount of solute on the water potential of a solution : The more we add solutes to a solution the lower becomes its water potential.[184]

23. Effect of the concentration of solute on the water potentia of solutions: From above, a solution with high solute concentration should be expected to have low water potential.

24. Effect of the solute concentration on the direction of water flow between solutions: Bearing in mind that the water potentials of solutions are determined by their concentration with respect to solutes, pupils have to know that particles of water would flow from the least concentrated solution to the most concentrated one.

25. Computation of the water potential value from its components: Realising that osmotic potential is working in a direction opposite to that of the cell wall pressure, the pupil must be able to deduce that the total water potential value for a given cell can be computed by the subtraction of the former from the latter. (Here, the researcher was obliged to be consistent with the scheme adopted in the sample schools as long as it did not carry scientific mistakes in it, though considered to be out of date.)

26. <u>Ranking (Ψ) values in order of magnitude to identify the highest</u>: By definition, pure free water has the value zero for its water potential under one bar of pressure, hence aqueous solutions have lower (negative values) water potentials under the same pressure. Nevertheless, raising the pressure around a system (by means of machines or by the cell wall pressure) will raise the water potential of that system by exactly the same amount.(184) From this, $\Psi = +1$ is higher than $\Psi = 0$, which in turn is higher than $\Psi = -1$.

27. <u>Ranking (Ψ) values in order of magnitude to identify the lowest</u>: Proceeding from what is mentioned above, $\Psi = -1$ is lower than $\Psi = 0$ which in turn is lower than $\Psi = +1$.

28. <u>Significance of (Ψ) values as an indication of the relative concentration of free water particles in cells</u>: The higher the (Ψ) value of a cell, the higher the concentration of the free water particles in that cell.

29. <u>Significance of (Ψ) components as an indication of the state of cells</u>: If the cell wall pressure is equal to the osmotic potential of a cell sap, such cell will be water balanced if soaked in pure water. But if the cell wall pressure equals zero, such cell is almost plasmolysed.

30. <u>Significance of (Ψ) components as an indication of water gain and loss from cells</u>: If the cell wall pressure exceeds the sap osmotic potential, the cell tends to lose water. If the situation inside the cell is reversed, it will tend to gain water.

31. <u>Direction of water flow between cells, and between cells and pure water</u>: Water flows from a cell with a high water potential (positive, or zero, or negative but nearer to zero) to another with a lower water potential

(less positive, or zero, or negative but further away from zero, respectively).

All ideas and concepts included in the water potential study are highly abstract since none bears directly on observed events. Pupils have to apply formal operational thought to understand these learning elements.

(D) <u>Water Potential on Plant-Soil Situation (Higher Grade Syllabus)</u>:

To continue with the plant situation, the 'Higher Grade' candidates must be able to use their knowledge in understanding the relevant biological situations. The following ideas and concepts are a continuation of the similar ones discussed earlier as relevant to diffusion and osmosis:

8. <u>Differences in osmotic properties between soil and plant solutions</u>: Pupils know that water flows, in normal circumstances, from soil to plant. Thus, they must be able to deduce that solutions of the former have lower osmotic potential compared to those of the latter. Accordingly, plant solutions must be able to show higher osmotic pressure.

9. <u>Direction of water flow as an indication of the difference in water potential between root cells</u>: From the same phenomenon of water flow, pupils must be able to deduce that the water potential of root hair cells is higher than that of the inner cells of the same root at a given time.

10. <u>Direction of water flow as an indication of the difference in solute concentrations between root cells</u>: From the same phenomenon, pupils must be able to deduce that the inner cells of the root are more concentrated with solutes than the sap of root hair cells are.

11. Direction of water flow as an indication of the difference in cell wall pressures ~~between~~ root cells at a given time. Again, pupils must be able to deduce that, at a given time the outer root cells have most probably developed higher wall pressure compared to that developed in the inner cells to cause the water inflow.

12. Direction of water flow as an indication of the relation between the concentration of free particles of water and the osmotic pressure of plant and soil solutions: Without the need to memorize that soil solutions are less concentrated with respect to solutes than cells saps are, pupils must be able to deduce from the flow of water that the former is more concentrated with free particles of water, and less able to show osmotic pressure when compared to the latter.

6.6 Assessment of the Pupils' Learning of the Topics

As mentioned earlier in Section 6.1, there are two major types of assessment, i.e. the norm-referenced and the criterion-referenced assessments.

1. Norm-referenced assessment: According to Popham (1978), a test of this type is usually designed to ascertain an examinee's status in relation to the performance of a group of other examinees who have completed that test.(146) A test of that kind usually tends to maximise differences between testees at the expense of the amount of information they can provide about each.(187) Items on such a test are of average difficulty, ranging from 35% to 70%, with some very easy and some very difficult items.(12) Schools always use this type of assessment at the end of a year or a grade to certify or grade pupils. Thus, it is used where there is a constraint placed upon the number of individuals who can be admitted to a particular situation.

This was not certainly the concern of the present study.

2. Criterion-referenced assessment: To Dunning and his collaborators (1977), a test of this type is intended to assess the mastery of a specific topic, skill, operation and the like.[188] Results of such test can indicate the correspondence between what an individual does learn and the underlying continuum of achievement. The emphasis thus with this measure is upon assessing an individual relative to a set of criteria rather than comparing his performance with other people's.[187]

The correspondence between what a pupil learns and a learning hierarchy which includes all the subordinate elements of a topic would be a reasonable approach to a criterion-referenced assessment. Parlett and Hamilton (1976) urged researchers to seek as much information about the learner as possible in order to achieve an illuminative type of evaluation.[189] To the present researcher, it has been quite clear that the criterion-referenced type of assessment is the one which could provide him with the information about the pupils' understanding of the topics being researched. In this situation one must tend to be information-centred rather than decision-centred, broad rather than narrow.[190]

6.6.1 Assessment of the pupils' understanding of the topics through interviews:

To conduct this type of assessment, the researcher elected to hold several interviews with samples of the fourth and fifth year pupils representing a wide range of learning ability from different schools. Schofield (1972) pointed out that the interview has many points of credit as a tool of assessment.[174] Hurd (1970) mentioned that one way to test the pupils' understanding of a concept is to have him explain it to someone else through interview.[177] Many researchers used the technique of interviewing pupils to assess their level of understanding of school topics and reported it to be a powerful tool. Archenhold (1975) used it to investigate pupils' understanding of the concept of potential in physics,[36] Nussbaum (1976) used it to assess children's concepts of the earth,[40] Okeke (1976) to study Nigerian pupils' understanding of three biological concepts,[39] and Mughol (1977) to find out the reasons for the misconceptions in some topics in school physics.[14]

In general, interviews can fall into one of the following types:

(A) Fully structured or fixed interviews: In this type all the interviewed pupils are asked, individually or in groups, exactly the same questions, in the same order. All questions are predetermined, and the interviewer is not allowed to change questions or the wording of a question, nor to ask additional ones. Though this approach achieves a high degree of uniformity which could facilitate comparability between examinees, it does this at the expense of its fruitfulness. Since the interviewer does not develop his questions over the course of interviewing, he cannot probe into the thought of the respondents to check on their understandings. If the questions were not giving good coverage of all possibilities, much valuable information could be out of reach, specially if the interviewed pupils are of a wide range of abilities. When used in single individual interviewing, predetermined questions minimise rapport between the testee and the interviewer, since they tend to make the testee in scope and uncomfortable. The situation also becomes far removed from the real classroom situation where groups of pupils interact with each other and with their teacher, getting feedback.

(B) Unstructured or non-directed interviews: Here the respondent is encouraged to talk freely about the subject under investigation and he mainly determines the shape of the interview. There are no set questions and usually no predetermined framework for recording answers. For this reason, it is difficult to summarise and quantify the material gathered through it. This type is usually recommended for the study of complex issues, or whenever the researcher is still vague about the core of his study.

(C) Guided or focussed interviews: Still relatively unstructured since the respondent is allowed a good deal of freedom. In spite of that, the interviewer aims to cover a given set of topics and to identify specific points in a more or less systematic way. The schedule is flexible, and most of the questions are not fixed and are designed to encourage the respondent to express himself freely around each topic.

The researcher, having decided to apply a form of guided type of interviews for its merits, carried out the following steps:

1. The researcher considered the analysis of the topics (Table 6.5.A) while preparing flexible questions for interviewing groups of pupils. Moreover, he planned that such questions should be raised around concrete things, such as pieces of apparatus, solutions, drawings of plants and cells and coloured beads. The idea behind that is to get the interviewed pupils involved in evaluative activities similar to those they should have undertaken in the courses themselves.[175] Moreover, questioning around concrete things helps to eliminate ambiguities since pupils are not obliged to perform with mental images of absent objects.[176]

2. The researcher discussed frankly with the biology principal teachers in the nine selected schools the purpose of the diagnostic interviews. Each of them was asked to provide the researcher with a group of six pupils from the fourth year and a similar one from the fifth year. It was made clear that each group must

represent equally three levels of learning abilities, i.e. two from the least able pupils in the classes, two from the most able and two from the middle ability level. Eight of the nine schools agreed to participate in that stage of diagnosis. The time fixed for the group interviews was arranged to be after the pupils had studied all the biology course. The reason was to assess their final understanding of the topics.

3. On the fixed days, the researcher as well as a British lady biologist held the interviews with the groups. At the beginning of each interview, the interviewers explained to the group the purpose for such a meeting and assured them that the results would be confidential and would not affect in any way their school marks. Rapport was established in the first few minutes through group discussion around the school science syllabuses and the enquiry went gently towards the topics of the research.

Throughout the interviews, the researcher and his collaborator took into account the pieces of advice suggested by writers of the field of interviewing. Some of those suggestions outlined the necessary functions of the interviewers as follows:

1. Listening to the candidate in a friendly, patient, but in intelligently critical manner.
2. Refraining from showing an authoritarian attitude or suggesting that their status as interviewers makes them superior and sets them at an advantage over the candidates.
3. Avoiding asking questions in such a way that the candidate is compelled to give the reply which the interviewers wish. It is much more revealing to allow the candidate to give the information which he thinks fit.[174]
4. Clarifying points of questioning, and making sure precisely what the candidate means by his answers.

5. If the candidate does not talk coherently and goes off at a tangent, he should be allowed a certain time to realise that he is entering irrelevant areas and given the chance to bring himself back on to the right track. If he fails to do so of his own accord, he should be gently guided back on to the right lines by the interviewer.

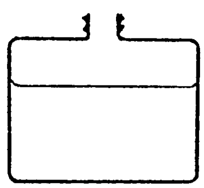
Throughout the interviews, the researcher used questions similar in their pattern to those used by Piaget and Inhelder in their 'clinical' interviews.[66][68] These type of questions, which typically involved 'How', 'Why' and 'What would happen if ...', are credited for their efficiency in revealing the interviewee's own understanding of specific phenomena.[36][39][40] With the help of the concrete materials which accompanied the questioning procedures, the researcher was able to make the problem situations clear and highly specific. Moreover, the tasks which were required from the pupils helped to minimise the need for verbal communication throughout the interviews, and hence raising the objectivity of both the interrogations and the replies. Figure 6.6.1.A shows diagrams of the materials used. Every pupil in the groups was urged to express himself and to give a full answer to every question, and whenever it was suitable, discussions among pupils were encouraged.[195] Sound tapes were used to record the interviews, and explanation for their use was made clear to the pupils.

Although the questions were made flexible to fit into the various conditions for each interview, the following were the most dominant questions used by the researcher and his collaborator:

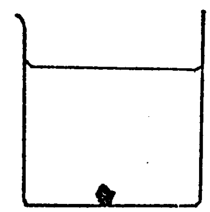
1. What are solids, liquids and gases made of?
2. Could you tell how the molecules (let us call them particles for simplicity) of scent leave this open bottle and reach our noses?

Figure No. 6.6.1.A

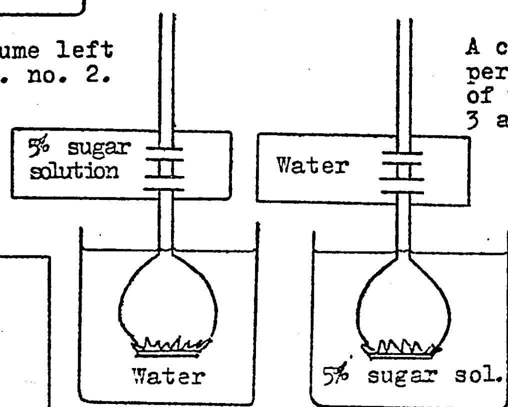
Schematic diagram of the apparatuses and drawings used throughout most of the interviews.



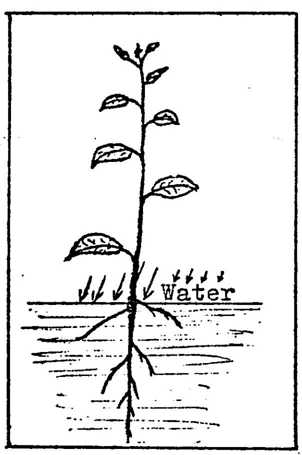
A bottle of perfume left opened, for ques. no. 2.



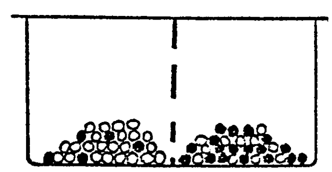
A crystal of potassium permanganate in beaker of water, for ques. nos. 3 and 5.



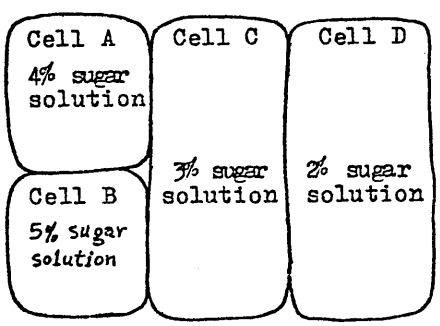
Thistle funnels experiment, for ques. nos. 6 and 10.



Drawing, for ques. no. 8.



Coloured beads in different ratios separated by a perforated membrane, for ques. no. 9.

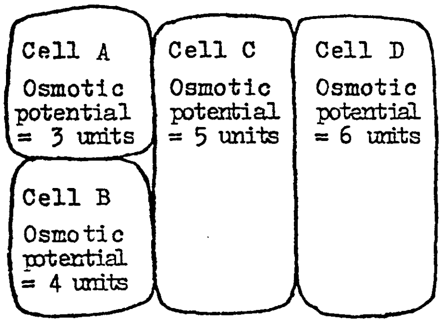


Drawing, for ques. no. 11.

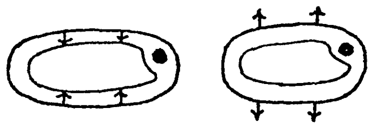
(Continued)

3. Could you tell what would happen if these crystals of potassium permanganate were dropped into this beaker of water?
4. Could you explain what is meant by 'diffusion'?
5. Could you explain exactly what is going on inside this solution?
6. On this apparatus, could you predict the direction of the water flow between this beaker and this Thistle funnel? (water in the beaker and sugar solution in the funnel, then vice-versa.) Why so? What does a 'semi-permeable' membrane mean to you? In this experiment, does water travel in one direction or in both directions across the membrane?
7. What is meant by 'osmosis'?
8. On this drawing of a plant growing in a watered soil, could you identify the direction of water particles movement? Could it ever be the other way?
9. In this box the red beads represent the particles of one substance while the green ones represent the particles of another. This perforated partition divides the box into two equal compartments and would provide equal chances for beads of any colour to go through its holes from one side to the other. Notice that the ratio 'red:green' is not the same for the two compartments. If we shake the box several times what would you expect to happen with regard to the number of red and green beads which would migrate from one side to the other? How could you explain that? Is there any possible link between this model and the plant and soil situation just discussed before?
10. Back to the Thistle funnel experiment, could you explain why water rises up? What is meant by 'osmotic pressure'? Could you tell how it is caused? Which of the two sides is responsible for it? At what point would the column of liquid stop rising?

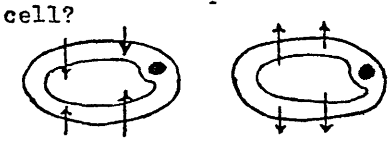
Figure No. 6.6.1.A (Continued)



Drawing, for ques. no. 12.

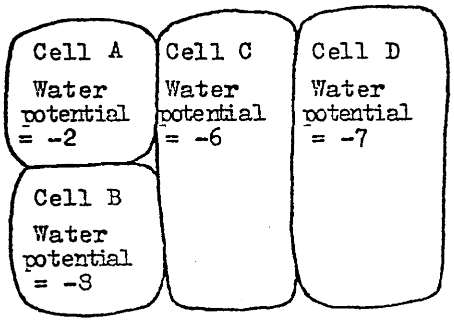


(a) which one shows the direction of the cell wall pressure of a turgid cell?



(b) which one shows the expected direction of water flow between a turgid cell and its surroundings?

Drawings, for ques. no. 13.



Drawing, for ques. no. 14.

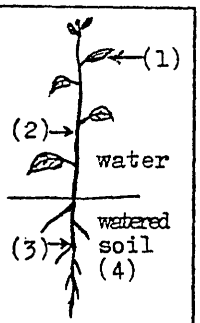
Write the number of the place which has the highest

(a) concentration of the free-moving particles of water

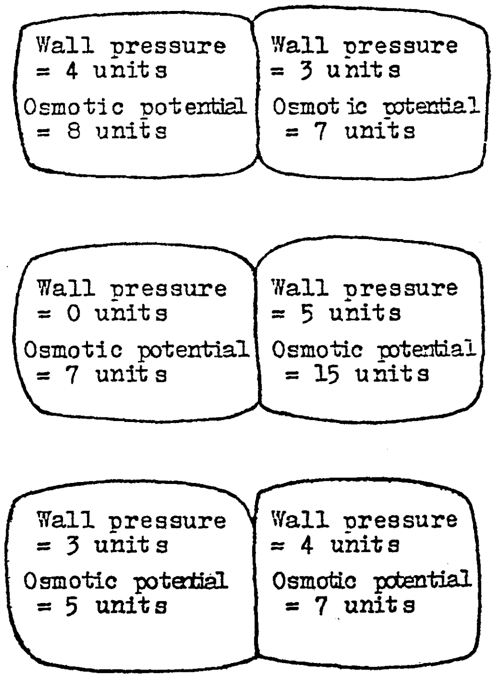
(b) concentration of dissolved substances

(c) osmotic potential

(d) water potential



Drawing, for ques. no. 15



Drawings, for ques. no. 14.

11. As it appears on this drawing, some of the cells have sap which is more concentrated with sugar than the other adjacent cells. Could you draw arrows to show the expected direction of water flow between these cells? Explain. At what point will that flow of water come to an end? Do you think that the particles of water will stop moving completely at that point?
12. What is an osmotic potential of a solution, or a cell sap? On this diagram of cells which have saps with different osmotic potentials, could you draw arrows to show the expected direction of water flow between these cells?
13. Could you tell what would happen if a cell receives water in excess amount? What would heppen to its wall in that case?

    Which arrows show the direction of the cell wall pressure in these diagrams of turgid cells? On the other diagram, which way does the water flow because of the cell wall pressure?
14. What do we mean by water potential? On this diagram of an adjacent group of cells with different water potential values, would you draw arrows to show the expected direction of water flow between these cells? On this other drawing you find adjacent pairs of cells with each cell different in its osmotic potential and cell wall pressure values. Would you put in arrows to show the expected direction of water flow between each pair of cells? Which of these cells has the highest concentration of solute in it? Which is plasmolysed?
15. On this drawing of a plant growing on a well-watered soil, could you indicate which part has each of the following properties:
    (a) Highest concentration of free-moving particles of water.
    (b) Highest concentration of solute.
    (c) Highest osmotic potential.
    (d) Highest water potential.

Following the advice given by Ausubel (1973) with respect to pupils' assessment,[113] answers of a cliché type were not accepted as such but more clarifications were always sought from the pupils who gave them. As the recorded dialogue of each interview was transcribed verbatim and studied carefully, the need for more revealing questions became clear. New solutions, pieces of equipment, drawings of cells placed in solutions carrying labels with various osmotic properties were prepared for the next interviews. More tasks were assigned whenever it was useful to check on the pupils' understanding of a fundamental concept.[40] For example, the researcher asked some later groups to draw their mental picture of the arrangement of sugar and water particles in a sugar solution. This task proved to be helpful as it revealed a common misconception of the structure of solutions, which was responsible for other subsequent misunderstanding as will be discussed later. Another example was when the researcher realized that many pupils seemed not to visualise correctly the effect of cell wall pressure on the water particles flowing into the cell. Pupils were asked, thereafter, to identify on ready made drawings the correct arrows among others showing various plausible directions of the effect of wall pressure in a turgid cell.

The average interview with a fourth year group lasted for forty-five minutes, while that with a fifth year group lasted up to seventy-five minutes since the topics of osmotic potential and water potential were discussed with the latter but not with the former.

6.6.2 Results of the interviews

The researcher and his collaborator separately studied the written transcriptions of the recorded interviews in order to reveal the ideas in which the sample pupils showed weak understanding. A double check was made between the two evaluators. Both evaluators came to an agreement that most of the interviewed fourth and fifth year pupils showed superficial and fragile learning. There was misunderstanding of the following scientific ideas and concepts:

1. The spontaneous, random and continuous movement of the particles of water, and how this leads to their even distribution in a single solution.
2. The non-spontaneous movement of the particles of a dissolved substance and the role of the particles of water in causing their diffusion throughout solutions.
3. The dissolving process and how it happens as a result of the attraction between the individual particles of water and of the dissolved substance.
4. The combined movement of the particles of water and those of the dissolved substances throughout solutions.
5. The consequent hindering effect of solute upon the free movement of the particles of water in solutions.
6. The notion of probability involved in the explanation of why water tends to migrate mainly from where it is more concentrated to where it is less so.
7. The direction of the effect of the cell wall pressure in the turgid cells.
8. The nature of osmotic pressure, how it is generated in solutions and how it is responsible for the rise of solutions inside thistle funnels.
9. The application of knowledge got from the laboratory models to the plant-soil situation with regard to the concepts of osmosis and osmotic pressure.

In addition, the fifth year pupils showed weak understanding of the following topics, which appeared in their syllabus alone:

1. The relation between osmotic potential on the one hand, and the concentration of solutes in solutions and/or osmotic pressure on the other hand.

2. The use of osmotic potential and cell wall pressure values in the determination of the water potential values of cells.
3. The interpretation of given water potential values of cells, and using these values to predict the direction of water flow among those cells.
4. The application of knowledge obtained from the models, to the plant-soil situation with regard to the concept of water potential.

Apart from that, all interviewed pupils showed an adequate understanding of the two following notions:

1. The particulate make-up of substances.
2. The meaning of a semi-permeable membrane.

Appendix No. 6.6.2.A shows various samples of the answers given by the pupils. These results will be discussed along with those from the written tests in a following section.

6.6.3 Assessment of pupils' understanding of the topics through written tests:

One way of improving the validity of assessment is to use the results obtained from one tool of assessment to form a hypothesis. This then can be subjected to examination using another tool of assessment.[178] Following this line, the researcher regarded the results obtained from the interviews as a set of hypotheses about the pupils' misconceptions, and constructed a written test in order to verify the validity of those hypotheses. He believed that this type of mass-evaluation tool could be powerful enough to provide a variety of responses. This, in turn, would throw more light on the prevailing levels of understanding of the major concepts as well as of the subordinate ideas. For this, the researcher constructed a test on diffusion and osmosis with forty true-false items and one simple essay question for both the fourth and fifth year pupils. He also constructed another test on water potential with fourteen true-false items and twenty-three short completion questions. The second test was designed for the fifth year pupils only. Both tests were within the boundaries of the Integrated Science and the biology syllabuses. Wrong answers obtained from pupils through the interviews were carefully used as plausible distracters on these tests instead of relying on artificially formulated wrong answers.

In order to make the tests as valid as possible, the researcher carried out the following two steps:

1. Scientific ideas and concepts revealed by the analyses of the topics were all taken as cores around which the questions were constructed. This would guarantee a good coverage of all elements required for the meaningful learning of the topics.

2. The questions were discussed with biology teachers

in two schools in order to reveal any irrelevancy or lack of coverage of the topics. The questions were modified in the light of these discussions.

To be sure that the results of the assessment would be as reliable as possible, the researcher carried out the following steps:

1. According to the experience of Gagné and his collaborators with testing the outcomes of learning,(110) the researcher devoted two or more questions for each of the elements subsuming the researched topics. This provided the researcher with a reasonable number of samples of the performances of the examinees. It was decided in advance that a pupil would not be considered cognisant of an element unless he responded correctly to all questions assigned to that element. With the true-false type of questions used, this meant that the guessing factor did not contribute to the answers by more than 25% in the case of two questions, or 12.5% in the case of three items per element. This ratio is similar to what one would expect with a multiple-choice question with four or eight alternative answers respectively. To get more reliable assessment of the pupils' understanding, for each idea one of the true-false questions stated a correct answer whereas the other(s) stated wrong one(s).

2. No limit was put on time. This helped the pupils to minimize their reliance on hasty guessing.

3. Pupils were advised to opt for "Don't know" wherever they found themselves unable to choose "True" or "False" for a given question statement.

4. The wording of the statements were made clear as possible, and both negative forms and difficult terminology were avoided.(27)(154)

5. Key words in each statement were underlined to help the pupils to recognize the core part of the fact which they were asked to judge for correctness.[164]

6. Questions were grouped around a limited number of clearly specified situations in order to help the pupils to concentrate their thoughts around a few problems. Some of these situations were set around simple laboratory models while others around a plant in its soil. All situations were accompanied by illustrative diagrams and clarifying statements in order to help the pupils to construct clear mental images of the problems around which they were questioned. Thorndike (1969) recommended this step to be taken to provide pupils with a defined frame of reference in terms of which to judge the truth or falsity of a statement.[154]

7. Some of the questions aimed to check on explanations, others on predictions, others on factual knowledge and conceptualisation of the behaviour of water and solute particles. Other questions checked the pupils' ability to compare some osmotic properties of solutions with different concentrations.

8. Clear instructions were given on how to provide answers for each type of questions used in the tests.

9. Criteria for the correct answers on the essay-type question were clearly specified in advance. Those criteria were applied to several examples which were scored on three dimensions of increasing merits.[113]

10. In order to avoid placing any undue burden on the pupils, which would lead to unreliable results, the total number of questions was made as small as possible so that they could be answered by the average pupil within a reasonable time.

The pilot trial:

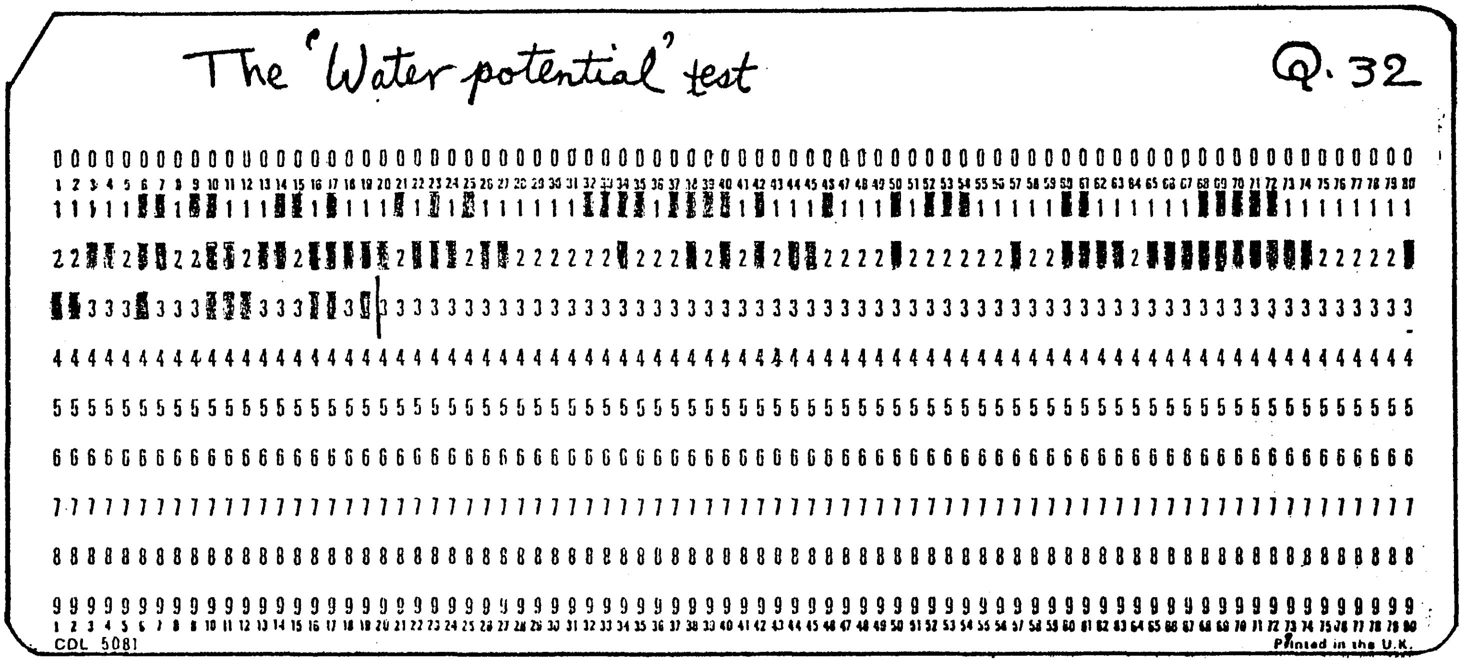
When the tests reached their final format, a pilot run was conducted in one school with a sample of fifteen pupils in order to discover any ambiguity in the instructions or in the items, and to estimate the time required for the completion of the tests. Since no troubles were revealed in that trial run, the tests were considered to be ready for application. The time estimated for answering the 'diffusion and osmosis' test by the fourth year pupils was thirty minutes, while answering the same test in addition to the 'water potential' test by the fifth year pupils required around forty-five minutes. This was an acceptable time which would cause neither fatigue to the examinees nor undue disturbance to the school timetable. Appendix 6.6.3.A shows the tests as well as the correct answers.

Administration of the written tests:

The tests were administered in each of the eight schools after all topics of the biology syllabuses had been taught and revised. The total number of the fourth year pupils who answered the 'diffusion and osmosis' test was 348 (113 boys, 235 girls) all drawn from 26 classes. The fifth year sample numbered 179 pupils (59 boys, 120 girls) all drawn from 18 classes. Using the graphs suggested by Kellett[191] for the significant differences in proportions, it was revealed that the percentages of girls in the fourth and fifth year samples were not significantly different at 1% level from the corresponding percentages of the general census for the year 1976.[124] (For range, mean and S.D. of ages of the two samples see page 84).

Correction of the answers:

The correction of the two objective tests was carried out manually with the help of perforated key answer sheets. Lists were then completed with information



A Sample Computer Card

about each pupil which had been provided by him on his answer sheet as well as the serial numbers of questions to which he responded correctly and his total score on the test(s). Correct responses were given one mark each. The correction of the essay question on the 'diffusion and osmosis' test was carried out with the help of a guide sheet. On that sheet, six possible answers at successive levels were proposed. The levels were related to the theories of Piaget, Gagné and Ausubel. Appendix No. 6.6.3.B shows the contents of that sheet.

6.6.4 Results of the written tests:

As it was arranged earlier, a pupil was not to be considered as understanding an idea unless he responded correctly to all the questions set on that learning element. In order to determine that, the researcher gave a serial number to each pupil within a continuous system of numbering which brought all the pupils together on one list. One computer card was devoted to each question, and holes were made on each card corresponding to the serial numbers of the pupils who responded correctly to that question. By superimposing cards of the questions which tested the same element, the researcher was able to identify and count the pupils who showed understanding of that element. Tables Nos. 6.6.4.A through 6.6.4.F as well as Figures 6.6.4.A through 6.6.4.D show the results of that count. Table No. 6.6.4.G shows the results of the correction of the essay question according to the scheme of scoring detailed on Appendix No. 6.6.3.B. Both sets of results turned out to be in complete agreement with those obtained from the interviewing procedure, and so, the validity of those results can be taken to be high.

TABLE No. 6.6.4.A

Result of the test on diffusion and osmosis - the laboratory situations (Fourth year pupils)

Idea	Corres-ponding serial nos. of ques. as on the test	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=174	Biology + other science(s) N=174	Boys N=113	Girls N=235	All pupils N=348	
1. Spontaneous movement of water particles	3,4	38.5	44.8	45.1	40.0	41.7	13
2. Random movement of water particles	12,23	23.6	17.8	21.2	20.4	20.7	7
3. Continuous movement of water particles	9,29	24.7	17.2	17.7	22.6	21.0	8
4. Leading role of water particles in the molecular movement inside solutions	2,4,6	8.6	10.3	12.4	8.1	9.5	2
5. Dependent movement of solute particles on the movement of water particles	1,2	40.8	33.9	44.2	34.1	37.4	11
6. Combined movement of water and solute particles	6,7	10.9	14.9	16.8	11.1	12.9	5
7. Attraction between particles of water and particles of solute inside solutions	5,6	10.3	4.6	10.6	6.0	7.5	1
8. Concentration of water v. concentration of solute	18,26,27	37.4	50.6	39.8	46.0	44.0	14
9. Rule of diffusion with regard to solute particles	8,10	58.0	56.9	54.0	59.1	57.5	15
10. Rule of diffusion with regard to water particles	8,11	35.6	45.4	39.0	41.3	40.5	12
11. Effect of solute on the free movement of water particles	17,19	9.8	10.3	8.8	10.6	10.1	3
12. Probability in the redistribution of water particles	8,14,16	27.0	28.2	31.0	26.0	27.6	9
13. Direction of water flow between solutions with different concentrations	22,25,28	19.5	42.0	34.5	28.9	30.7	10
14. Pressure of the free particles of water inside solutions	13,24	16.7	12.1	15.9	13.6	14.4	6
15. Balanced state between solutions with different concentrations	15,20,21	10.3	26.5	15.9	9.8	11.8	4

TABLE No. 6.6.4.B

Result of the test on diffusion and osmosis - the plant-soil situation (Fourth year pupils)

Idea	Corres-ponding serial nos. of ques. as on the test	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=174	Biology + other science(s) N=174	Boys N=113	Girls N=235	All pupils N=348	
1. Initial differences between the soil and plant solutions	30,35	18.4	37.9	31.9	26.4	28.2	7
2. Initial situation of water in soil and plant solutions	31,35	14.9	17.8	18.6	15.3	16.4	4
3. Initial situation of solutes in soil and plant solutions	30,32	15.5	13.2	16.8	13.2	14.4	3
4. Effect of solutes on the flow of water between the soil and the plant	32,33	12.1	12.6	16.8	7.7	12.4	2
5. Osmotic pressure of the soil and plant solutions	34,38	4.0	2.3	5.3	2.1	3.2	1
6. Cell wall pressure and the flow of water from the soil to the plant	36,37	21.3	22.4	26.5	5.9	21.8	5.5
7. Manifestations of diffusion and osmosis in the plant and its surroundings	39,40	26.4	17.2	13.3	5.1	21.8	5.5

TABLE No. 6.6.4.C

Result of the test on diffusion and osmosis - the laboratory situations (Fifth year pupils)

Idea	Corresponding serial nos. of ques. as on the test	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=57	Biology + other science(s) N=122	Boys N=59	Girls N=120	All pupils N=179	
1. Spontaneous movement of water particles	3,4	36.8	45.1	38.9	44.1	42.5	11
2. Random movement of water particles	12,23	15.8	25.4	25.4	20.8	22.3	6
3. Continuous movement of water particles	9,29	28.1	31.1	32.2	29.1	30.2	10
4. Leading role of water particles in the molecular movement inside solutions	2,4,6	8.8	13.9	13.5	11.6	12.3	3
5. Dependent movement of solute particles on the movement of water particles	1,2	28.1	27.1	32.2	25.0	27.4	9
6. Combined movement of water and solute particles	6,7	10.5	19.7	13.5	18.3	16.8	4
7. Attraction between particles of water and particles of solute inside solutions	5,6	5.3	11.5	10.1	9.1	9.5	2
8. Concentration of water v. concentration of solute	18,26,27	59.6	59.0	52.5	63.5	59.2	14
9. Rule of diffusion with regard to solute particles	8,10	78.9	75.4	71.1	79.1	76.5	15
10. Rule of diffusion with regard to water particles	8,11	45.6	49.2	44.0	50.0	48.0	12
11. Effect of solute on the free movement of water particles	17,19	7.0	9.0	8.4	8.3	8.4	1
12. Probability in the redistribution of water particles	8,14,16	31.6	22.1	18.6	28.3	25.1	8
13. Direction of water flow between solutions with different concentrations	22,25,28	50.9	57.4	49.1	58.3	55.3	13
14. Pressure of the free particles of water inside solutions	13,24	19.3	27.0	22.0	25.8	24.6	7
15. Balanced state between solutions with different concentrations	15,20,21	17.5	20.5	16.9	20.8	19.6	5

TABLE No. 6.6.4.D

Result of the test on diffusion and osmosis - the plant-soil situation (Fifth year pupils)

Idea	Corresponding serial nos. of quest. as on the test	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=57	Biology + other science(s) N=122	Boys N=59	Girls N=120	All pupils N=179	
1. Initial differences between the soil and plant solutions	30,35	36.8	54.9	57.6	45.0	49.2	7
2. Initial situation of water in soil and plant solutions	31,35	12.3	18.1	18.6	15.0	16.2	3
3. Initial situation of solutes in soil and plant solutions	30,32	17.5	27.9	22.0	25.8	24.6	4
4. Effect of solutes on the flow of water between the soil and the plant	32,33	22.8	27.0	25.4	25.8	25.7	5
5. Osmotic pressure of the soil and plant solutions	34,38	1.8	13.9	10.2	10.0	10.1	1
6. Cell wall pressure and the flow of water from the soil to the plant	36,37	22.8	39.3	38.9	31.7	34.1	6
7. Manifestations of diffusion and osmosis in the plant and its surroundings	39,40	14.0	11.5	6.8	15.0	12.3	2

TABLE No. 6.6.4.F

Result of the test on water potential - the laboratory situations (Fifth year pupils)

Idea	Corresponding serial nos. of ques. as on the test	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=57	Biology + other science(s) N=122	Boys N=59	Girls N=120	All pupils N=179	
16 Effect of solute concentration on the osmotic pressure of solutions	6,7	42.1	46.7	44.0	45.8	45.3	9
17 Effect of solute conc. on the amount of free particles of water causing pressure in solutions	13,14	75.4	69.7	66.1	74.1	71.5	16
18 Effect of the amount of solute on the osmotic potential of a solution	1,2	56.1	66.4	55.9	66.6	63.1	14
19 Effect of solute conc. on the osmotic potential of solutions	3,4	40.4	50.8	50.8	45.8	47.5	10
20 Effect of water inflow on the cell wall pressure	36+37	61.4	62.3	57.6	64.1	62.0	13
21 Differences between pure water and solutions in their osmotic properties	5,12	28.1	38.5	28.8	38.3	35.2	4.5
22 Effect of amount of solute on the water pot. of sol.	8,9	40.4	54.1	42.3	53.3	49.7	11
23 Effect of conc. of solute on the water pot. of sol.	10,11	33.3	45.1	32.2	45.8	41.3	8
24 Effect of conc. of solute on the direction of water flow between solutions	15	57.9	75.4	67.7	70.8	69.8	15
25 Computation of (Ψ) from its components	16	35.1	59.8	47.4	54.1	52.0	12
26 Ranking (Ψ) values to identify the highest	17,24	24.6	36.1	23.7	36.6	32.4	2
27 Ranking (Ψ) values to identify the lowest	18,25	26.3	45.1	28.8	44.1	39.1	7
28 Significance of (Ψ) values as an indication of the relative conc. of the free particles of water	27	29.8	39.3	35.5	36.6	36.3	6
29 Significance of (Ψ) components as an indication of the state of cells	21,22	31.6	31.1	38.9	27.5	31.2	1
30 Significance of (Ψ) components as an indication of water gain and loss from cells	19,20	28.1	35.2	35.5	31.6	33.0	3
31 Direction of water flow between cells and between cells and pure water	23,26	28.1	38.5	37.2	34.1	35.2	4.5

TABLE No. 6.6.4.F

Result of the test on water potential - the plant-soil situation (Fifth year pupils)

Idea	Corresponding serial nos. of quest. as on the test	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=57	Biology + other science(s) N=122	Boys N=59	Girls N=120	All pupils N=179	
8 Differences in osmotic properties between the soil and plant solutions	35,37	43.9	44.3	52.5	40.0	44.1	4
9 Direction of water flow as an indication of differences in water potential between root cells	28,29	56.1	58.2	52.5	60.0	57.5	5
10 Direction of water flow as an indication of differences in solute concentrations between root cells	30,31	36.8	46.7	47.5	41.7	43.6	3
11 Direction of water flow as an indication of differences in cell wall pressure between root cells	32,33	29.8	44.3	40.7	39.2	39.7	1
12 Direction of water flow as an indication of the relation between the concentration of the free particles of water and the osmotic pressure of the plant and soil solutions	34,35	38.6	44.5	47.5	40.0	42.5	2

Figure 6.6.4.A — Results of the test on diffusion and osmosis — laboratory situations

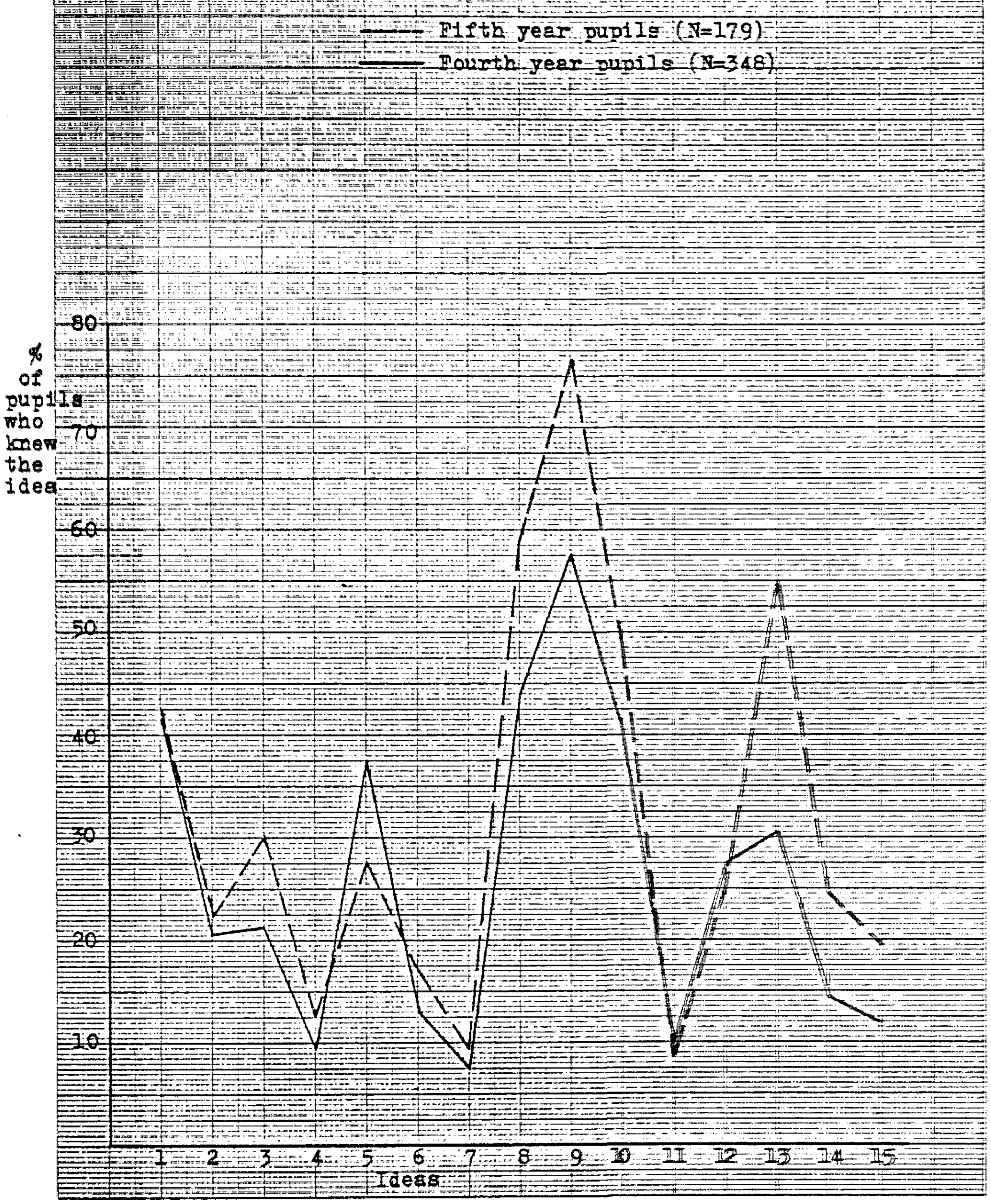


Figure 6.6.4.B Results of the test on diffusion and osmosis - Plant-soil situation

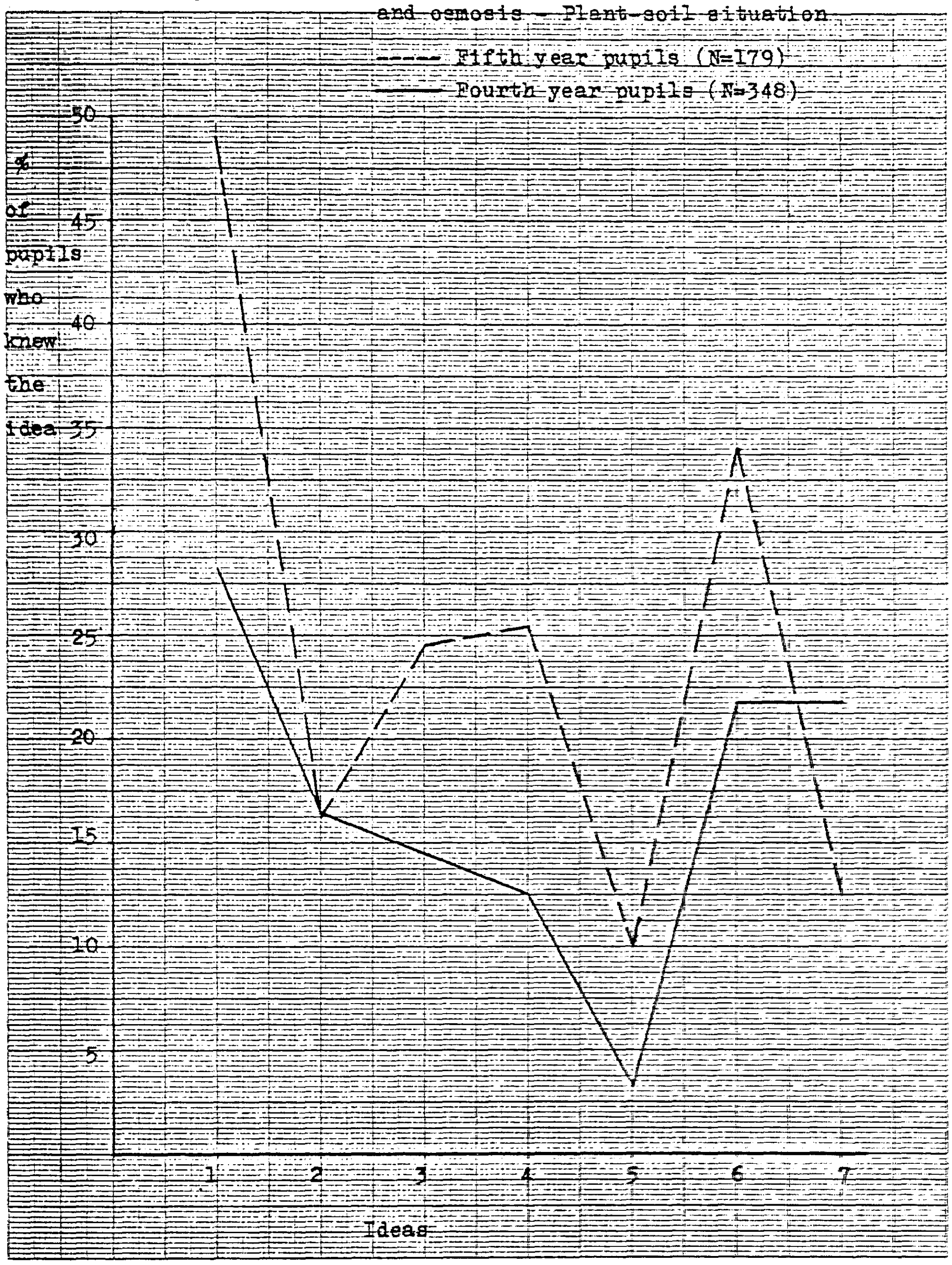


Figure 6.6.4.C Result of the test on water potential - laboratory situations

Fifth year pupils (N=179)

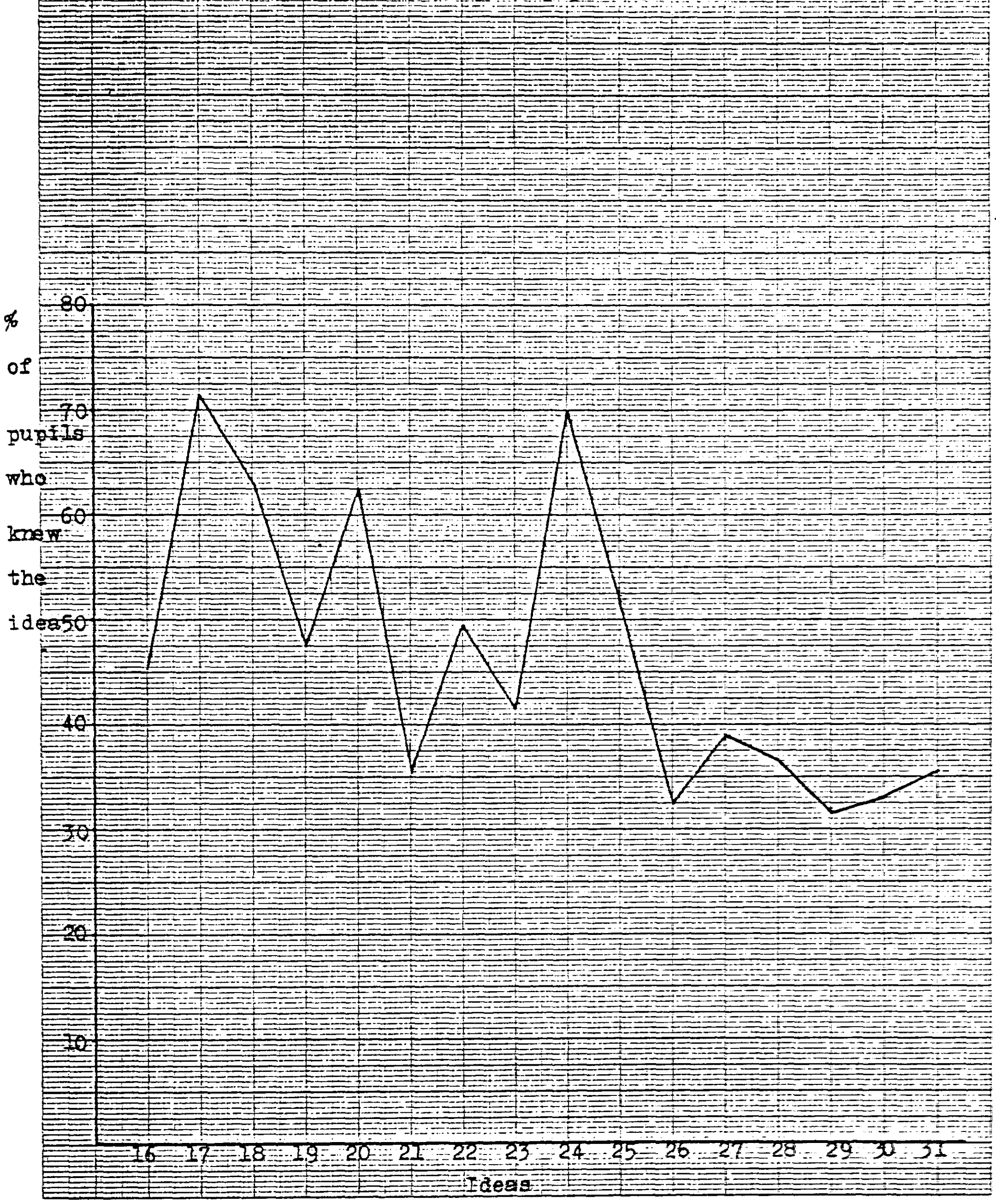


Figure 6.6.4.D Result of the test on water potential - Plant-soil situation.

Fifth year pupils (N = 179)

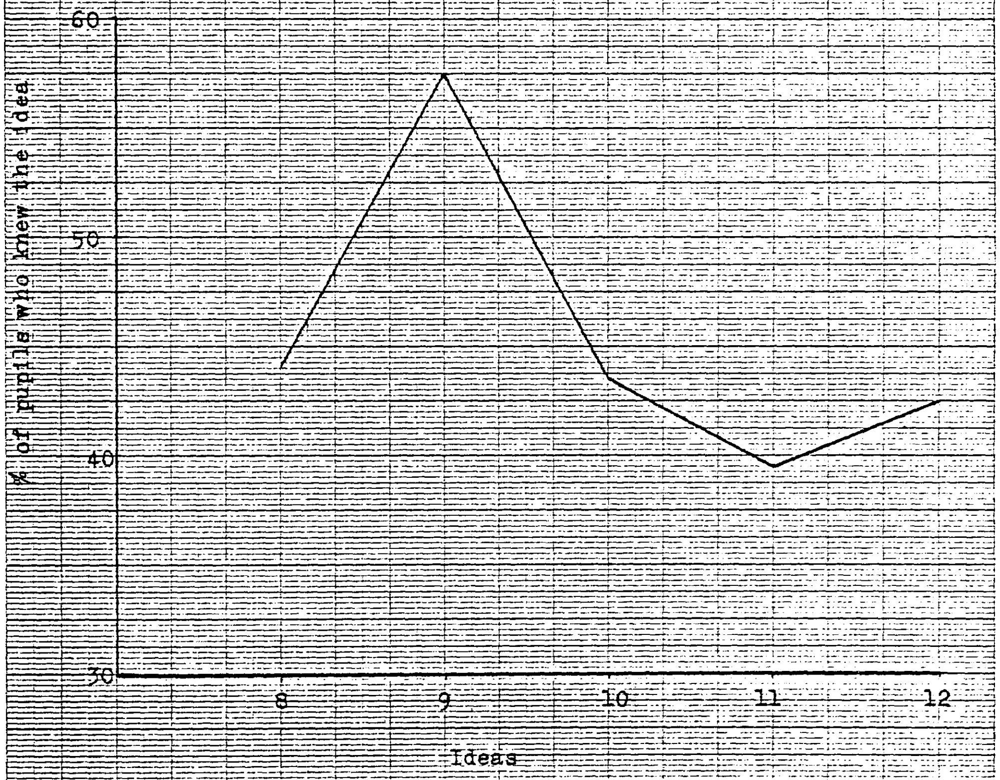


TABLE No. 6.6.4.G

Results of the essay question (reported for those who answered it)

Score	Fourth year pupils N = 279		Fifth year pupils N = 158	
	N	%	N	%
0	77	27.6	31	19.6
1	94	33.7	61	38.6
2	15	5.4	9	5.7
3	88	31.5	44	27.9
4	5	1.8	13	8.2
5	0	0.0	0	0.0

6.7 Discussion and interpretation of the results of the diagnostic study:

Using the results obtained from both the interviews and the written tests, the researcher tried to answer the four questions which had been set earlier as guidelines for this stage (questions 3 through 6 on the statement of the problem).

6.7.1 The level of understanding reached by the pupils:

The first question raised for this stage was: "What level of understanding of the concepts did the pupils reach?" In fact, it was clear to the researcher that the majority of the pupils were at the disadvantage of being ignorant of most of the basic ideas which subsume the concepts of the topics being researched. From Tables Nos. 6.6.4.A through 6.6.4.G, one can recognise the following:

(1) Although pupils had been told, in their earlier science studies, that when matter exists in its liquid state its particles move spontaneously, continuously and randomly, the sample pupils showed weak recognition of those ideas (ideas nos. 1, 2 and 3). As a result of that, the majority of them had established a wrong picture about the behaviour of water molecules in solutions. Dow (1978) and Kellington (1978) reported similar weakness.(37)(135) Almost 60% of the pupils thought that the particles of the dissolved substance is responsible for pushing forward the particles of water hence causing its flow among cells and solutions. This is because they have been taught much about the diffusion of dissolved substances but nothing about that of water. Common phrases in books like 'water intake by root cells' give them the wrong impression of immobility of water particles. About 80% of the pupils believed that water particles travel one way only between solutions in osmosis. This is due to

the false argument taught to them about the 'suction' pressure exerted by 'strong' solutions on water from 'weaker' solutions. Between 79% and 70% of the pupils thought that water particles would stop moving completely once the balance state in osmosis is achieved. This was expected since biology books always concentrate on the net flow of water as a final outcome and refer to the state of balance as the one at which water will 'stop' entering a cell or a solution.[143] All these ideas need intelligent imagination on the pupils' part, since they are difficult to demonstrate by direct experiments. Weakness in grasping them leads to misunderstanding of higher ideas, such as the formation of solutions, the cause of water flow from one solution to another and the dynamic nature of equilibrium in osmosis.

(2) Ideas nos. 4 through 6 were poorly understood by the majority of the pupils as a result of their weakness in the previous ideas. Between 90% and 88% of them did not know that the water particles take the lead in the molecular movement inside aqueous solutions. On the contrary, they believed that the dissolved substance is responsible for that movement. It seems that they had concluded from the Brownian movement, to which they were introduced earlier, a plausible and wrong conclusion. Attached to that, between 63% and 73% of the pupils thought that the solute particles travel of their own accord without being carried by water particles. Both Mughol (1977) and Dow (1978) reported separately similar findings with their pupils.[14][37] This could be because they had been taught superficially that digested food materials diffuse through the walls of gut into the body, without stressing the role played by water particles.[132][135] What makes it worse is that some school textbooks state that the solute 'moves' by diffusion.[141] This apparent weakness in understanding that idea was confirmed by finding that 87-83% of the pupils did not know about the combined movement of

water and solute particles in their solutions. This also means that when pupils are told that plant fertilisers and human food materials must be made soluble in water in order to be of use to them, pupils do not realise the reason behind that. Partington (1977) in his report about the situation of school biology attributed similar weakness to the shallow treatment of liquids and diffusion on the integrated science course.(139)

This weakness in all the six mentioned ideas hindered their understanding of the next higher idea about how aqueous solutions are formed, which proved to be almost the least one to be understood by them.

(3) As few as 7.5% of the fourth year sample pupils showed understanding of how solutions are formed (idea no. 7). Not very much better than that were the fifth year pupils (9.5%). Needless to say that missing such an essential bit of knowledge would put the pupils at a disadvantage of being unable to envisage the structure of the aqueous solution which is the main factor of all situations and experiments of osmosis. Surveying the textbooks used in schools, the researcher noticed that that common misunderstanding was due to a wrong notion given on those books. Pupils were told that dissolved substances break spontaneously into minute particles which fit later into spaces already found between the particles of water. It seemed unfortunate that a very limited number of teachers tried to rectify this wrong notion, so it was left to establish itself as a strong belief among the pupils. This put them in difficulties when facing other ideas such as the hindering effect of solute on the free movement of water particles (idea 11), and their lowering the water potential of cell sap solutions (idea 4 in plant situation).

(4) Of the pupils tested, 56% from the fourth year group and 40% of the fifth year did not show understanding of the inverse relation between solute and water concentrations in their solutions (idea 8). This indicated that whenever they thought of diffusion, osmosis or water potential, they did this by vague reasoning and had to 'twist' the meaning of what they read or heard to make it fit with what was in their minds. Johnstone (1977) reported similar findings when pupils had to study chemical equilibrium on weak foundations.(116) Ausubel (1973) suggested that when a pupil is presented with a new difficult idea he can treat it in a number of ways. He may place it in a compartment alongside his existing body of knowledge according to his own understanding and not try to incorporate it. He may attempt to attach the new knowledge to his existing knowledge and, if his relevant knowledge is vague or wrong, he will build wrong conceptions.(113) From the results of our sample on the higher ideas, it became clear that they had followed one or another of these possibilities. When discussing the concentration of solutions and the derived concept of concentration gradient, teachers should have helped all of their pupils to focus on the concentration of the free water particles not of the solute. If this precaution was taken, each pupil could easily have incorporated the new concept of concentration gradient into a well-established body of knowledge. This successful 'integrative reconciliation' is able to eliminate any ambiguity or confusion.(113)

(5) Though still relatively insufficient, a comparatively higher percentage of pupils recognized the rule of solute diffusion than those who recognized the rule of water diffusion (ideas 9 and 10). This could be because the spread of coloured particles of solids is more easily seen and traced than that of the invisible water particles. Thus, we can deduce

that the pupils who got the idea correct with regard to solute but not correct with regard to water were concrete bounded in their thinking in this respect. With some effort, teachers could have recognized this and helped them to realise that the same rule is applicable to the unseen water particles. Animated figures would be the best means of reaching this end. Another reason for this weakness could have arisen from their previous weakness in the ideas about the combined movement of solute and water particles in their solutions (idea 6), and that of how solutions are originally formed (idea 7).

(6) Almost 90% of the fourth year pupils and 92% of the fifth year pupils did not know that the addition of solute to water hinders its molecular movement thus rendering it less able to travel across membranes (idea 11). Many of them suggested that dissolved glucose increases the movement of water particles. This result was not so astonishing, since great numbers of them did not know correctly that some water particles attach themselves to the solute particles (idea 7), and that both move around together in their solutions (idea 6). Surveying school textbooks, no mention of that idea was found. One wonders how pupils were expected to understand the reason why water is more available from dilute solutions than it is from those concentrated with dissolved substances. A mere comparison of water concentration in solutions is not sufficient to give the full explanation for the phenomenon of water flow. Weakness in knowing that the concentration of water goes reversibly to that of solute rendered this alternative explanation unavailable to the majority of those pupils.

(7) Nearly three quarters of the pupils were not able to reason that the even redistribution of water among adjacent solutions is the most probable result to take

place under such circumstances. Since the majority proved not to know what is going on in solutions (ideas 1 through 11) the result is that they attributed this even redistribution to a fake 'suction pressure' caused by concentrated solutions. This wrong reason has been the most dominant one in all biology books as far as the researcher has surveyed them. "Salt solution is more concentrated than cell sap, and so 'withdraws' water from vacuoles by osmosis" is one of the misleading statements given by one of those books.[140] This in turn is due to the wrong handling of chemical terminology in the study of biology. Most biology books and teachers used to refer to the concentrated solution as the 'strong' one, and to the dilute solution as the 'weak' one. From this, they reached a wrong conclusion that the so-called 'stronger' solution acts as a 'sponge' which 'sucks' water from the other. MacDonald (1976) remarked that it is quite misleading to lean on the 'middle category' analogies, i.e. analogies that are neither very far from nor very near to the phenomenon which they purport to explain.[192] Bearing in mind the effect of solute on water, the combined movement of water and solute particles, and the concession offered by s.p. membranes only to the free particles of water, which move spontaneously, continuously and to all directions, pupils must deduce that the even distribution and redistribution of this kind of particle is only governed by a simple probability rule under such circumstances. One can interpret the weakness shown by pupils in this respect to either their ignorance of these successive and related notions, and/or to their inability to perform probabilistic reasoning. Inhelder (1971) defined this reasoning as the one which aims at organizing 'chance events' and requires the development of both concrete and formal operations.[66] During the interviews, pupils were able to appreciate the role played by probabilities in the redistribution of coloured beads between two adjacent compartments.

But when they were asked to apply this idea to the redistribution of water particles among solutions, many of them were unable to do so. This would indicate that a considerable number of the pupils who are studying biology were not at the formal level of reasoning, and ought to get more consideration from the syllabus designers and more help from their teachers.

(8) As many as 69% of the fourth year pupils, and 45% of the fifth year pupils were not able to determine which of two specified solutions would increase in volume as a result of receiving water from the other (idea 13). Ignorance of this idea indicated their weakness in the pinnacle concept of osmosis. It could also indicate the failure to apply this concept to the test situations by some of the pupils who already knew it. This possibility was found valid with many pupils who responded correctly to question no. 22 on the simpler situation, but not correctly to questions 22 and/or 28 on the comparatively more difficult situation (see appendix 6.6.3.A). Being aware of the fact that correct responses to the questions on this top idea do not necessarily indicate a meaningful learning of the concept of osmosis, the researcher counted the pupils who showed understanding of that idea beside all the other subsuming ideas. The result of counting showed that none of the pupils knew all of them together. He counted again those who understood the top idea with all ideas except the one at the bottom of the hierarchy. None was recorded. He proceeded further in the counting, keeping the top element but eliminating one idea at a time in a serial sequence. Table 6.7.A below shows the results of that counting.

TABLE No. 6.7.A

Accumulation of the ideas	% of pupils who understood that accumulation of ideas	
	Fourth year pupils N = 348	Fifth year pupils N = 179
1 through 13	0	0
2 " 13	0	0
3 " 13	0	0
4 " 13	0	0
5 " 13	0	0
6 " 13	0	0
7 " 13	0	0
8 " 13	0	0.6
9 " 13	0	0.6
10 " 13	0.6	0.6
11 " 13	0.6	0.6
12 " 13	13.5	14.0

This result would suggest that all who were able to determine which direction water would flow between solutions (idea 13) were not able to show full understanding of why this was so, or what was taking place in the relevant solutions. Such group of pupils were thus proved to have the ability only to memorize the simple rule of osmosis and to apply it to tested situations, without knowing really what osmosis is or what causes it to take place.

(9) Next to the idea on the top of osmosis, the pupils were tested in ideas 14 and 15, which are necessary for learning the higher concepts of osmotic potential and water potential. Results showed that the majority of pupils did not perform well. They were not able to realise that the free particles of water available in a dilute solution exert higher pressure on the s.p.

membrane than that caused by their counter parts in a concentrated solution. Associated with this, they were not able to determine that the state of balance would be achieved when pressure becomes equal on both sides. Missing these two ideas from their cognitive structure would curtail further understanding of the relevant higher concepts.

In order to see whether the difficulty order of the fifteen ideas included in diffusion and osmosis was almost the same for the fourth and the fifth year pupils, those ideas were arranged in a descending sequence according to the percentage of pupils who answered correctly the questions set on each. The smaller the percentage of those pupils, the first an idea appeared on that ranking order of difficulty. Spearman's Coefficient of correlation (p) was computed according to the formula

$$p = 1 - \frac{6 \sum d^2}{n(n^2-1)}$$

where d is the difference in rank order, and n is the number of ideas. The computed (p) value was 0.94, which was found significant at the 1% level. This means that one can reject, with 99% confidence, that such correlation was caused by chance alone. Therefore, one would conclude that those ideas were causing a genuine difficulty for all tested pupils almost at the same rate.

(10) With regard to the ideas on the plant-soil relationship, it was clear that pupils revealed the lack of essential knowledge. Though it is clear to every pupil that plants receive water from soil, many of them did not agree that the sap of plants is more concentrated with solutes than the soil solutions are. This meant that they had no good reason for how water would flow from soil to plant. Associated with this, they did not know that sap solutions of the higher parts of the

plant exert osmotic pressure higher than that exerted by the lower parts, which in turn is higher still than that exerted by the soil solutions. Because pupils had been told that soil is rich with dissolved nutrients, on one hand, and that around 80% of the plant weight is due to its water content, on the other hand, they were not able to reckon that soil solutions are richer still with water compared to plant sap solutions. Besides, the established wrong notion of 'suction pressure' gave pupils an alternative explanation for the water flow from soil to plant. It also led them to regard this flow as a deliberate action planned by plant, not a physical phenomenon. This distortion in understanding provided evidence that they learned, just intuitively, that water flows from soil to plant. It showed also their inability to transfer what had been learned on the visking tubing and thistle funnel experiments to the plant situation. Moreover, their inability to recognize some manifestations of diffusion and osmosis meant that they did not get sufficient experience on how to distinguish between instances from non-instances of the concepts.[62] To Gagné, this means that even the learning at the discriminative level (type 5 of his proposed hierarchy) was not achieved in this respect.[5]

(11) With regard to the fifth year pupils, a considerable percentage of them did not show a very good understanding of the effect of solute concentration on both the osmotic properties and the water potential of pure water and solutions (ideas 16 through 19, and 21 through 23). This is attributed to their initial weakness in appreciating the effect of solute on the free movement of water particles (idea 11 on the diffusion and osmosis test).

(12) Similar to what was observed during the interviews, many pupils failed to indicate that cell walls would exert more pressure with the increase of water flow

into those cells (idea 20). It seemed that they regarded this pressure as one of the reasons for that inflow, not one result of it. This is supported by their weak understanding of the relevant idea no. 6 on the plant situation.

(13) The computation of (Ψ) values requires the understanding of the relation between the two opposing variables which contribute to that value. Since 48% of the pupils did not work out correctly the required simple calculations, one can deduce that the meaning and the structure of water potential was not understood by them. This conclusion is completely supported by their obvious weakness in interpreting the significance of (Ψ) values (ideas 28 through 30). It was clear that they did not grasp the prime notion of the concept, i.e. water potential of a cell as the likelihood with which water will flow into or out of a cell. This could be attributed to the inherent difficulty in the terminology itself. Through discussions with school teachers, the researcher got evidence that the definition of water potential did not carry the same meaning to all of them. As a result, teachers transferred to their pupils this uncertainty about the whole concept. Added to that, the failure of about two-thirds of the tested pupils to rank some (Ψ) values to identify the highest and the lowest, gave evidence of the difficulty faced by them in handling the concept in a mathematical manner. Although Lovell (1974)[91] remarked that ordination is easier for pupils to handle than cardination, it could be the negative values which are included in (Ψ) values that made the study of water potential deep in its abstraction.

(14) When the pupils were asked to predict the direction of water flow, given the concentrations of solutions and guided to consider their osmotic properties, about 70% succeeded in that task (idea 24). But when they

were asked to do the same task, given the water potential values for some cells, only 35.2% succeeded this time (idea 31). This was another indication of the great difficulty which they were having in learning about water potential.

One of the well-established dogma in the field, demonstrated itself clearly at this concept. It was revealed when the majority insisted that pure water has the highest water potential, and it would even donate water particles to a cell with a positive value of water potential. One can deduce that they were taking the subject of water potential by heart without appreciation of what Ψ = -1, 0, or +1 differentially mean. Again, this is the fault of school textbooks.

(15) With regard to the plant-soil situation, the fifth year pupils did not perform satisfactorily when it was related to the concept of water potential. Comparing the successive layers of the plant root according to their water potential and osmotic properties was a difficult task for the majority of them. This was a result of their weakness on the simpler ideas of diffusion, osmosis and water potential.

(16) With regard to the results of the essay question, Table 6.6.4.G shows that the larger category of the answers scored only 'One'. According to the marking scheme (see appendix 6.6.3.B), this score was given to answers such as: "Water flows from soil to plant by osmosis/by diffusion/by osmotic pressure/or by water potential." This type of answer does not necessarily indicate an acceptable level of understanding. The category next to that in number scored 'Three'. This score was given to answers like: "Water flows from soil to plant because of the difference in concentration." Though good in itself, such an answer does not give any hint about what is associated with this difference in concentration and really causes the flow

of water. Nearly 5% of the answers scored 'Two', which meant that some pupils were taking the difference in the 'amount' of water as a reason for the water flow between soil and plant. The relatively low percentage of pupils who obtained 'Four' revealed that the majority did not build their learning of the topics on a good deal of information. Score 'Five' was not obtained by any pupil.

From what has been revealed, one can conclude that a considerable area of knowledge at the very basis of the topics was completely missing from the pupils' cognitive structure. Moreover, pupils who were able to predict the direction of water flow between solutions or cells did not show understanding of the reasons for that phenomenon. Therefore, one can conclude that pupils were learning the topics only at a superficial level. Reaching this conclusion, the first question set earlier for this stage was hopefully answered.

6.7.2 Comparing the performance of the pupils' subgroups:

The second question raised earlier for this stage was, "Is there any significant difference between the performance of pupils who studied biology alone and that of those who studied other branches of science besides biology?" From Tables Nos. 6.6.4.A through 6.6.4.F, and Figures Nos. 6.7.2.A through 6.7.2.C, it appeared that there were some differences in the performance of the above mentioned subgroups of pupils. One could think of applying a statistical test to check the significance of those differences, such as the t-test or the χ^2-test, but it was believed that it would be a misleading exercise. Principally because, whether the differences were proved to be significant or otherwise, the pupils who usually study more than one science are generally more able than those who study biology alone.[153] Thus the interpretation of such results would not be a perfect one, unless a firm experimental control had been taken. Such practice was found to divert the present study from its original line and was avoided. Therefore, the question raised above was not a simple one to answer if a valid conclusion was to be reached.

Figure 6.7.2.A Results of the test on diffusion and osmosis.

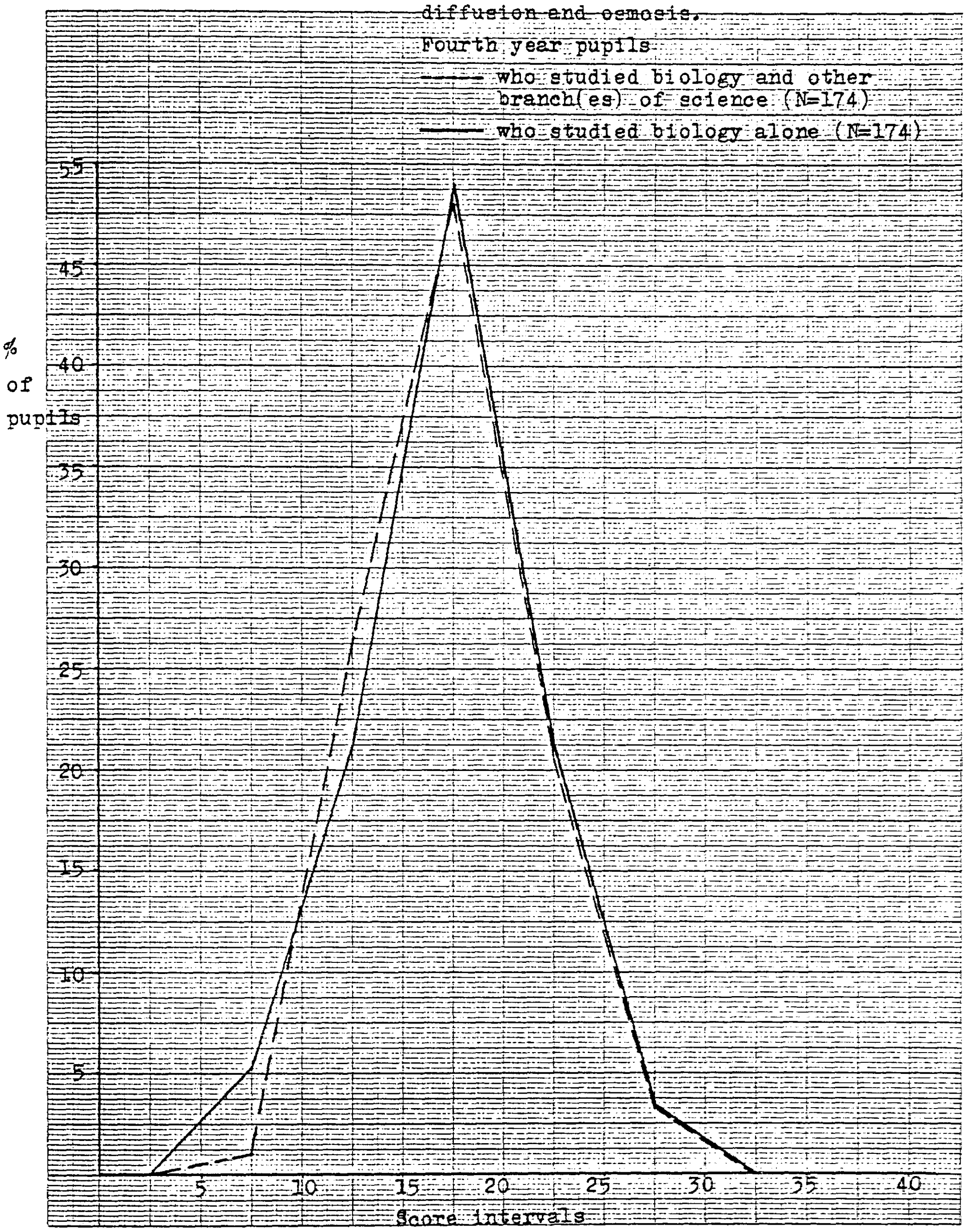


Figure 6.7.2.B Results of the test on diffusion and osmosis.

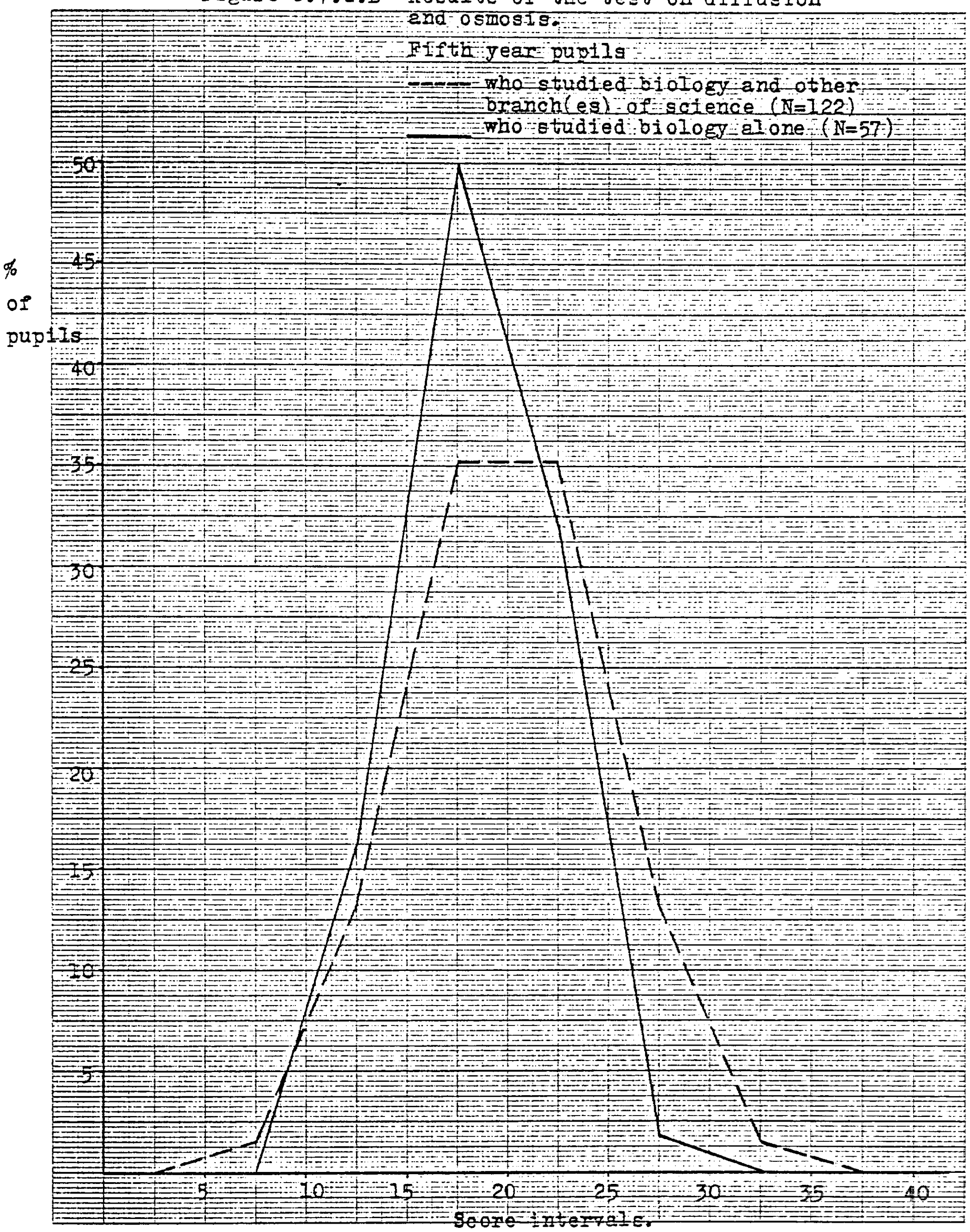
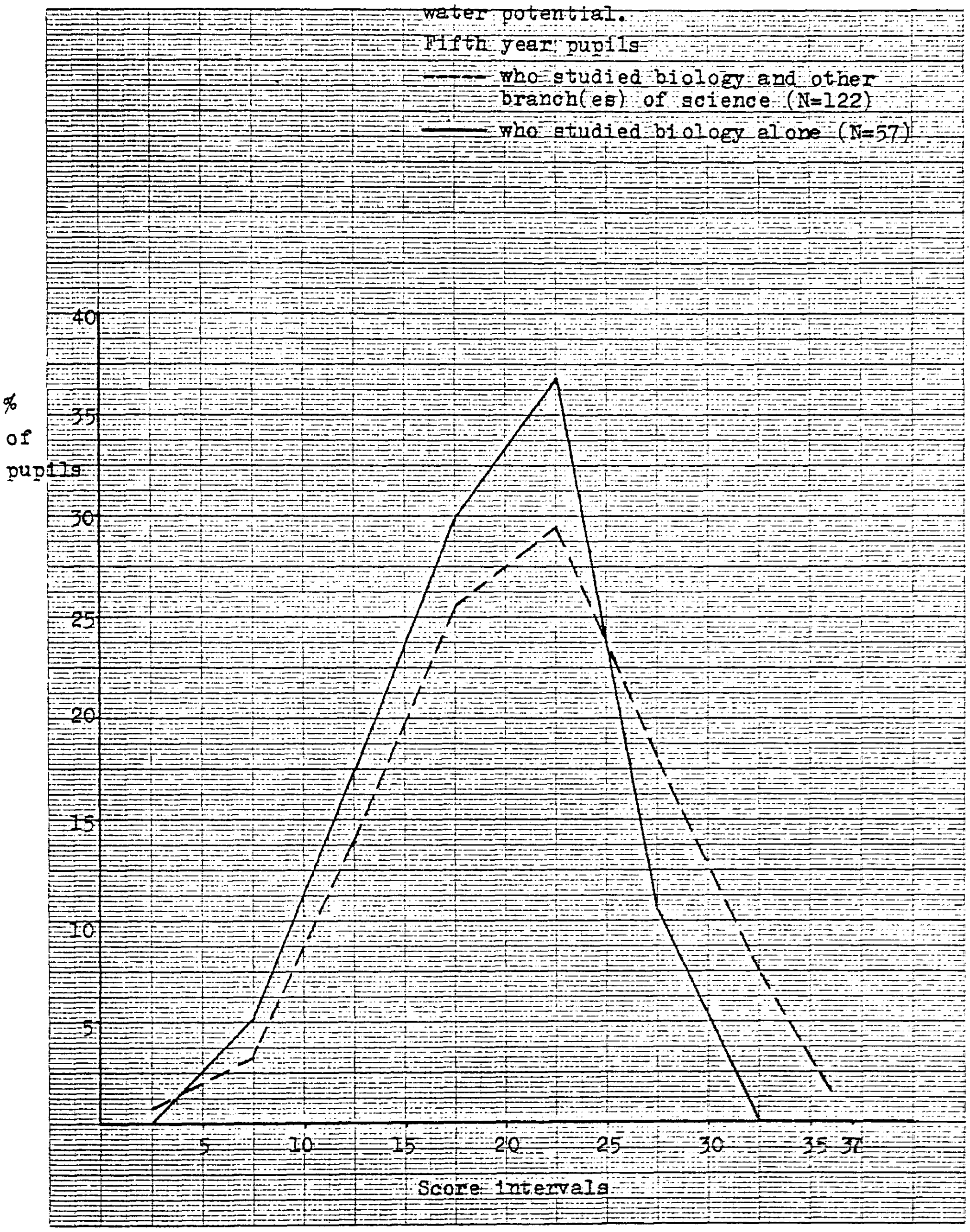


Figure 6.7.2.C Results of the test on water potential.



The third question raised for this stage was, "Is there any significant difference between the performance of boys and that of girls? From Tables Nos. 6.6.4.A through 6.6.4.F and Figures Nos. 6.7.2.D through 6.7.2.F, it appeared that there were some differences between the performances of these subgroups. In line with the argument explained above, it was believed that a valid conclusion with regard to such differences should be preceded by a firm experimental control. Again, it was found more fruitful to concentrate on the main line of the diagnostic study rather than branching through a less valuable ramification.

Figure 6.7.2.D Results of the test on diffusion and osmosis.

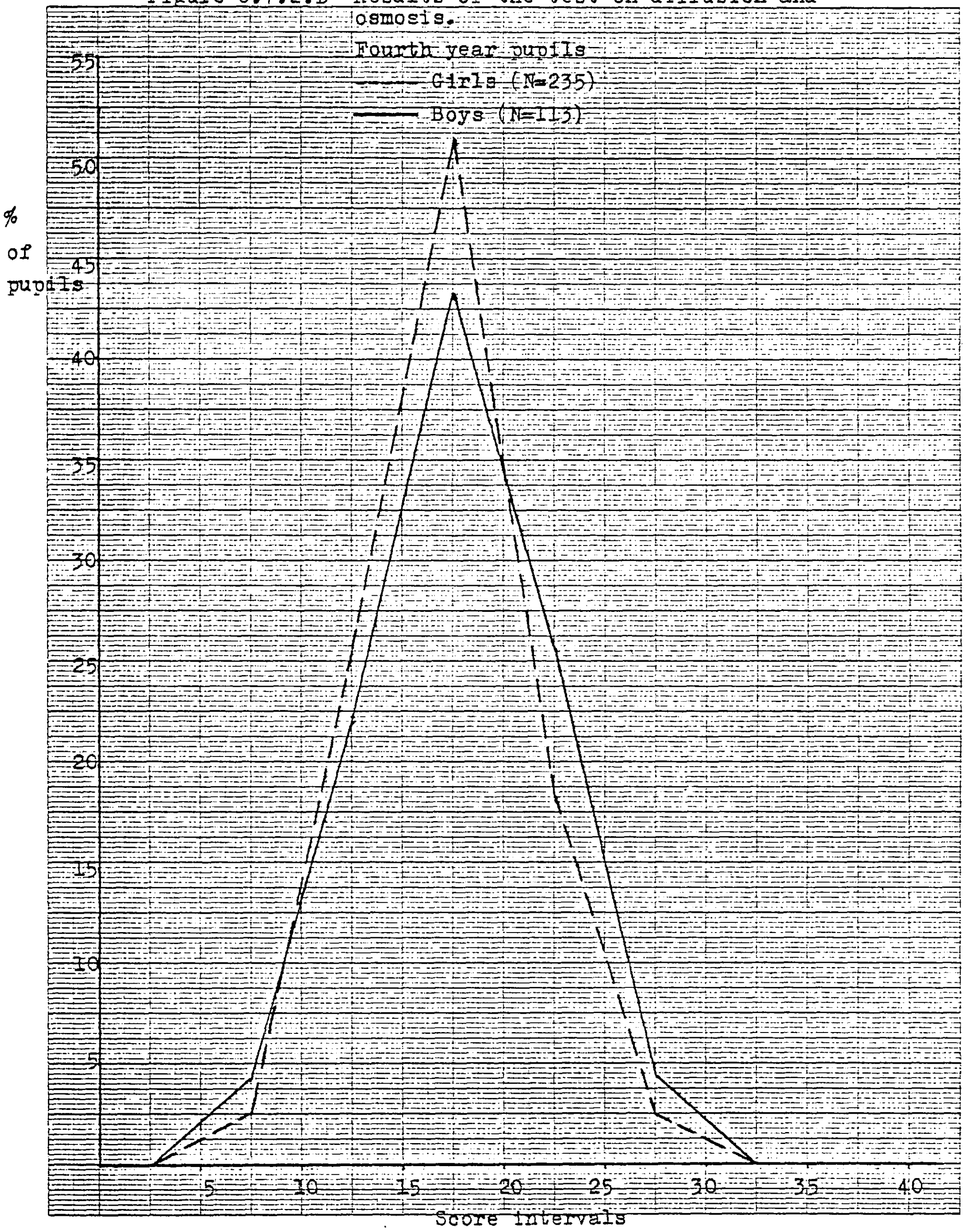


Figure 6.7.2.E Results of the test on diffusion and osmosis.

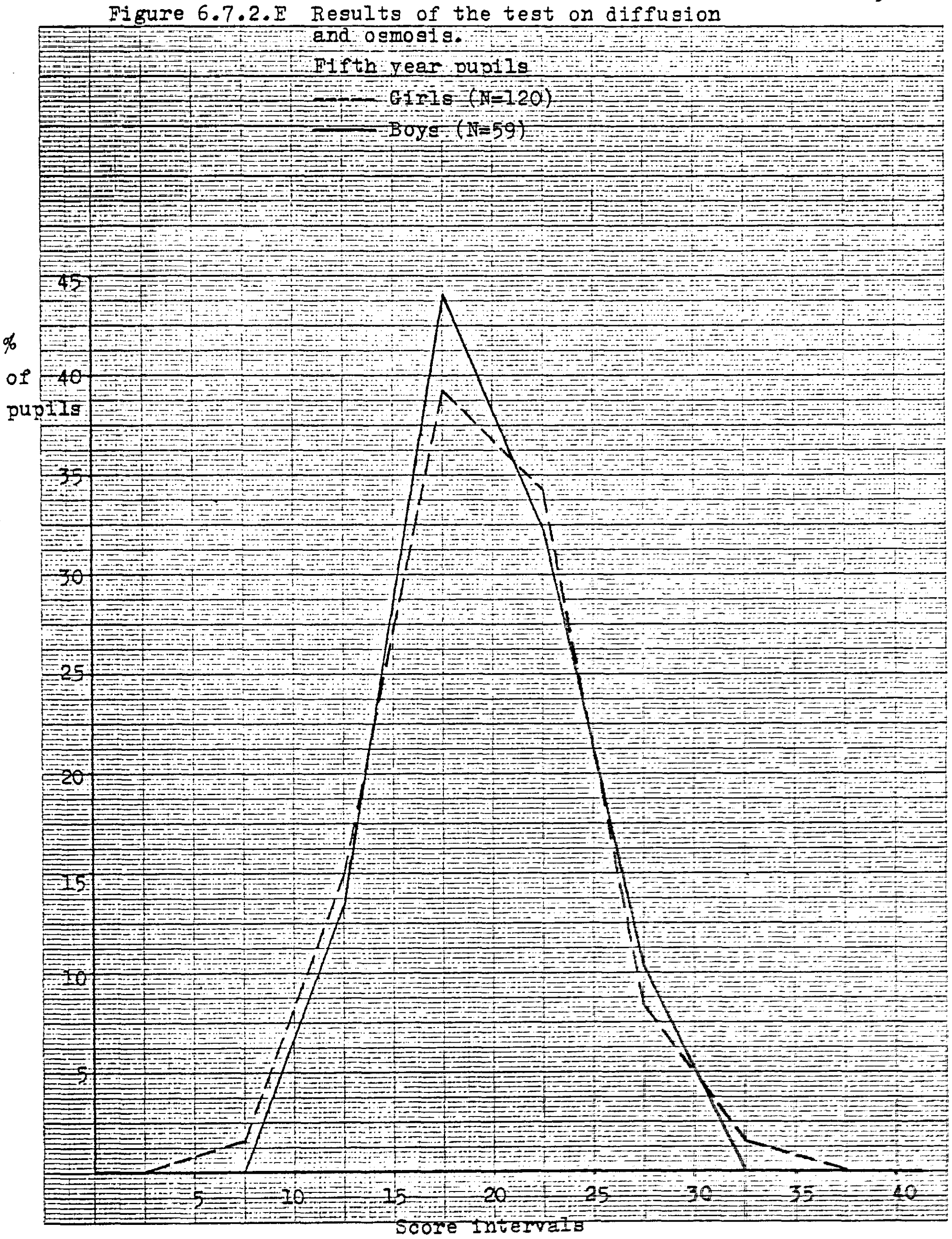
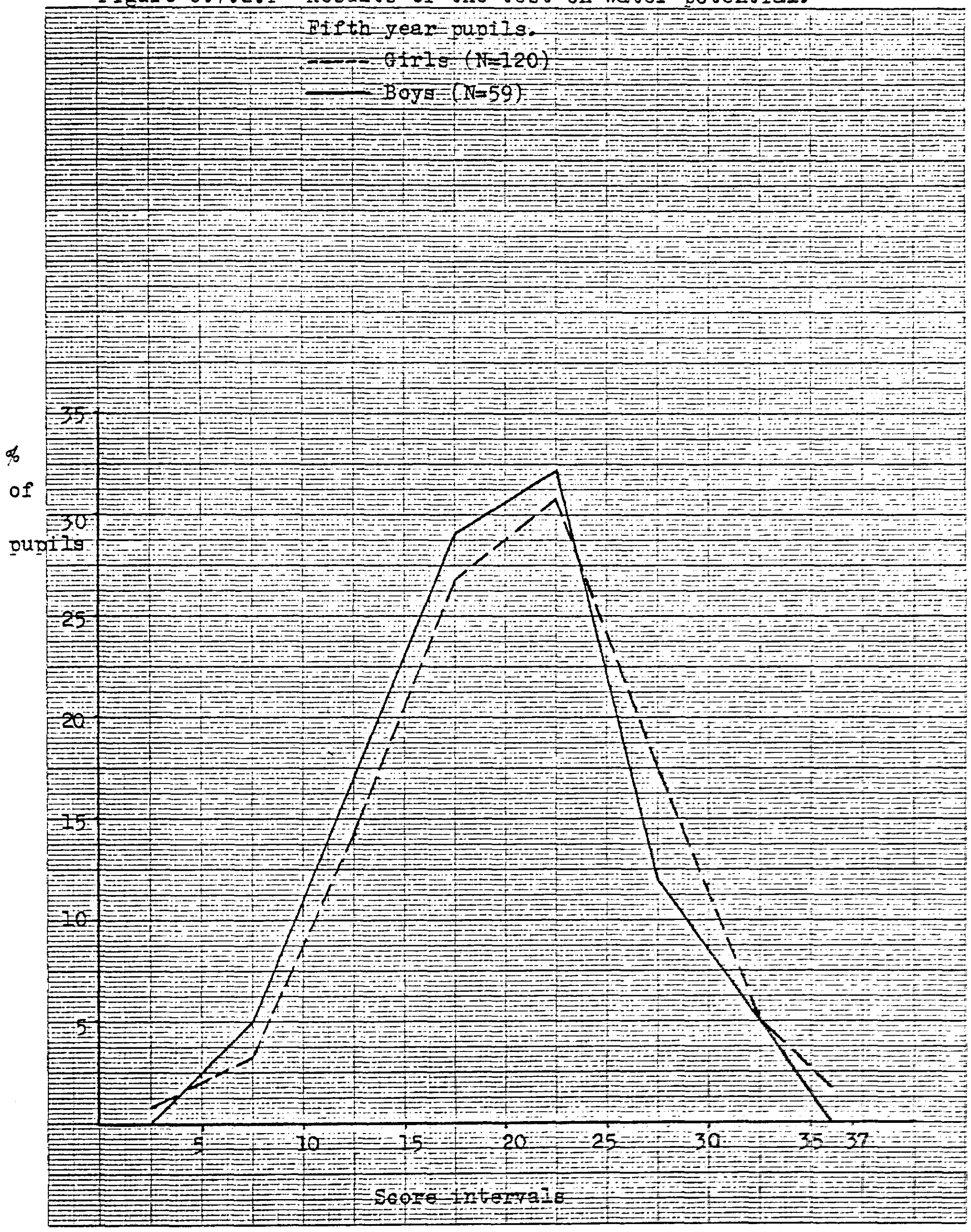


Figure 6.7.2.F Results of the test on water potential.



6.8 Factors contributing to the difficulty of the topics:

From what has been observed and discussed so far, one can attribute the difficulty of the topics to the following reasons:

1. The experience of every-day observations is not likely to provide pupils with sufficient knowledge and insight into these topics. Although pupils can observe the dissociation of a crystal placed in water, the gross movement of water from soil to plant or from a soaking water bath into dried piece of fruit, there would be no concrete clues to these phenomena at the molecular level.

2. The science courses in the earlier years of secondary schools do not furnish pupils with basic facts about the physical chemistry of water nor the behaviour of particles in osmosis.[139] The problem started from the assumption made by the biology course designers that the Integrated Science Course has covered the chemical concepts required for the understanding of the biology topics. Now, it became clear that the treatment of such concepts has not been sufficient for the meaningful learning of the topics. This is clearly demonstrated by "Section 5: solvents and solutions" on the I.S.C. In that section, far less than satisfactory attention is given to the molecular behaviour of water particles in solutions. The stress is laid on the diffusion of solid substances rather than on water itself. Needless to say, the understanding of osmosis and water potential depends largely on the missing knowledge. If it is intended not to overburden young pupils by such knowledge, it could have been a good point to include the missing knowledge in the biology courses for the grown up pupils of the fourth and fifth years. University biology books usually devote an introductory part to the discussion

of fundamental chemistry which is highly related to the proceeding biological concepts.

3. In the physical sciences, pupils are taught that things tend to move from where there is a higher potential to where there is a lower one. In biology they are taught that water travels from a cell with higher water potential to another with a lower one. Contrary to that, they are taught that water travels from a solution with lower osmotic potential to another with a higher one. This is because school biology books are adopting the confusing scheme where both osmotic pressure and potential were given identical values for the same solution. It would have been better, for the sake of consistency, if the new trend was adopted where osmotic potential is given the negative value of the osmotic pressure.[184] If a teacher is unwilling to do so, he should stress that osmotic potential is a property of the solute rather than of the solvent. In such a case, a better term, i.e. 'solute potential' should be used instead.[183]

4. The poor and superficial visual presentation associated with these topics must share in the responsibility for the difficulty. Learning abstract concepts should develop gradually through concrete experience. The very few experiments with visking tubing, thistle funnel and cubes of potatoes in solutions seem to be the only visual aids in use in the teaching of these topics. All of these aids are introducing the concepts at the macro level of treatment with no possibility of referring to what is going on at the micro level. The effect of solute on the free movement of water particles is one example of what cannot be observed through those experiments. Better advance organizers must be researched and used in addition to some laboratory investigations. Animated films could probably do the job perfectly well.

5. As pointed out earlier in Section 6.5 (the analysis of the topics), and Subsection 6.7.1 (the level of understanding reached by the pupils), the abstract nature of the ideas involved could be one of the major reasons of their difficulty. It is not always easy for every pupil to establish a correct picture about the spontaneous, random and continuous movement of water particles both ways between two systems, with different ratios of hindering solute particles leading to a difference in the rate of bombardment caused by the excess-free water particles. This is a very abstract situation, and the terminology of it is far removed from the concrete. In addition, the probabilistic reasoning is not always easy to perform since it requires abstract properties in unseen situations.(39)

6. The mathematical treatment, though simple still, adds some more to the difficulty of the study of water potential. As many of the pupils who study biology are not mathematically oriented, the computation with the handling of the negative values of (Ψ) could be confusing to them. The observed weakness of the pupils tested on this matter must call for the examination of the way in which these points are treated in biology classes. Numerical examples should be given to pupils, and the employment of the 'line of numbers' could serve as a good advance organizer in this respect.

7. Biology teachers seem not to be completely convinced of the factual structure of the topic of water potential. It has been an issue for debate and controversy among the majority of them. It was clear from their discussion with the researcher, and from their reports to the 'Joint Working Party' on the biology syllabuses that they wished something to be done to simplify that topic.(151) School textbooks and references have added more confusion to their understanding of the topic, since these books are adopting either an old, invalid

terminology (e.g. suction pressure, and diffusion pressure deficit), or an unmatched blend of old and new ones. In spite of the published memorandum,(185) and the organized training courses on the topic, they feel that their needs have not yet been met.

The last question stated for this stage (number 6 on the statement of the problem) was hopefully answered so far.

6.9 Conclusion of the diagnostic stage

From the analysis of the topics of diffusion, osmosis and water potential, one can realise that they are high information topics since many subordinate ideas and concepts are included in their body of knowledge.

It can also be noticed that most of these topics are highly abstract since their understanding requires dealing with molecules, ratios, several variables, probability of redistribution of molecules, negative values and relation between relations. This means that advanced formal thought is required for the understanding of most of the concepts included in these topics.

From the assessment of a considerable number of pupils through interviews and written tests, it was clear that both the fourth and fifth year pupils did not understand those topics up to the satisfactory level. They did not show understanding of the various ideas which are fundamental to the learning of the topics. Many of the pupils tend to recall the statements of rules without being able to explain what was taking place.

To Ausubel this level of achievement is not meaningful learning, since many of the relevant subsumers were missing from their cognitive structure. To Gagné it is not a complete learning, since the mastery of subordinate capabilities was not attained, nor was the ability to apply their knowledge to situations demonstrated. To Piaget it is not successful learning at the formal level of thought, since most of the abstract ideas were not learned and no correct picture of the abstract situations was established. The hypotheses stated for this stage were proved to be valid, and the relevant questions on the statement of the problem were answered satisfactorily so far.

CHAPTER SEVEN

Stage Three: The construction and Application of New Learning Materials

7.1 Rationale and Considerations

The implication from the theories of Ausubel, Gagné and others for teaching is clear: test the learner to determine whether he possesses the prerequisites for the learning of new concepts, and then provide him with those he does not possess.[100] From the analysis of the topics, the researcher was able to determine the prerequisites for the meaningful learning of those topics. From the assessment of the pupils' learning, he was able to identify which of those prerequisites was not possessed by the majority of the pupils.

Schafer and Byers (1975),[87] Linn and Thier (1975),[88] Lawson and Wollman (1976)[89] offered training on specified learning elements to pupils who were initially considered to be unable to develop good understanding of those elements and reported the achievement of reasonable learning outcomes by their sample pupils.

With regard to the present study, the researcher took into consideration the following points in order to offer a remedy for the revealed difficulty in learning the topics:

1. Knowledge of the relevant learning elements has to be provided to the pupils.
2. Sufficient visual experience relevant to the topics should be made available to the pupils to make the ideas more concrete.
3. Better appreciation of the chemical and physical contents of the topics should be attained by the biology teachers.

7.2 Determination of the New Learning Materials

Since one major reason for the difficulty of these topics was the lack of correct basic knowledge in the pupils' repertoire, it was clear that a printed material including all the missing subsumers would be required. And since the pupils were not able to construct for themselves a correct visual picture of the behaviour of the mobile water particles, it was clear that an animated film would also be required to illustrate this clearly to them.

7.3 The Preparation of the Printed Material

The researcher began by surveying the scientific subject matter of the topics as well as consulting the specialists among the teaching staff of the University of Glasgow. When he came to the stage of writing the material, he posed the following points for his own consideration:

1. The treatment of the subject should give priority to the learning elements which had been revealed to be missing, and to those which were presented badly in school textbooks.

2. The body of knowledge should develop from the understanding of the ideas and concepts on laboratory models to the understanding of them on a plant situation.

3. The treatment should be made suitable for the least able pupils. Information should be presented in small and separate points, and the body of knowledge should be gradually built from simpler to more complex.(113) As many diagrams as possible should accompany the written information in order to bring it much nearer to the senses. Where information load was in danger

of becoming large, a summary should be provided to help pupils to grasp the information in smaller and meaningful 'chunks'. Simple language should be used to introduce the scientific terms gradually. Misleading analogies should be avoided.(192)

4. The total amount of the printed material should be kept to a minimum to minimize the burden on pupils and to make the material acceptable by teachers.

All the above points were considered, and an eight-page unit was prepared. In addition to this, supplementary recapitulation and numerical treatment, with the help of the 'line of numbers', were incorporated on two additional pages. The first eight-page unit was called the 'standard' printed material, whereas the other two-page unit was called the 'additional' one. The reason for this plan was to check on the importance of providing the fifth year pupils with such extra numerical guidance. Appendix 7.3.A shows the 'standard' material, where Appendix 7.3.B shows the 'additional' one.

7.4 The Preparation of the Animated Film

The objective of that film was to provide pupils with visual concrete evidence by which they would be able to construct a correct mental picture of the concepts at the micro level of treatment.

While preparing the film, the researcher took into account the same points which were considered earlier while preparing the written material. University specialists, as well as an artist and film experts were consulted during the writing of the story board for the film. Due to the illness of the artist, tens of successive transparent animation sheets were prepared by the researcher himself. Different opaque backgrounds were also prepared to match the corresponding groups of transparencies. Stress was placed on the behaviour of water particles when free, when mixed with particles of dissolved substances, and when given the chance to cross semi-permeable membranes from two sides with different concentrations of solute. Numbers appeared from time to time to draw the attention of the viewers to the different concentrations of water particles at different sites. Short written phrases and labels appeared for similar reasons. Illustrations were included to demonstrate and explain the higher concepts of osmotic pressure and water potential in both laboratory and plant-soil situations. The film story was made in three parts to correspond with the three parts of the printed material mentioned before. The main points treated on the three parts of the film were as follows:

I. Dissolving and diffusion: this part demonstrates the following basic ideas:
   1 - The particulate nature of matter.
   2 - The formation of aqueous solutions.
   3 - The effect of the solute on water.
   4 - The diffusion of water and solute.

II. Osmosis: this part demonstrates the following ideas:
   1 - The concentration gradient.
   2 - The hindering effect of the solute on water.
   3 - Pressure inside solutions compared to that in pure water.
   4 - How water flows more readily from a pure water side to a solution side.
   5 - How osmotic pressure is generated in a solution.
   6 - The equilibrium state in osmosis.

These two parts are suitable for pupils doing biology at both 'O' and 'H' Grades.

III. Water potential: this final part demonstrates the following ideas and phenomena:

1 - The initial situation in roots and soil in terms of water concentration and osmotic properties
2 - How water flows more readily from the soil to the root.
3 - Recovery from plasmolysis, and return to turgidity in plant cells.
4 - Development of cell wall pressure and its effect on the inflow of water.
5 - The cell water potential as a result of the two major factors opposing each other.
6 - How water flows more readily from the root hair cell to the next cell.

This part is mainly intended for the fifth year pupils, but still of great value to the fourth year pupils as it informs them about the plant-soil-water relationships. with the application of what has been learned on the laboratory models on that situation.

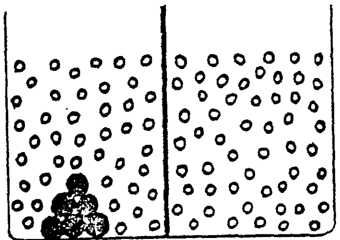
The transparencies with their backgrounds were used to prepare an animated film in colour on 16mm film at the Film Unit of the University of Strathclyde. This was done in conjunction with the TV-Centre of the University of Glasgow.

After editing, the running time was found to be fourteen minutes at twenty-four frames per second. This was considered a suitable time for both pupils and teachers as it would neither overburden the former nor occupy much of the lesson time. No sound commentary was made in order to allow every teacher to comment on and discuss every scene with his pupils according to their abilities.

A copy of the film accompanies this volume, and selected frames from the film are shown on Figure No. 7.4.A.

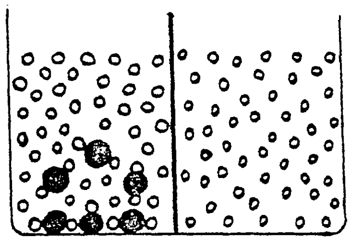
Figure No. 7.4.A Selected frames from the prepared film

Part One: Dissolving and diffusion:



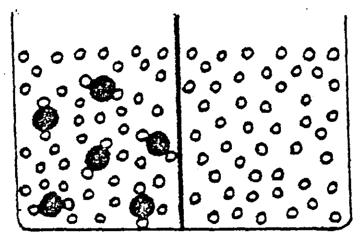
Frame 1

Water and salt | Pure Water



Frame 10

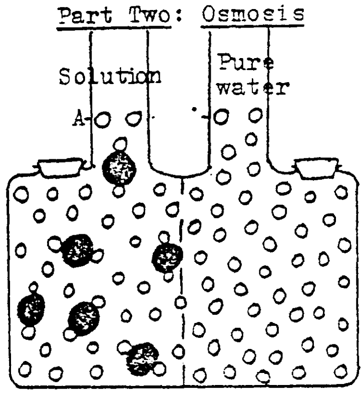
"Some minutes later"



Frame 15

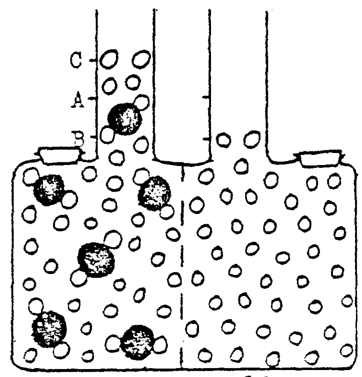
"Some hours later"

Part Two: Osmosis



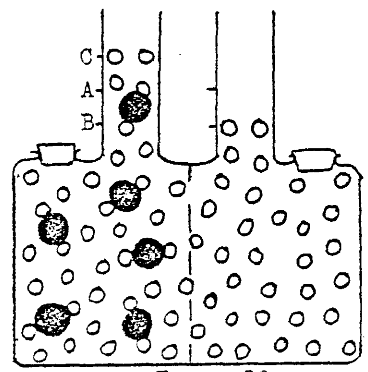
Frame 1

"Note the free-moving particles of water - both sides different. Compare their numbers within the two equal areas."



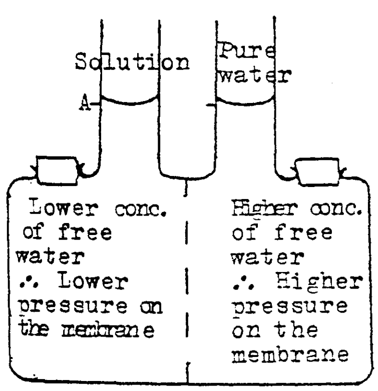
Frame 10

(After a period of movement) "Compare the numbers of immigrant particles within the two equal areas."



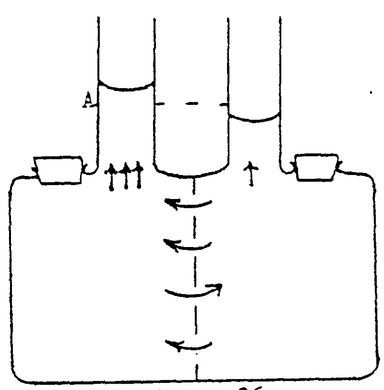
Frame 20

(Movement continues, with no net flow either side) "The balanced state."



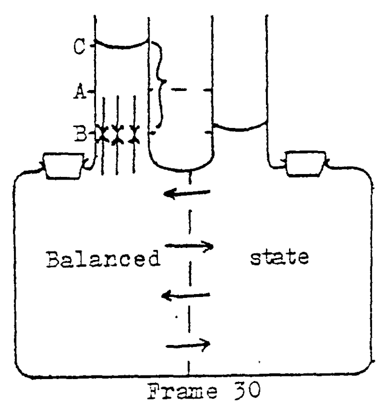
Frame 25

Diagrammatic representation of how osmotic pressure is generated.



Frame 26

Difference in concentration results in a difference in pressure, hence a difference in rate of flow.

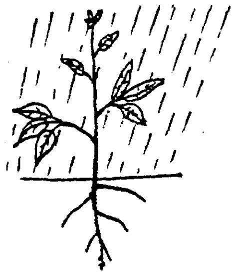


Frame 30

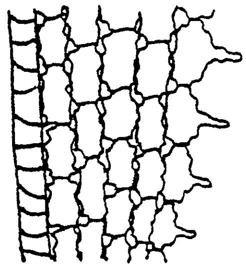
When pressure becomes equal on both sides, no net flow takes place.

(Continued)

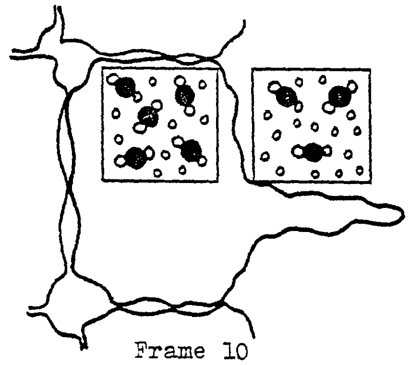
Part Three: Water potential:



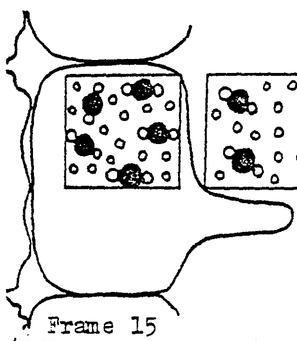
Frame 1
(Rain falling on a dry soil)



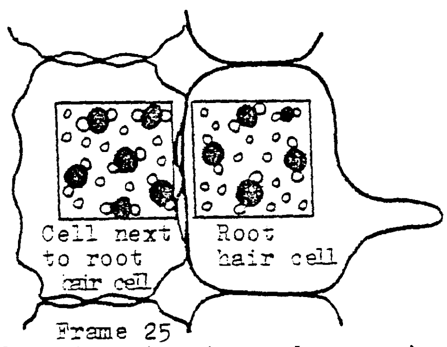
Frame 5
(Camera zooms in to root hair cells)



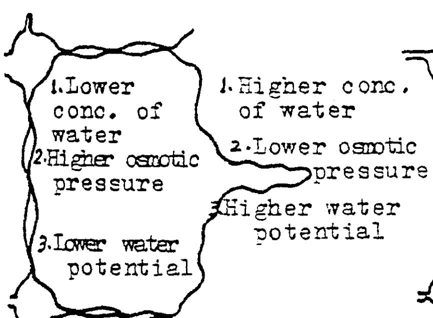
Frame 10
"Note the free-moving particles of water - both sides different. Compare their nos. within the two equal areas."



Frame 15
(After a period of movement)
"Compare the nos. of immigrant particles with the two equal areas.

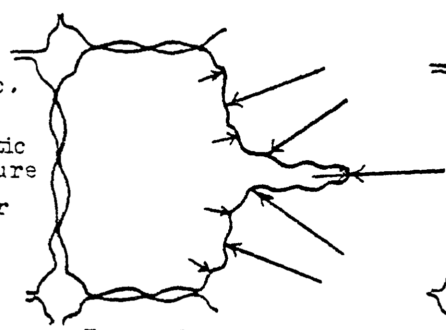


Frame 25
(Counting, tracing and comparing the free-moving particles of water as before)

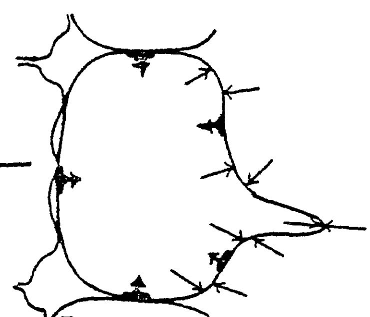


Frame 26.
(Initial situation)

Diagrammatic representation of how water enters root cells.



Frame 27



Frame 30

More water flows into than from the cell.
Results: 1. Osmotic pressure decreases. 2. Cell volume increases. 3. Cell wall stretches (turgor commences). 4. Cell wall reacts by increasing inward pressure. 5. Cell water potential increases until it equals the soil water potential. 6. Equal amounts of water flow in and out. (Whole sequence repeated between r.h.c. and the cell next to it.)

7.5 The Early Try-Out of the New Materials

In order to investigate the suitability of these materials in classroom situations and to get a preliminary idea about their efficiency, one of the schools was approached to arrange for a preliminary showing to a limited number of pupils (one fourth year and one fifth year group). The trial groups were given the printed material to study, and a week later the film was shown to them and discussed by their teachers in the presence of the researcher. Questions were raised for the pupils, and their responses were noted. Good understanding of the factual contents was demonstrated by these trial groups, but it was believed that a second showing would be needed for some of the pupils.

In general, the result was encouraging and the materials were considered to be satisfactory in fulfilling their objectives.

7.6 The Preparation of a Teacher's Guide

In view of the experience gained through the pilot trial, the researcher prepared a teacher's guide to the new materials in which the following points were discussed:

1. The need for the new materials.
2. Objectives of those materials.
3. Contents of the film and the levels for which each part is suitable.
4. A suggested sequence of presentation.

Appendix 7.6.A shows a copy of that guide.

7.7 The Employment of the New Materials

Personal visits were paid to the same eight schools which participated earlier in the diagnostic stage, and samples of the printed material were introduced to all biology teachers in those schools. The researcher emphasised the reliability of the factual content of that material and how it was constructed through several consultations with the University specialists. He also demonstrated how it would not place any undue burden on the pupils, with regard to the expected benefits to be gained. He also showed how the contents are completely fitting to the syllabus requirements. A quick survey of the contents was carried out with each group of teachers, and the samples of the material were left with them for further reading. A week or so later, the researcher showed the film to the same teachers, and discussed it carefully. After being sure that they were convinced of the factual contents and the potential benefits of the new materials, the researcher suggested the following instructions:

1. Printed notes are to be distributed among the pupils a day or two before the day of the projection. Pupils have to be advised to review the relevant facts previously studied in separate or integrated sciences which would be of great help to them later on.

2. A discussion is to follow after this and immediately before the projection. The aim is to reinforce their understanding of the basic factual ideas and to prepare them for the film.

3. A silent showing of the film is to follow, with no commentary or questions from all sides. This would help every individual pupil to grasp as many ideas as possible of his own accord.

4. A discussion of what has been on the screen is recommended at this point in order to receive their

reaction and to evaluate the benefit they manage to get out of it. The teacher will need to draw their attention to some ideas concealed from them.

5. A second projection of the film with the teacher's comments is needed at this point. It would be far better if the projection is stopped from time to time to enable the teacher to give a longer talk on some points. The pupils will be able to note every feature on the film and receive the message completely.

6. The pupils' time for enquiry and asking for further explanations is to follow. This would help each pupil to remove any conflict between his old background and his new experience. Their understanding of the topic will be much clearer with this enquiry.

7. The teacher's time for asking questions is suitable at this stage. He could decide whether it is necessary to make a third projection or not. He may find it reasonable to highlight some key points or to refer to some hints which appeared on the screen in order to rectify the understanding of one or more of his pupils.

N.B. Laboratory experiments relevant to these topics are recommended to be carried out prior to the first showing of the film. The film and the discussion that would accompany its showing would furnish the pupils with the explanations for what they have studied earlier in the laboratory.

When time for teaching the topics in each school was almost due, the researcher provided the principal teacher with a copy of the film. Four of those eight schools were provided only with the 'standard' eight-page printed material, while the other four schools were provided, in addition to that, with the 'additional' two-page material. The choice was made according to the similarity between the two groups of schools, based on the performances in the previous year of their pupils on the diagnostic test. Teachers in the eight schools were asked to employ both the film and the printed material in classes similar in ability to those used for diagnosis on the previous year.

7.8 Teachers' Opinions about the New Learning Materials

The researcher investigated how teachers felt about the new materials. During initial discussions about the film when it was first introduced to teachers, their reactions were quite encouraging. They expressed their appreciation of using an animated pictorial aid to the demonstration of the water particles behaviour in solutions and between cells. They also appreciated providing pupils with printed material to go with the film. However, two groups of teachers out of the eight groups expressed their apprehension that it would overburden pupils to take them back to the chemical and physical foundations of the topics. Their reasons rested on the fact that such foundations are not explicitly included in the biology courses, therefore pupils, especially the less able ones, would not find it necessary to take the trouble of paying attention to these foundations. Nevertheless, the researcher explained the necessity of those parts for the real understanding of the topics and requested full support for the materials from the teachers' side. He also constructed a questionnaire and asked the teachers to complete copies of it when the use of the materials in their classes was finished. Eighteen teachers answered that questionnaire. Appendix 7.8.A shows the contents as well as the data obtained from it.

Discussion of the teachers' opinions:

One would expect in advance that teachers would respond differently to a new approach being suggested for a troublesome area in the syllabus. This is due to their different pedagogical views and level of appreciation to the involvement of chemical and physical facts in biology. Differences in the pupils' abilities and motivations from one class to another would also affect the teachers' reception to the factual contents of a new learning material. As appeared from Appendix No. 7.8.A, all teachers included in the experiment agreed with the factual contents of the new material as such. However, a few of them showed a little apprehension. This apprehension was based on the new ideas brought in the material about the dissolving process and osmotic pressure. Others considered the film very helpful for thoughtful pupils, but too full for less able pupils. Some teachers remarked that with the repetition of the film show, they managed to solve the problem for poor pupils. As for the screen treatment of the ideas, some teachers noted that the part on diffusion was too long, while the parts on osmosis and water potential were worthy of longer treatment. They felt that a taped commentary would be of greater help. In fact, the researcher intended to devote a good deal of treatment to the fundamental part on diffusion in order to facilitate the understanding of the parts to follow. He left to teachers the responsibility of explaining what was happening on the screen to meet the various levels of learning abilities of their pupils. He believed that it was sufficient to discuss the contents with the teachers themselves when he introduced and showed the film to them first. However, it seemed later that their suggestion was correct in assuring the basic conformity in the learning of the various ideas. The most disappointing comment was that some teachers considered the presentation of the fundamental facts drawn from chemistry and physics was unnecessary, since they are not examinable pieces at the end of the years. This reflects the effect of external examinations on the classroom instruction.

With regard to pupils' reactions to the new materials, teachers remarked that a fair amount of extra explanation was required. This was understandable, especially with the part on water potential, since the material dealt with ideas which were not included in school biology books. Pupils were mostly able to link the ideas explained by the film to their previous knowledge. No confusion was reported with regard to the part on diffusion, whereas a little confusion was reported in the case of osmosis and water potential. The printed material was largely accepted by pupils, with few reservations when the part on water potential was considered. One can feel the reflection of the teachers' tension about the new approach since it took them far away from the one to which they have been using over the years. This would suggest that more contact should be made between biology teachers and their colleagues in the departments of chemistry and physics. However, some energetic teachers informed the researcher that they had already consulted the chemists and physicist and held discussions around the new materials. Since they became completely convinced of the factual contents, they showed their appreciation of that new approach. Some teachers also remarked that they had found the new idea about the nature of osmotic pressure was completely helpful as a key point to the whole question of osmosis and water potential. In general, teachers were most satisfied, but more time and efforts are required for some of them.

CHAPTER EIGHT

Stage Four: The Assessment of Learning as a Result of the New Materials.

8.1 Problem and Hypothesis

It was assumed earlier in this study that once the weak points in the pupils' cognitive structure were uncovered, specially designed learning materials could help pupils to develop better understanding of the topics. At this stage, the researcher put forward the following hypothesis:

"If the new learning materials were used by a group of pupils they would show better understanding of the topics than that shown by the group which did not use those materials, provided that the two groups are otherwise alike."

8.2 Method and Underlying Assumption

The hypothesis was tested by using the same diagnostic tests as had been used in the previous year. The numbers of the 'new materials' pupils tested were 291 from the fourth and 153 from the fifth years of the same schools as had been used in the previous year.

It was assumed that a fair comparison could be made between the 'new materials' group and the 'original' group of the previous year. That assumption was based on the following grounds:

1. Similarity in the schools' intake of pupils: According to the administrative regulations in effect, every secondary school has its own catchment area and connections with certain primary schools in its surroundings. Accordingly, it is reasonable to assume that a specified secondary school receives pupils of

similar abilities in two successive years of admission. Moreover, when pupils move up from year I to year IV and V, they become completely affected by the type of teaching used in that school, hence differences between the intake of one year and the next will be small. For more precision, the researcher requested the principal teachers to exclude from the post-test stage any classes which were different in their biological ability from those who participated in the diagnostic stage in the previous year. To be sure of that, the researcher compared the scores of the 'original' and the 'new materials' samples on the preliminary tests of biology held in their schools. Since every school constructs its own test, the comparison was made for each school separately. Table No. 8.2.A shows the comparison.

TABLE 8.2.A

(i) Fourth year samples:

School ser. no.	'Original' samples (N=348)			'New materials' samples (N=291)			't' for difference in mean	Significance
	No. of pupils	Mean score	S.D.	No. of pupils	Mean score	S.D.		
1	31	56.7	17.6	25	56.2	17.7	0.10	Not sig. at 5%
2	23	39.1	14.0	20	38.0	13.4	0.23	" " " "
3	19	48.1	17.9	14	46.2	16.6	0.30	" " " "
4	66	68.2	10.9	53	68.1	11.8	0.02	" " " "
5	39	47.8	16.2	31	49.0	15.1	0.30	" " " "
6	71	51.3	15.9	60	50.9	16.7	0.14	" " " "
7	22	54.1	16.6	20	50.2	17.7	0.71	" " " "
8	77	50.8	14.5	68	51.8	13.7	0.40	" " " "

Continued.....

TABLE 8.2.A (Continued)

(ii) Fifth year samples:

School ser. no.	'Original' samples (N=179)			'New materials' samples (N=153)			't' for difference in mean	Significance
	No. of pupils	Mean score	S.D.	No. of pupils	Mean score	S.D.		
1	27	56.3	9.7	23	58.6	10.9	0.75	Not sig. at 5%
2	7	55.7	13.3	6	48.3	18.1	0.80	" " " "
3	24	38.4	15.9	20	36.0	16.1	0.49	" " " "
4	29	53.7	10.2	25	55.0	9.9	0.46	" " " "
5	19	54.8	18.3	16	57.4	14.3	0.48	" " " "
6	30	54.7	14.8	25	53.7	18.5	0.23	" " " "
7	6	56.4	12.7	5	50.4	18.3	0.59	" " " "
8	37	50.7	9.9	33	51.4	10.8	0.29	" " " "

2. Consistency in representation:

The ratio by which each school contributed to the 'original' and the 'new materials' groups were almost the same in both. Table No. 8.2.B below shows this consistency:

TABLE 8.2.B

(i) Fourth year samples:

School ser. no.	'Original' samples (N=348)		'New materials' samples (N=291)	
	N	% in sample	N	% in sample
1	31	8.9	25	8.6
2	23	6.6	20	6.9
3	19	5.5	14	4.8
4	66	18.9	53	18.2
5	39	11.2	31	10.7
6	71	20.4	60	20.6
7	22	6.3	20	6.8
8	77	22.2	68	23.4

(ii) Fifth year samples:

School ser. no.	'Original' samples (N=179)		'New materials' samples (N=153)	
	N	% in sample	N	% in sample
1	27	15.1	23	15.0
2	7	3.9	6	3.9
3	24	13.4	20	13.1
4	29	16.2	25	16.3
5	19	10.6	16	10.5
6	30	16.8	25	16.3
7	6	3.3	5	3.3
8	37	20.7	33	21.6

3. Consistency in the internal structure of the two groups: With regard to 'boys-girls' ratio, the application of chi-square test for distributions showed the absence of any significant difference between these distributions. Tables Nos. 8.2.C and 8.2.D below illustrate this observation.

TABLE 8.2.C

(i) Fourth year groups:

Observed frequencies (fo):

Group	Boys	Girls	Total
'Original' group	113	235	348
'New materials' group	96	195	291
Total	209	430	639

Expected frequencies (fe):

Group	Boys	Girls
'Original' group	113.8	234.2
'New materials' group	95.2	195.8

Differences (fo-fe):

0.8	0.8
0.8	0.8

$$\chi^2 = \frac{0.8^2}{113.8} + \frac{0.8^2}{234.2} + \frac{0.8^2}{95.2} + \frac{0.8^2}{195.8} = 0.019.$$

Looking up in the tables for critical values of χ^2 under one degree of freedom $[(2-1)(2-1)]$, one finds that the value required for the 1% level of significance is 6.64. Since the computed χ^2 is smaller, this suggests the validity of the null hypothesis, i.e. there was no significant difference between the two distributions.

TABLE 8.2.D

(ii) Fifth year samples: Observed frequencies:

Group	Boys	Girls	Total
'Original' group	59	120	179
'New materials' group	49	104	153
Total	108	224	332

Following the same procedure, one finds that the computed $\chi^2 = 0.03$ is not significant at 1%. This also reveals no significant difference between these two distributions.

With regard to the ratio between those who studied biology alone and those who studied it in addition to one or more of the physical sciences, no significant differences were revealed by the application of the χ^2 test to the relevant distributions. Table No. 8.2.E below shows this observation.

TABLE 8.2.E

(i) Fourth year samples: Observed frequencies:

Group	Studied biology alone	Studied biology plus one or more science	Total
'Original'	174	174	348
'New Materials'	137	154	291
Total	311	328	639

Computed $\chi^2 = 0.53$, not significant at 1% level.

(ii) Fifth year samples: Observed frequencies:

Group	Studied biology alone	Studied biology plus one or more science	Total
'Original'	57	122	179
'New Materials'	33	120	153
Total	90	242	332

Computed $\chi^2 = 4.43$, not significant at 1% level.

4. Similarity in performance on marker questions: The new learning materials did not treat the idea No. 7 of the plant-soil situation, i.e., "Manifestations of diffusion and osmosis in the plant and its surroundings." Questions Nos. 39 and 40 on the first test were based on that idea. The comparison of the 'original' group with the 'new materials' group, with regard to their performances on those questions, revealed later that there was no significant difference between those groups in that respect. This observation will be discussed in a following section.

Being satisfied that both the 'new materials' and the 'original' groups had been drawn from the same population in statistical terms, the researcher was able to compare the performances of the two.

8.3 Results of the 'New Materials' Group

The answers of the new group of pupils were marked and scored exactly in the same manner as before, and the results were tabulated as shown below. These results will be compared with those obtained at the diagnostic stage.

Tables Nos. 8.3.A through 8.3.H show the results of the 'new materials' groups.

TABLE NO. 8.3.A

Results of the fourth year pupils on the diffusion and osmosis test - laboratory situations

Ser. no. of idea	Idea	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=137	Biol. + other science(s) N=154	Boys N=96	Girls N=195	All pupils N=291	
1	Spontaneous movement of water particles	81.8	89.6	82.3	87.7	85.9	15
2	Random movement of water particles	70.8	79.9	66.7	80.0	75.6	13
3	Continuous movement of water particles	55.5	60.4	47.9	63.1	58.1	6
4	Leading role of water particles	62.8	74.1	68.8	68.7	68.7	9
5	Dependent movement of solute particles on the movement of water particles	68.6	85.1	78.1	76.9	77.3	14
6	Combined movement of water and solute particles	70.1	74.7	70.8	73.3	72.5	12
7	Attraction between particles of water and particles of solute inside solutions	42.3	53.9	38.5	53.3	48.5	4
8	Concentration of water v. conc. of solute	62.8	76.6	67.7	71.3	70.1	11
9	Rule of diffusion with regard to the solute particles	67.9	70.1	68.8	69.2	69.1	10
10	Rule of diffusion with regard to the water particles	59.1	57.8	49.0	63.1	58.4	7
11	Effect of solute on the free movement of the particles of water	50.4	57.8	52.1	55.4	54.3	5
12	Probability in the redistribution of the particles of water	33.6	46.8	44.8	38.5	40.5	2
13	Direction of water flow between solutions	31.4	57.8	42.7	46.7	45.4	3
14	Pressure of the free particles of water inside solutions	52.6	68.8	54.2	64.6	61.2	8
15	Balanced state between solutions with different concentrations of solute	16.8	22.1	16.7	21.0	19.5	1

TABLE NO. 8.3.B

Results of the fourth year pupils on the diffusion and osmosis test - plant-soil situation

Ser. No. of idea	Idea	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=137	Biol. + other science(s) N=154	Boys N=96	Girls N=195	All pupils N=291	
1	Initial differences between the soil and plant solutions	43.1	59.1	38.5	58.0	51.5	7
2	Initial situation of water in the soil and plant solutions	38.7	42.2	31.3	45.1	40.5	6
3	Initial situation of solutes in the soil and plant solutions	30.7	37.0	38.5	31.8	34.0	4.5
4	Effect of solutes on the flow of water between the soil and plant solutions	27.0	40.3	39.6	31.3	34.0	4.5
5	Osmotic pressure of the soil and plant solutions	32.1	28.6	36.5	27.2	30.2	2
6	Cell wall pressure and the flow of water from the soil to the plant solutions	32.1	29.9	31.3	30.8	30.9	3
7	Manifestations of diffusion and osmosis in the plant and its surroundings	29.2	20.8	27.1	23.6	24.7	1

TABLE NO. 8.3.C

Results of the fifth year pupils on the diffusion and osmosis test - laboratory situations

Ser. no. of idea	Idea	% of pupils who responded correctly					
		Doing biology alone N=33	Biol.+ other science(s) N=120	Boys N=49	Girls N=104	All pupils N=153	Rank of idea according to difficulty
1	Spontaneous movement of water particles	87.9	85.8	87.8	85.6	86.3	15
2	Random movement of water particles	90.9	83.3	77.6	88.5	85.0	14
3	Continuous movement of water particles	63.6	73.3	77.6	68.3	71.2	9
4	Leading role of water particles	75.8	62.5	61.2	67.3	65.4	7
5	Dependent movement of solute particles on the movement of water particles	75.8	75.8	79.6	76.0	77.1	12.5
6	Combined movement of water and solute particles	75.8	68.3	61.2	74.0	69.9	8
7	Attraction between particles of water and particles of solute inside solutions	60.6	50.0	42.9	56.7	52.3	4
8	Concentration of water v. conc. of solute	66.7	78.3	75.5	76.0	75.8	11
9	Role of diffusion with regard to the solute particles	66.7	75.0	75.5	72.1	73.2	10
10	Role of diffusion with regard to the water particles	51.5	66.7	63.3	63.5	63.4	6
11	Effect of solute on the free movement of the particles of water	42.4	50.0	59.2	43.3	48.4	3
12	Probability in the redistribution of the particles of water	36.4	41.7	42.9	39.4	40.5	2
13	Direction of water flow between solutions	57.6	58.3	67.4	53.9	58.2	5
14	Pressure of the free particles of water inside solutions	78.8	76.7	81.6	75.0	77.1	12.5
15	Balanced state between solutions with different concentrations of solute	27.3	37.5	49.0	28.9	32.3	1

TABLE NO. 8.3.D

Results of the fifth year pupils on the diffusion and osmosis test - plant-soil situation

Ser. no. of idea	Idea	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=33	Biol.+ other science(s) N=120	Boys N=49	Girls N=104	All pupils N=153	
1	Initial differences between the soil and plant solutions	69.7	80.8	81.6	76.9	78.4	7
2	Initial situation of water in the soil and plant solutions	63.6	65.8	63.3	66.4	65.4	6
3	Initial situation of solutes in the soil and plant solutions	48.5	49.2	55.1	46.2	49.0	4
4	Effect of solutes on the flow of water between the soil and plant solutions	48.5	50.8	59.2	46.2	50.3	5
5	Osmotic pressure of the soil and plant solutions	36.4	37.5	28.6	41.4	37.3	2
6	Cell wall pressure and the flow of water from the soil to the plant solutions	48.5	48.3	51.0	47.1	48.4	3
7	Manifestations of diffusion and osmosis in the plant and its surroundings	15.2	11.7	12.2	12.5	12.4	1

TABLE NO. 8.3.E

Results of the fifth year pupils on the water potential test - laboratory situations

Ser. no. of idea	Idea	% of pupils who responded correctly					Rank of idea according to difficulty
		Doing biology alone N=33	Biol.+ other science(s) N=120	Boys N=49	Girls N=104	All pupils N=153	
16	Effect of solute concentration on the osmotic pressure of solutions	60.6	45.0	38.8	52.9	48.4	4
17	Effect of solute conc. on the amount of free particles of water causing pressure in solutions	72.7	79.2	73.5	79.8	77.8	14
18	Effect of the amount of solute on the osmotic potential of a solution	72.7	67.5	67.4	69.8	68.6	11
19	Effect of solute conc.on the osmotic potential of solutions	45.5	57.5	71.4	47.1	54.9	6
20	Effect of water inflow on the cell wall pressure	87.9	80.0	81.6	81.7	81.7	16
21	Differences in osmotic properties between pure water and solutions	69.7	57.5	63.2	58.7	60.1	9
22	Effect of amount of solute on the water pot.of a solution	60.6	75.8	85.7	66.4	72.5	13
23	Effect of solute conc.on the water pot. of solutions	42.4	65.8	71.4	55.8	60.8	10
24	Effect of solute conc.on the direction of water flow between solutions	69.7	80.8	75.5	79.8	78.4	15
25	Computation of (Ψ) from its components	72.7	71.7	69.4	63.5	71.9	12
26	Ranking (Ψ) values to identify the highest	45.5	45.8	38.8	49.0	45.8	2
27	Ranking (Ψ) values to identify the lowest	57.6	53.3	49.0	56.7	54.2	5
28	Significance of (Ψ) values as an indication of the relative conc. of the free particles of water	54.5	59.2	69.4	52.9	58.2	8
29	Significance of (Ψ) components as an indication of the state of cells	36.4	37.5	42.9	34.6	37.2	1
30	Significance of (Ψ) components as an indication of water gain and loss from cells	30.3	52.5	51.0	46.2	47.7	3
31	Direction of water flow between cells and between cells and pure water	45.5	60.8	55.1	58.7	57.5	7

TABLE NO. 8.3.F

Results of the fifth year pupils on the water potential test - plant-soil situation

Ser. no. of idea	Idea	% of pupils who responded correctly: Doing biology alone N=33	Doing biology + other science(s) N=120	Boys N=49	Girls N=104	All pupils N=153	Rank of idea according to difficulty
8	Differences in osmotic properties between the soil and plant solutions	45.5	47.5	49.0	46.2	47.1	1
9	Direction of water flow as an indication of differences in water potential between root cells	69.7	61.7	57.1	66.4	63.4	4.5
10	Direction of water flow as an indication of differences in solute concentrations between root cells	57.6	52.5	61.2	50.0	53.4	2
11	Direction of water flow as an indication of differences in cell wall pressure between root cells	72.7	60.0	55.1	66.4	62.7	3
12	Direction of water flow as an indication of the relation between the concentration of free particles of water and the osmotic pressure of the plant and soil solutions	69.7	45.0	59.2	65.4	63.4	4.5

TABLE NO. 8.3.G

Results of the pupils who answered the essay question

Score	Fourth year pupils N=253 (out of 291)		Fifth year pupils N=137 (out of 153)	
	N	%	N	%
0	26	10.3	6	4.4
1	68	26.9	12	8.8
2	44	17.4	10	7.3
3	101	39.9	46	33.6
4	14	5.5	41	29.9
5	0	0.0	22	16.0

TABLE NO. 8.3.H

Results of counting the numbers of pupils who were able to determine the direction of water flow between solutions (idea 13) as well as other subordinate ideas

Accumulation of ideas	% of pupils who understood that accumulation of ideas	
	Fourth year pupils (N=291)	Fifth year pupils (N=153)
1 through 13	5.8	9.2
2 " 13	5.8	9.2
3 " 13	5.8	9.2
4 " 13	6.5	9.2
5 " 13	6.5	9.2
6 " 13	6.5	9.8
7 " 13	6.5	9.8
8 " 13	7.9	13.7
9 " 13	8.6	15.7
10 " 13	10.7	17.0
11 " 13	14.4	21.6
12 " 13	20.3	26.1

8.4 Comparison of the Performance in Terms of the Obtained Scores

The main interest of the researcher was to investigate the extent to which pupils had shown mastery of the concepts. The distribution of a group of pupils on a test score intervals could yield a good indication of their mastery of the topics. On this basis, the researcher constructed figures nos. 8.4.A through 8.4.D to compare the general performance of the 'new materials' group with that of the 'original' one.

When the t-test for the difference in mean scores was employed, the fourth and the fifth year pupils of the 'new materials' group were found to be superior in performance over the corresponding pupils of the 'original' group.

In order to investigate whether all the sub-groups within the 'new materials' group had contributed to the improved level of achievement, the researcher compared the mean scores of the corresponding pairs of sub-groups. The sub-grouping was based on the differences in sex, and in the study of biology alone or with the physical sciences. From Tables Nos. 8.4.A through 8.4.C, it became clear that none of the sub-groups had failed to achieve better learning under the new materials.

Since the computed 't' values are all significant at the 1% level, one can reject that these differences in mean scores were due to chance. It is reasonable, therefore, to attribute such differences to the effect of learning with the aid of the new materials.

Figure 8.4.A Results of the fourth year pupils on the test of diffusion and osmosis

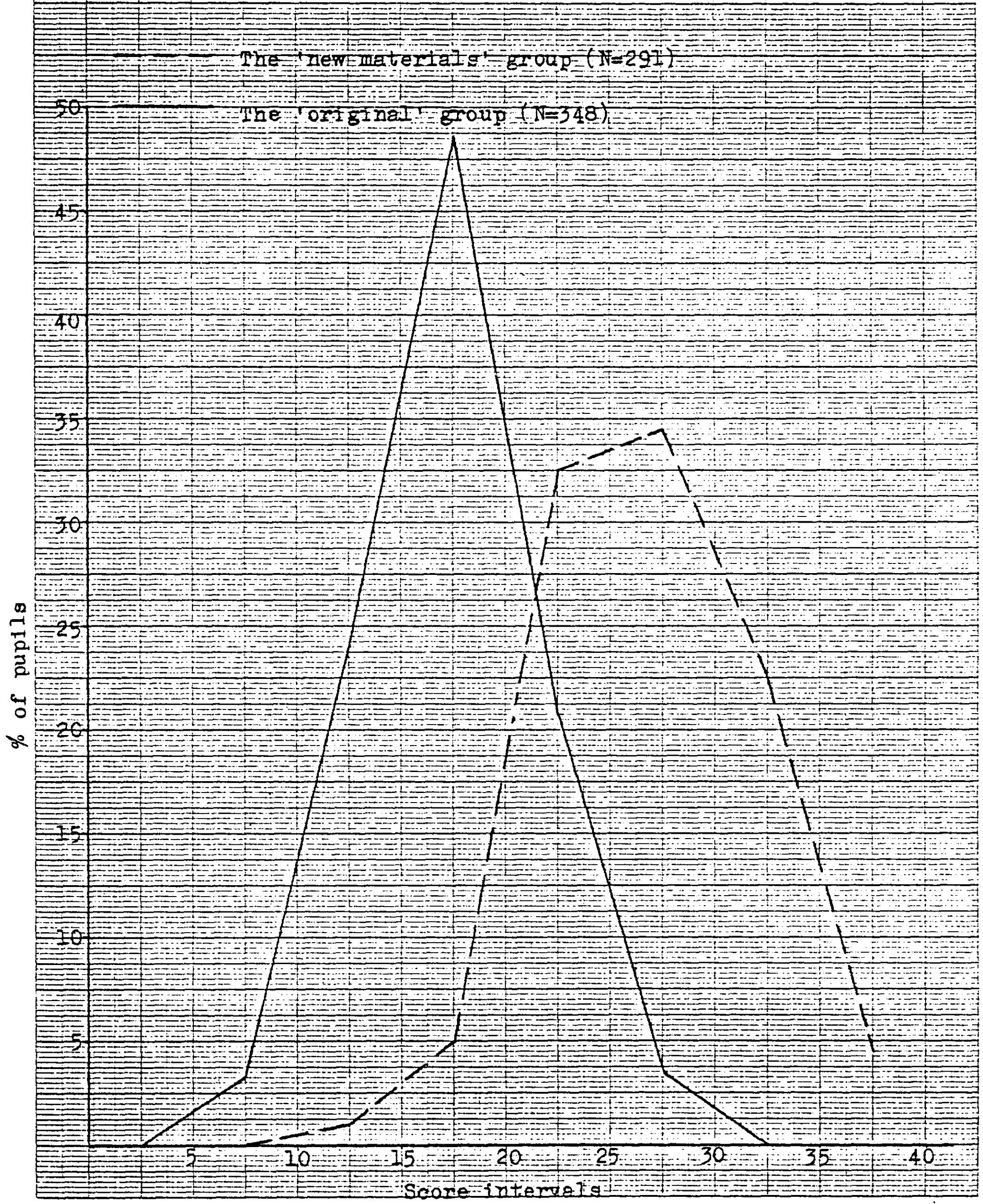


Figure 8.4.B Results of the fifth year pupils on the test of osmosis and diffusion

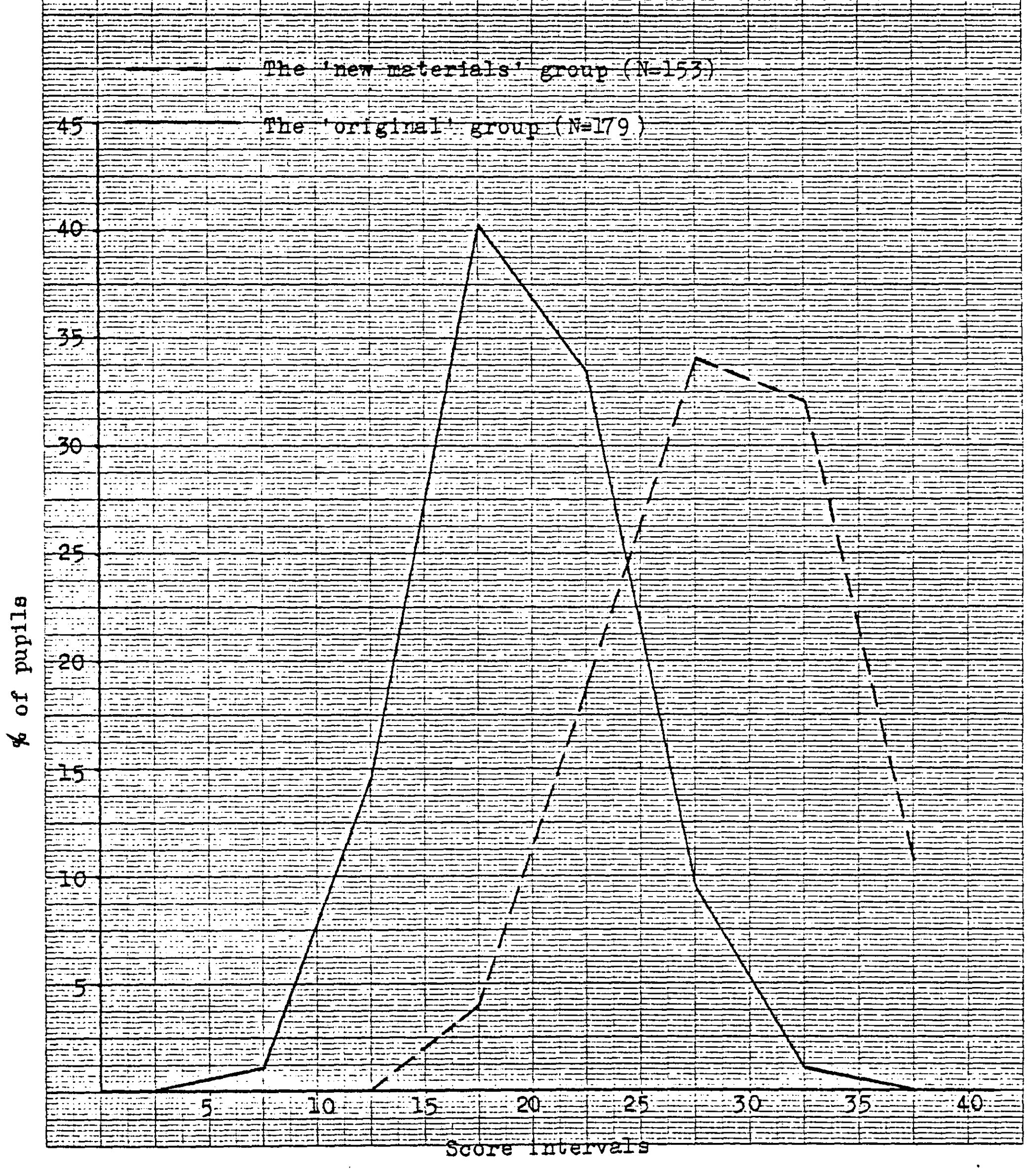


Figure 8.4.C Results of the fifth year pupils on the test of water potential

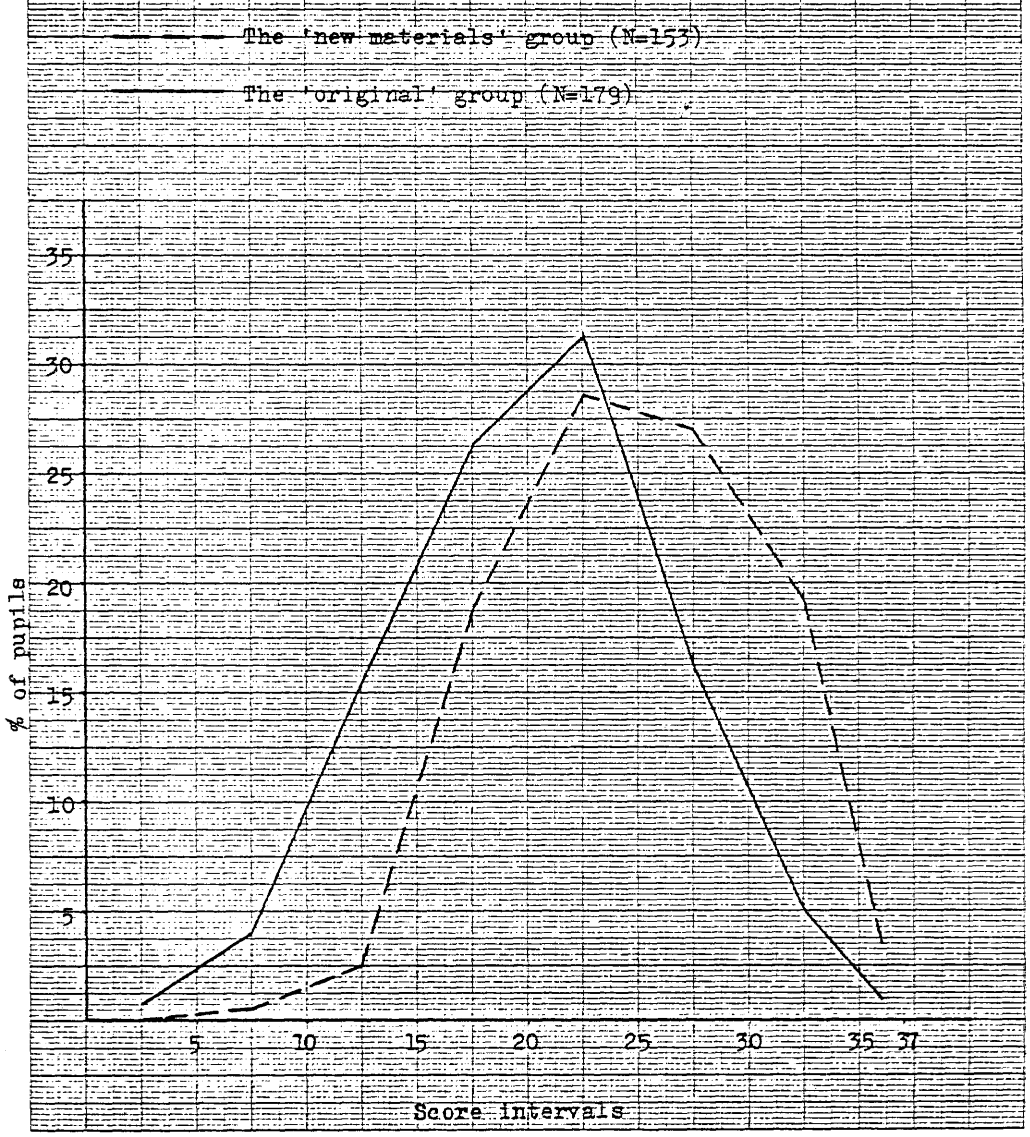


Figure 8.4.D Results of the pupils who answered the essay question

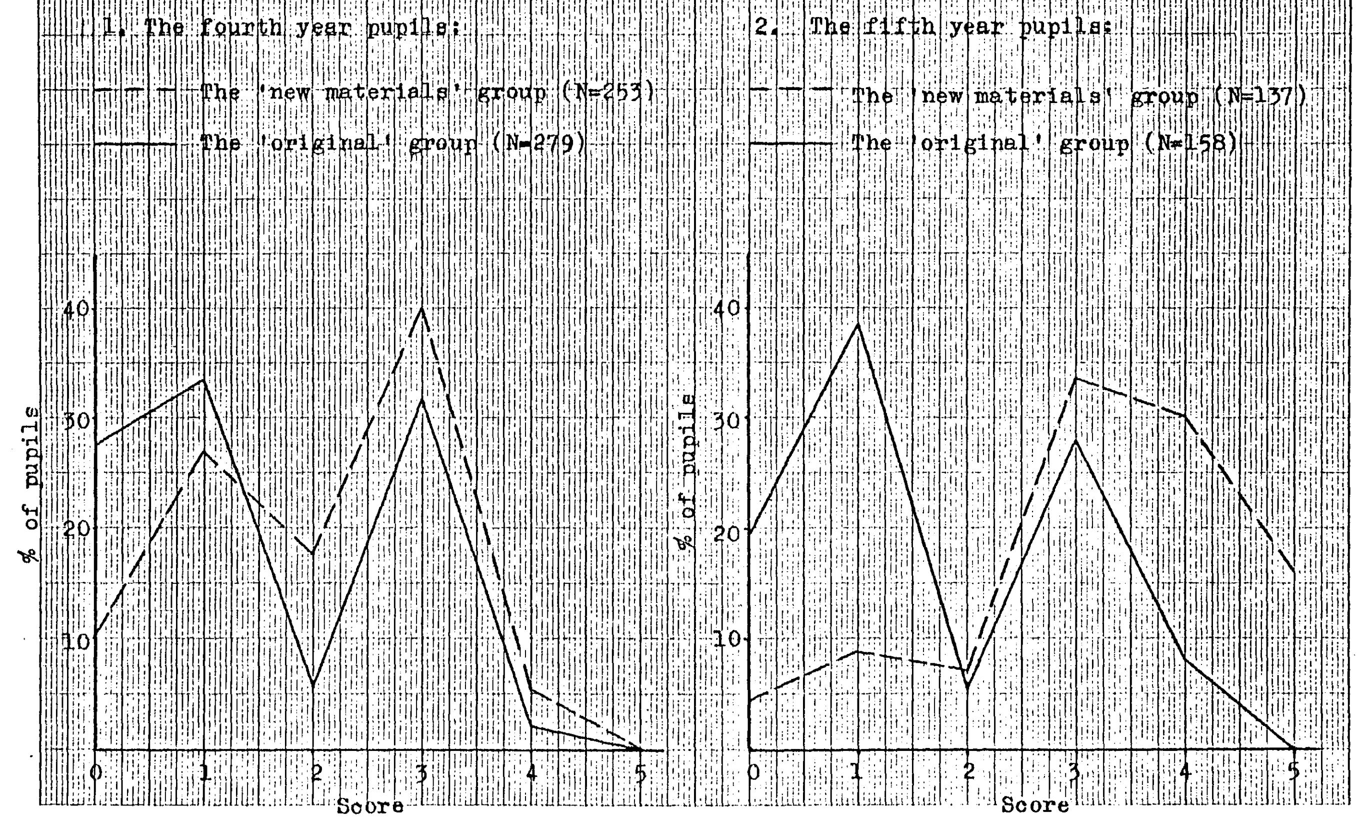


TABLE NO. 8.4.A

Comparison of the performances of the fourth year pupils on the test of diffusion and osmosis

	Specification	The 'original' group	The 'new materials' group	$t_{\bar{x}}$ value	Significance
1	No. of pupils in the group	348	291		
2	Mean score of the group	17.7	27.3	27.28	Sig. at 1%
3	S.D. of the group	4.1	4.7		
4	No. of boys in the group	113	96		
5	Mean score of this sub-group	18.2	26.5	12.86	" " "
6	S.D. of this sub-group	4.5	4.8		
7	No. of girls in the group	235	195		
8	Mean score of this sub-group	17.5	27.8	24.64	" " "
9	S.D. of this sub-group	3.8	4.6		
10	No. of pupils who studied biology alone in the group	174	137		
11	Mean score of this sub-group	17.7	26.6	18.39	" " "
12	S.D. of this sub-group	4.3	4.2		
13	No. of pupils who studied biology plus one or more of the sciences	174	154		
14	Mean score of this sub-group	17.8	28.0	20.41	" " "
15	S.D. of this sub group	3.8	5.1		

TABLE NO. 8.4.B

Comparison of the performances of the fifth year pupils on the test of diffusion and osmosis

Specification	The 'original' group	The 'new materials' group	$t_{\bar{x}}$ value	Significance
1 No. of pupils in the group	179	153		
2 Mean score of the group	19.9	28.3	16.15	Sig. at 1%
3 S.D. of the group	4.3	4.9		
4 No. of boys in the group	59	49		
5 Mean score of this sub-group	19.5	30.0	10.77	" " "
6 S.D. of this sub-group	4.9	5.1		
7 No. of girls in the group	120	104		
8 Mean score of this sub-group	19.9	29.2	14.77	" " "
9 S.D. of this sub-group	4.4	4.9		
10 No. of pupils who studied biology alone in the group	57	33		
11 Mean score of this sub-group	18.7	28.5	10.06	" " "
12 S.D. of this sub-group	3.3	5.0		
13 No. of pupils who studied biology plus one or more of the sciences	122	120		
14 Mean score of this sub-group	20.5	29.6	14.73	" " "
15 S.D. of this sub-group	4.6	5.0		

TABLE NO. 8.4.C

Comparison of the performances of the fifth year pupils on the test of water potential

	Specification	The 'original' group	The 'new materials' group	$t_{\bar{x}}$ value	Significance
1	No. of pupils in the group	179	153		
2	Mean score of the group	20.9	25.3	6.69	Sig. at 1%
3	S.D. of the group	6.0	5.9		
4	No. of boys in the group	59	49		
5	Mean score of this sub-group	20.3	25.8	4.85	" " "
6	S.D. of this sub-group	6.2	5.6		
7	No. of girls in the group	120	104		
8	Mean score of this sub-group	21.2	25.4	5.10	" " "
9	S.D. of this sub-group	6.2	6.1		
10	No. of pupils who studied biology alone in the group	57	33		
11	Mean score of this sub-group	19.3	25.6	6.09	" " "
12	S.D. of this sub-group	4.9	4.6		
13	No. of pupils who studied biology plus one or more of the sciences	122	120		
14	Mean score of this sub-group	21.6	25.5	4.67	" " "
15	S.D. of this sub-group	6.4	6.6		

8.5 Comparison of performance in terms of learning Individual Ideas

An important aspect in this study was to find whether the new learning materials had helped the pupils to establish a meaningful learning of the topics through the mastery of the underlying ideas. Figures Nos. 8.5.A through 8.5.F demonstrate the differences between the 'new materials' and the 'original' groups in that respect.

To check the significance of those learning differences the following formula was employed for each idea:

The obtained difference in proportions expressed in standard error units $= \sqrt{pq\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$

where p = proportion of pupils who learned the idea from both groups,

q = proportion of pupils who did not learn the idea from both groups (i.e. 1-p),

n_1 = number of pupils in the 'new materials' group, and

n_2 = number of pupils in the 'original' group.[179]

For example, the result of the fourth year pupils on the first idea on diffusion and osmosis was worked out as follows:

	N	No. of correct responses	Proportion
The 'new materials' group:	291	250	0.859
The 'original' group:	348	145	0.417
	639	395	

The best estimate for the true proportion, p, is therefore $\frac{395}{639} = 0.618$.

The standard error is

$$\sqrt{0.618 \times 0.382\left(\frac{1}{291} + \frac{1}{348}\right)} = 0.039$$

Figure 8.5.A Results of the test on diffusion and osmosis - laboratory situations

The fourth year pupils:

- - - - The 'new materials' group (N=291)

——— The 'original' group (N=348)

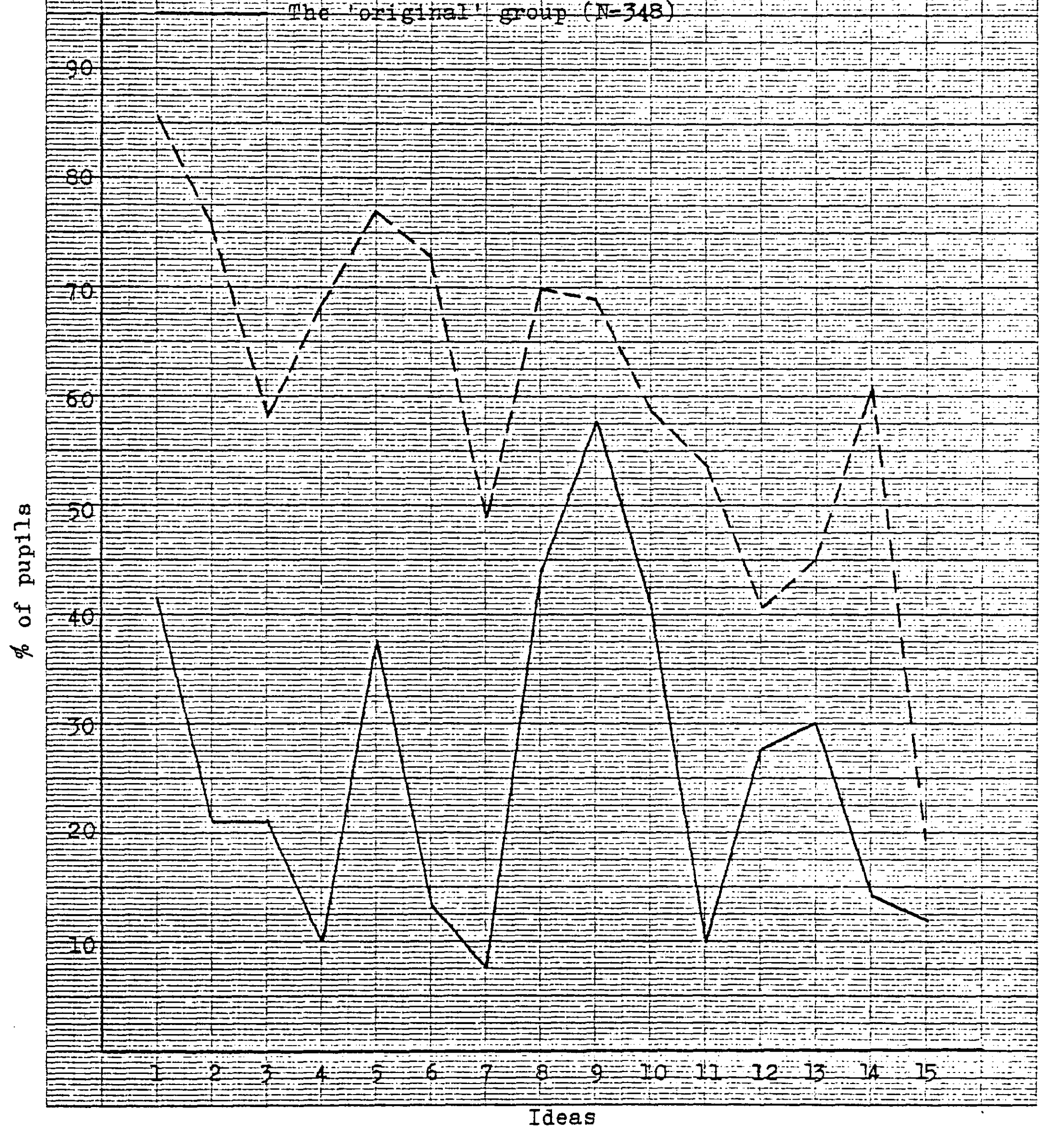


Figure 8.5.B Results of the test on diffusion and osmosis - Plant-soil situation

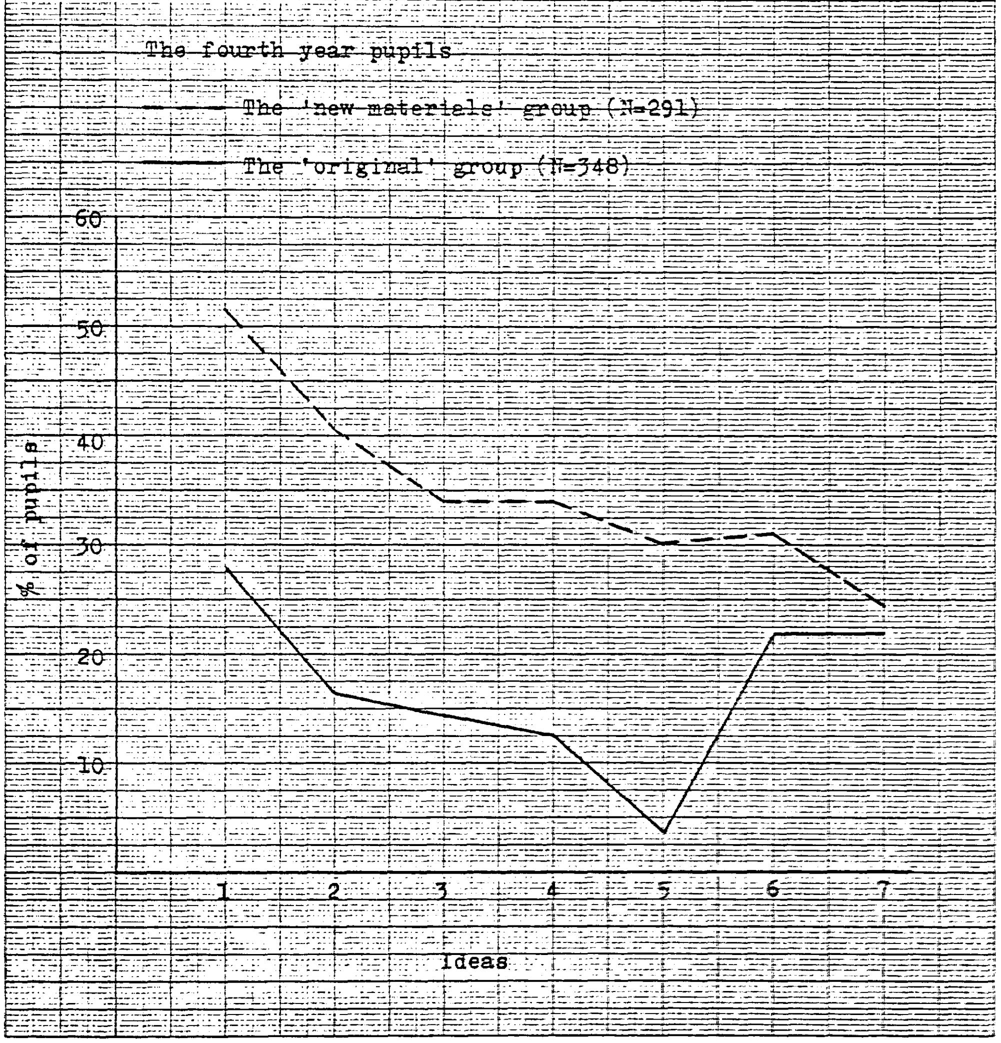


Figure 8.5.C Results of the test on diffusion and osmosis - laboratory situations.

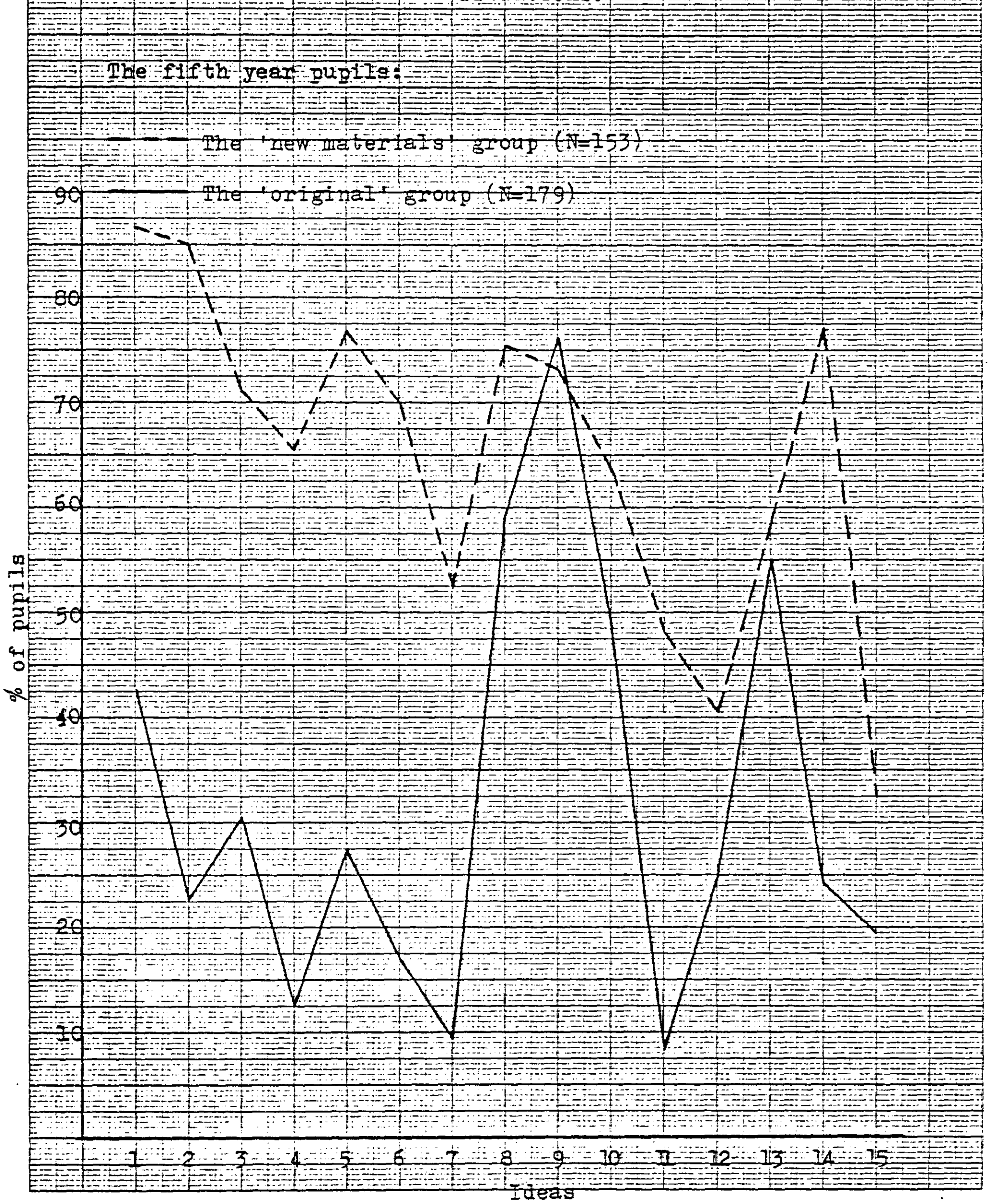


Figure 8.5.D Results of the test on diffusion and osmosis - Plant-soil situation

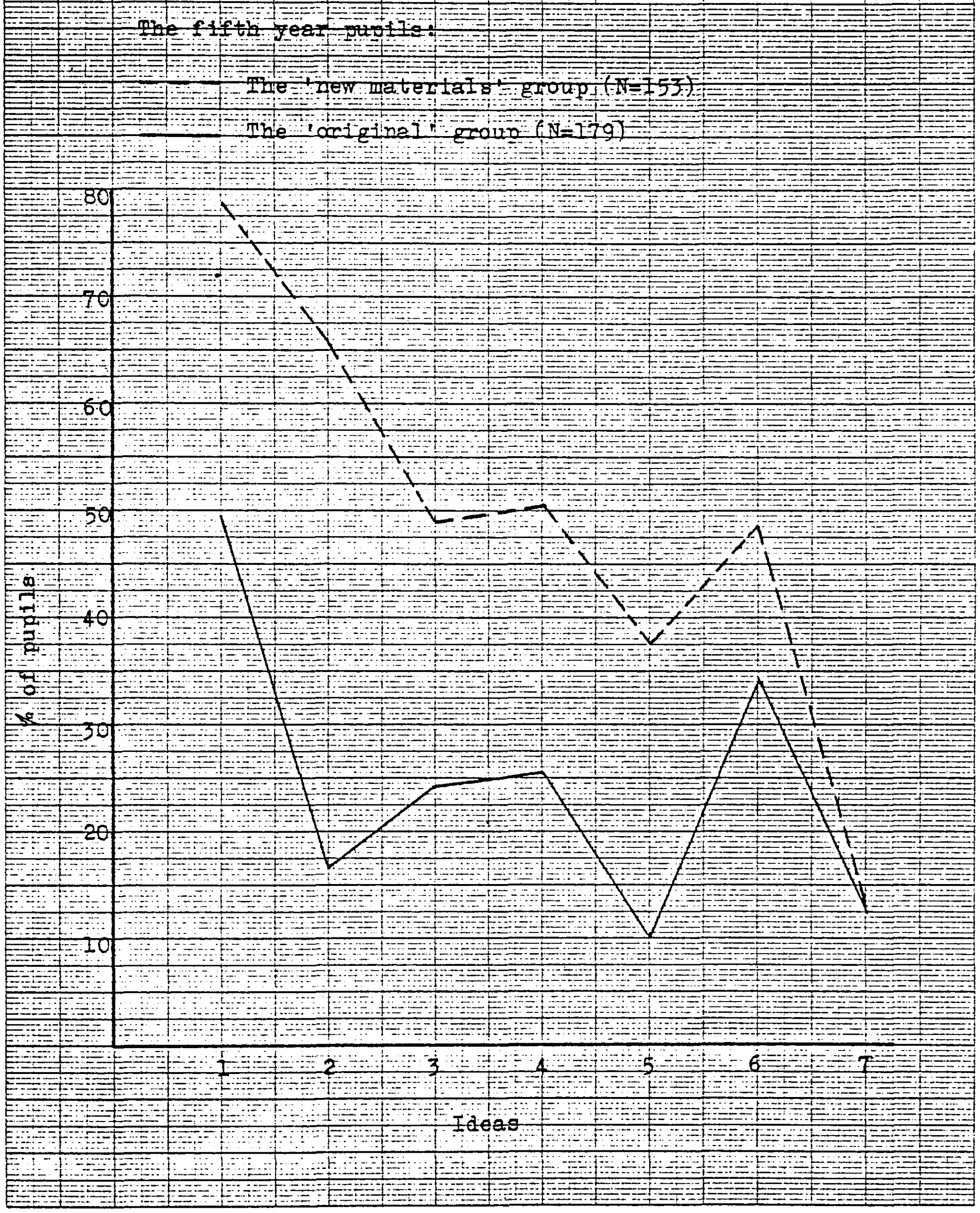


Figure 8.5.E Results of the test on water potential - laboratory situations

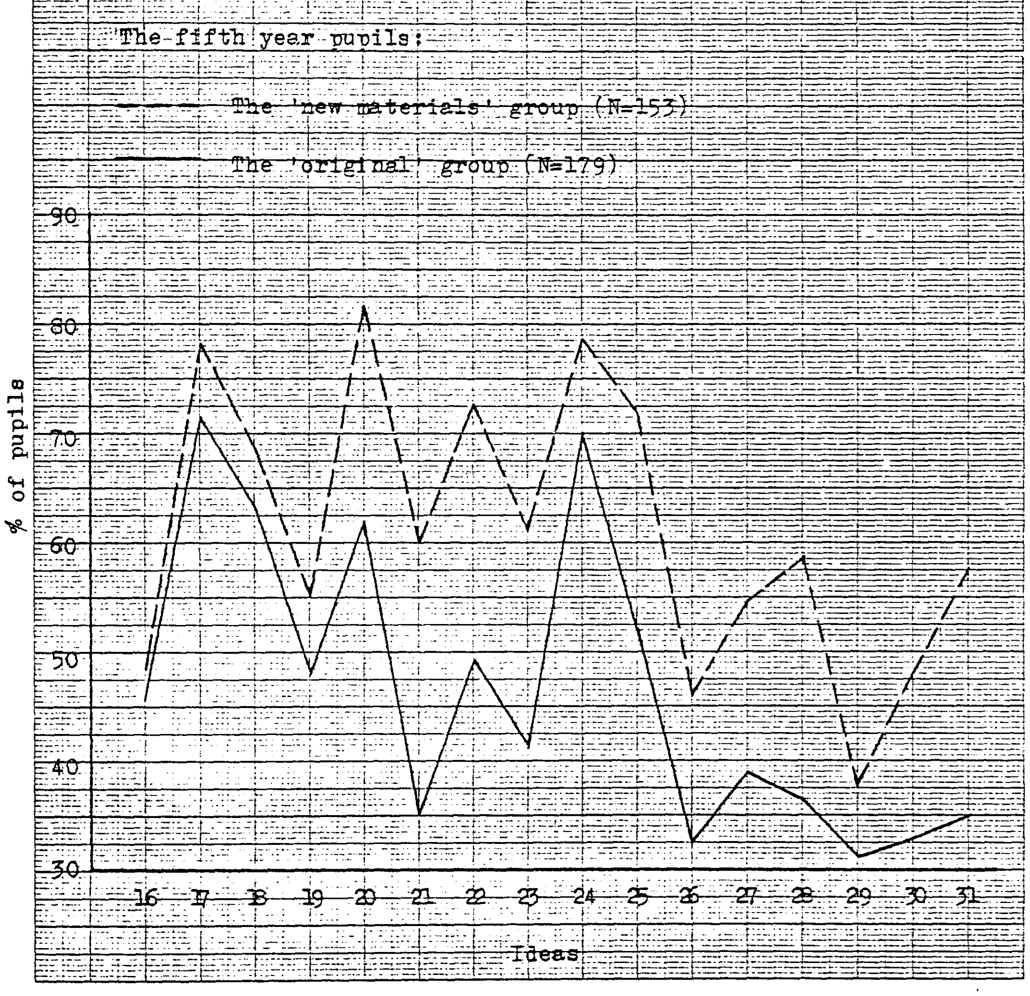
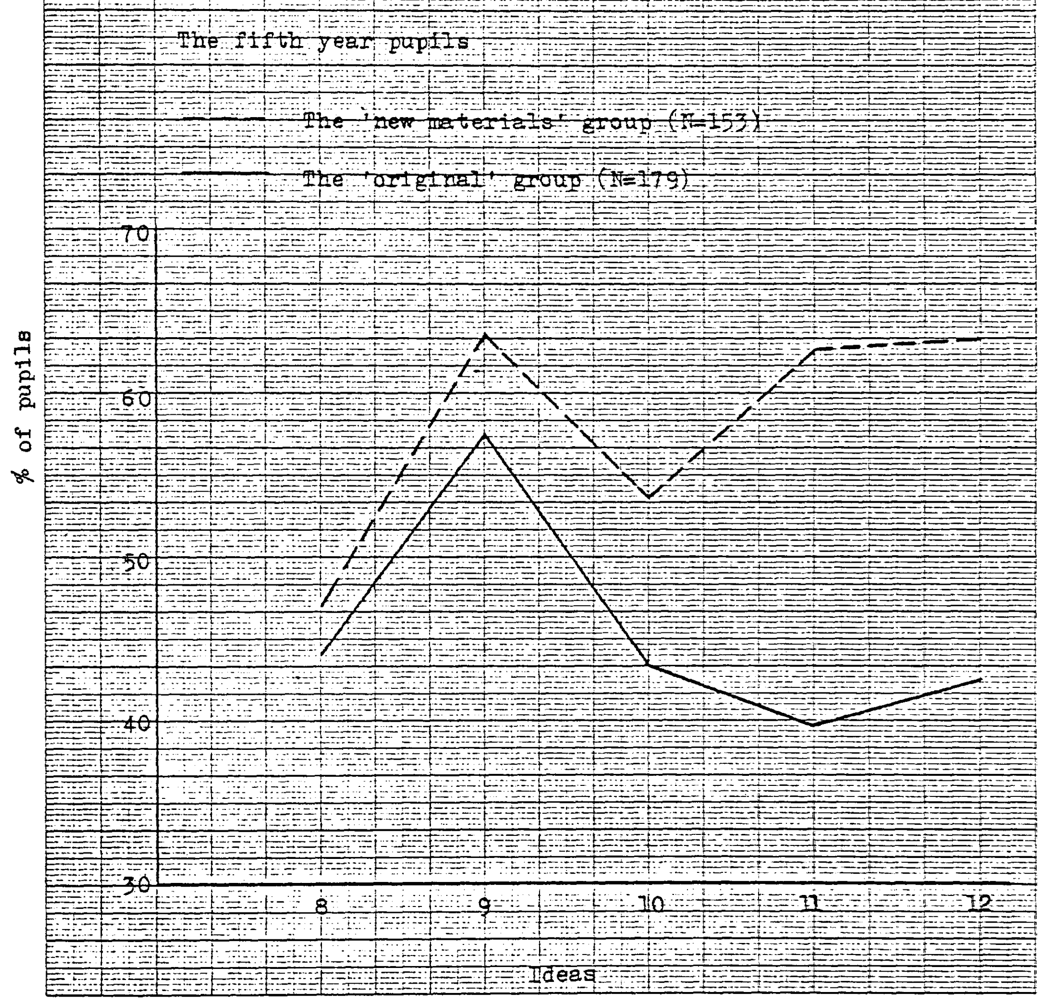


Figure 8.5.F Results of the test on water potential - Plant-soil situation



Therefore, the obtained difference in proportions expressed in standard error units becomes

$$\frac{0.859 - 0.417}{0.039} = 11.33$$

Using the table of fractional area under the normal curve, one can see that the null hypothesis (i.e., no true difference existed) can be rejected with 99% confidence. Thus, the performance of the 'new materials' group on that idea is significantly superior to that of the 'original' group. Similar treatment of the results obtained about their performances on the other ideas led to the following observations:

1. With regard to the ideas on diffusion and osmosis, the 'new materials' group performed significantly better than the 'original' group. The exceptions to this superiority were found in the following cases:

(i) The fifth year pupils of the 'new materials' group performed less satisfactorily than the original one on the idea no. 9, i.e. "Rule of diffusion with regard to the solute particles." Nevertheless, the difference was not significant at the 5% level. Such failure to perform better under the new materials could be attributed to the emphasis of the experimental learning materials on the behaviour of water particles rather than that of the solute ones. By that, it was hoped to focus the attention on water since it is the most important component in osmosis and water potential.

(ii) The same group of pupils performed better, but not at the 5% level, on the idea no. 13, i.e. "Determination of the direction of water flow between solutions which are different in solute concentrations." This could be due to the difficulty involved in the questions themselves where pupils were faced with situations completely new to them (questions 25 and 28 on the diffusion and osmosis test).

(iii) No difference in performance was shown between the two groups on idea no. 7 of the plant situation, i.e. "Manifestations of diffusion and osmosis in the plant and its surroundings." This is because the new learning materials did not include any treatment of such manifestations. It was hoped that teachers would discuss with their pupils the relevance of some phenomena in the plant. The absence of a difference in the performances of the two groups would lend support to the assumption raised earlier about the initial similarity in the learning ability of the two groups.

2. With regard to the ideas on water potential, most of them were shown to be understood better by the 'new materials' group, mostly at either the 5% or the 1% level. Nevertheless, the improvement on the ideas about the effect of solute on the osmotic properties of pure water and solution (ideas 16 through 19) was not highly significant. This could be because their learning requires a series of reasoning steps from considering the solute concentration up to the resulting effect on the various osmotic properties. It is worth noticing that some of the pupils who did not show learning of that group of ideas (16 through 19) managed to deal successfully with the relatively higher ideas of water potential (ideas 25 onwards). This means that some pupils could find their way up to the higher elements of a learning hierarchy without giving sufficient attention to the underlying notions. This was one common reservation to the idea of the learning hierarchies.[41] With regard to the plant-soil situation, ideas 8 and 9 were learnt better by the 'new materials' pupils, but still not to the 5% level. This reflects the failure of many pupils to transfer their established learning from the

laboratory models to the corresponding plant-soil situations. To be able to do so requires an advanced formal type of thought according to the Piagetian theory of cognitive development.[39][91] To Ausubel, it means that those pupils failed to link their new learning to the relevant subsumers in their knowledge about the plant and soil solutions.[113] Apart from that, the 'new materials' group showed good learning of the fundamental ideas whether applied to laboratory or plant-soil situations.

8.6 Comparison of Performance in Terms of the Learning of a Cumulative Number of Ideas

The researcher calculated the ratios of pupils from each of the two groups who showed understanding of the ideas from the basic level up to the one at the top of the concept of osmosis. Comparing such ratios revealed to what extent pupils of each group were able to build up a consistent cognitive structure as related to the proposed learning hierarchy. Figures Nos. 8.6.A through 8.6.C illustrate the revealed differences in that respect. From this comparison, it became clear that the 'new materials' group included a higher ratio of pupils who managed to learn ideas from the very foundations up to the idea of how to determine the direction of water flow between different solutions with respect to diffusion and osmosis. But considering the topic of water potential, the difference in the same ratios is not as great as in the previous topics. The difference in the ratios of understanding each idea separately is much higher than it is if the same ideas are to be considered in a cumulative manner. The reason could be that the 'new materials' group was in need of a longer teaching time and more elaborate discussions with their teachers in order to integrate all the ideas into one whole. This is what Ausubel means by "integrated reconciliation" in a meaningful learning.[113]

Figure 8.6.A Percentage of fourth year pupils who understood each idea in addition to the ideas subordinate to it (diffusion and osmosis)

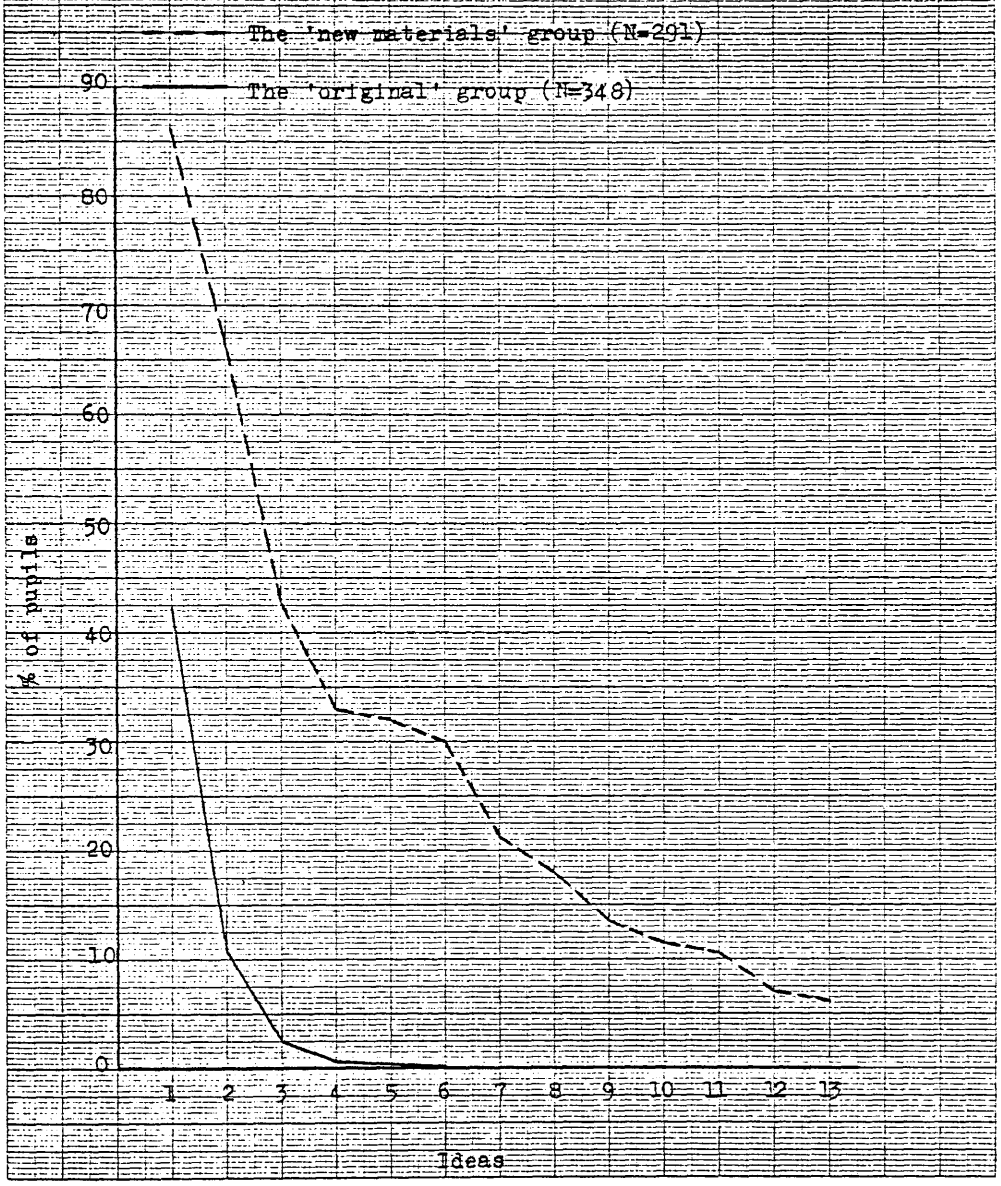


Figure 8.6.B Percentage of fifth year pupils who understood each idea in addition to the ideas subordinate to it (diffusion and osmosis)

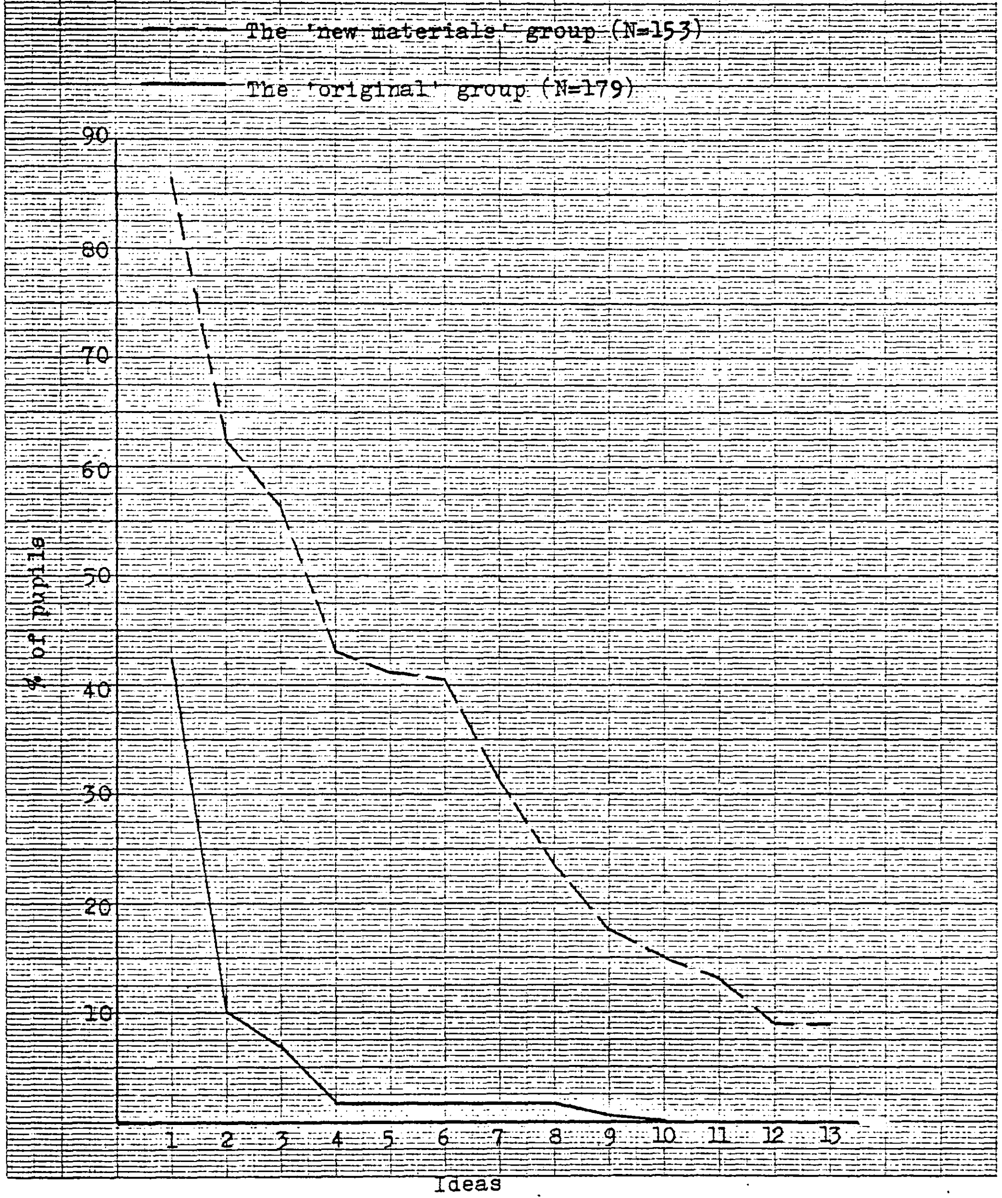
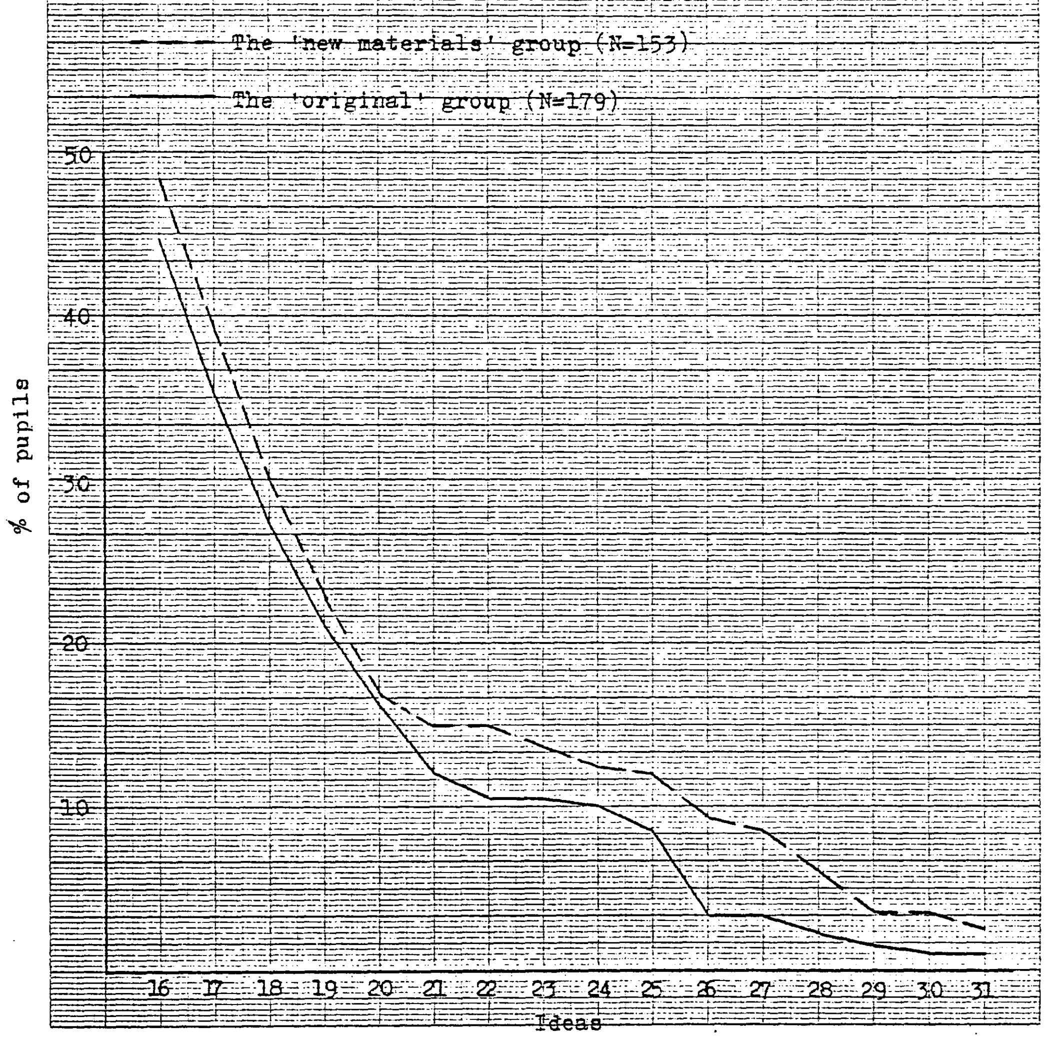


Figure 8.6.C Percentage of fifth year pupils who understood each idea in addition to the ideas subordinate to it (water potential)



In general, one can safely conclude that the use of the specially designed new learning materials has helped pupils to develop better understanding of the topics, compared to equivalent group of pupils who did not use them in their learning of the same topics.

8.7 Effect of Learning Basic Ideas on the Learning of Higher Ones

From these observed differences in performance, one can trace the constructive effect of learning some basic ideas on the subsequent learning of the relatively higher ideas. The following are the most obvious cases to notice:

1. The improvement in their knowledge about the molecular movement of water particles (ideas 1 through 4) gave rise to better understanding of several higher ideas. For example, pupils appreciated better than before that water particles have their own ability to move around in the body of solutions and redistribute themselves evenly in the most probable manner (idea 10). They can now reasonably reject the wrong notion that concentrated solutions 'draw' or 'suck' water into them. Thus the popularity of the fallacy of the 'strong' and the 'weak' solutions, as well as that of the 'suction' pressure was minimized (idea 12). The improvement in the same ideas (1 through 4) helped them to construct a good mental picture about the dissolving process and how aqueous solutions are formed (idea 7). In the meantime, they became able to grasp the notion of 'dynamic equilibrium' where particles of water keep on moving both ways between aqueous solutions when the balanced state is reached (idea 15).

2. The improvement in their knowledge about the relation

between the particles of water and the particles of solute in solutions (ideas 5 through 7) led to another improvement in the very important idea of the hindering effect of solutes on the free movement of water particles (idea 11). The latter is an essential foundation to the understanding of osmosis and water potential, such as why water presses harder on the s.p. membrane from the dilute solution side than it does from the concentrated solution side (idea 14).

3. Better understanding of the fact that the concentration of water particles goes inversely to the concentration of solute particles in their solutions (idea 8) gave a boost to their understanding of the rule of water diffusion (idea 10). The same understanding helped fourth year pupils to determine the direction of water flow between solutions (idea 13).

4. The understanding of the rule that governs the direction of water flow (idea 10) helped fourth year pupils to make better judgments about the possible direction of water flow between solutions if they were confronted with a problem situation in osmosis (idea 13).

5. When pupils got the idea that water movement is handicapped by the presence of solute (idea no. 11), they became more able to realise that there should be a net flow of water from solutions with lower concentrations of solute to others with higher solute concentrations. This was obvious by their comparatively better performance on ideas 12 and 13. They were also able to understand the relation between solute concentration in soil and plant solutions and the osmotic pressure generated in each of them (ideas 5 and 12 on the plant situation).

6. By improving their probabilistic reasoning about

the net flow of water (idea 12), fourth year pupils became more able to determine its direction between solutions, and to understand the difference in pressure caused by the free particles of water on the two sides of an s.p. membrane (ideas 13 and 14).

7. When their knowledge improved about the initial differences between soil and plant solutions (ideas 1 through 3 on the plant situation), they became more able to reason about the phenomena in connection with soil-plant water relationships. This was supported by the understanding of the many facts provided earlier on laboratory models. They realised that the low concentration of solute in soil solution allows a high proportion of the self-mobile water particles to remain free and to enter the root hair cells (idea 4). This threw more light on the concept of osmotic pressure and how its decreasing gradient from the top parts of a plant down to the soil solutions enables water particles to climb up the plant (idea 5). The 'new materials' group showed superiority in the attainment of these ideas when compared to the original group of pupils. This improvement is reflected in the better understanding of the higher ideas of water potential in the plant situation (ideas 8 through 12).

8. During the interviews and the first diagnostic testing, pupils had shown little understanding of the relation between the cell wall pressure and water inflow to cells (idea 6 on plant situation). When this idea was explained in the new materials, a substantial improvement was achieved by the new group of pupils. They knew that the cell wall has nothing to do with the intake of water, whereas it reacts to the excessive inflow of water by pressing inwards (ideas 6 on plant and 20 on laboratory situations). This helped the fifth year pupils to understand how this factor affects the determination of the cell water potential (idea 25).

It helped them also to reason out the relation between the passage of water from one cell to another and their comparatively different wall pressures (idea 11 on the plant situation).

9. Compared to the 'original' group, the 'new materials' group showed better appreciation of the effect of solute on the magnitude of the water potential of solutions (ideas 22 and 23). This could be associated with their comparatively better appreciation of the effect of solutes on the free movement of water particles (the basic idea no. 11).

10. The good understanding of osmosis and cell wall pressure helped the fifth year pupils of the 'new materials' group to perform better computations of the (Ψ) values (idea 25). They were also in a better position to interpret the significance of (Ψ) values (ideas 28 through 30). This in turn helped them to rank several values of (Ψ) in order to identify the highest and the lowest of them (ideas 26 and 27). The dogma of pure water being always of the highest possible water potential was now removed from as many as 70% of the fifth year pupils.

11. The 'new materials' group surpassed the 'original' one in their ability to determine the direction of water flow between solutions and between cells (ideas 24 and 30). This is due to their better understanding of the bases on which this determination is to be established.

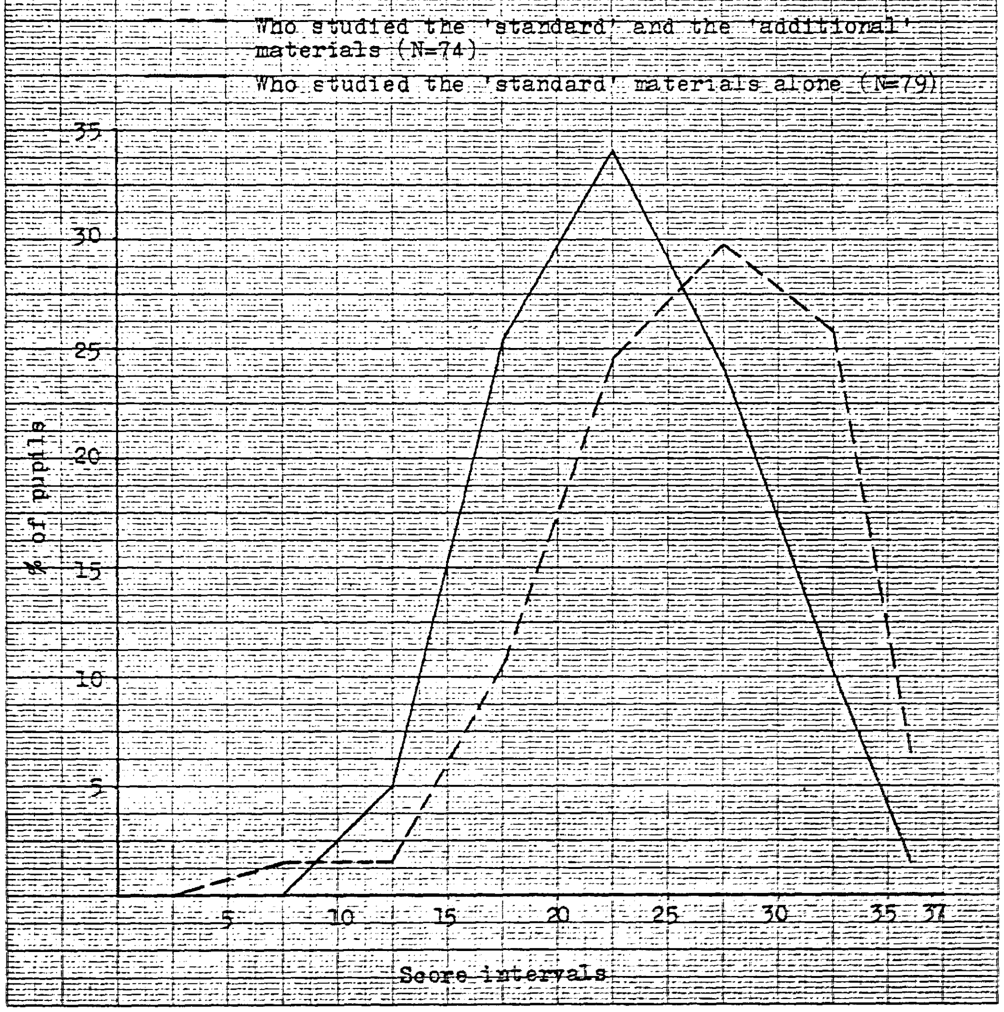
12. From figure no. 8.4.D earlier, it is clear that the 'new materials' group obtained better scores than the 'original' one when both were asked to explain how water particles leave the soil solution and accumulate in the root cells. According to the scoring scheme used in marking that essay question,

high scores indicate the learning of the derived concepts of osmosis and water potential on the solid grounds of understanding their fundamental ideas.

13. As mentioned in Chapter Seven, the fifth year pupils in four of the eight schools were provided only with a copy of the film and the 'standard' eight-page printed material. Their counterparts in the other four schools were provided, in addition to that, with the 'additional' two-page printed material which carried supplementary recapitulation and numerical treatment of the subject. When a comparison was made between the performance of the two sub-groups on the water potential test, the one which studied from both the 'standard' and the 'additional' materials was shown to be the best. Figure 8.7.A illustrates this observation. When a comparison was made between their mean scores and the t-test was employed, the superiority of the same sub-group was significant at the 1% level. Table 8.7.A below shows the details.

	Who studied the 'standard' materials alone	Who studied both the 'standard' and the 'additional' materials
1. Number of pupils in each sub-group	79	74
2. Mean score on the diffusion and osmosis test	26.2	30.3
3. S.D. of the scores (computed t=5.4)	4.9	4.6
4. Mean score on the water potential test	23.7	27.2
5. S.D. of the scores (computed t=5.5)	5.4	5.8

Figure 8.7.A Results of the fifth year pupils ('new materials' group) on the test of water potential.



From this, one can reject a hypothesis that such difference in the mean scores was due to chance alone. Therefore, it becomes clear that the learning of biological themes on a mathematical basis could be improved by a prior understanding of the relevant numerical notions.

14. In general, the understanding of water potential was shown to be reasonably correlated with that of diffusion and osmosis. Pearson's **r** for the correlation between the fifth year pupils' scores on the two tests came to the value of 0.531, which is significant at 1% level. Though this positive correlation does not necessarily imply a direct causal relationship,[179] it can still indicate a common trend in the levels of the learning of these topics. A good understanding of the fundamental ideas of diffusion and osmosis is associated with relatively good understanding of the subject of water potential.

8.8 A Second Look at the Proposed Learning Hierarchy

When the researcher constructed his proposed hierarchy for the learning of the topics being researched he was doing so in the hope that it would present the underlying ideas from the easiest to the most complex. Lovell (1974) pointed out that such an arrangement made by people who are acquainted with a topic may not be completely successful when it is subjected to the real learning situations.[91] In the light of this, the researcher believed that it would be useful if he re-examined his proposed hierarchy. To achieve this objective two questions were raised, namely:

(i) To what extent the relative difficulty (as shown by test scores) of each idea was matching its rank position on the hierarchy?

(ii) What is the possible reordering of those ideas?

To answer the first question, a Table was constructed on which the ideas were listed twice. Firstly, they were listed in the order as they appeared on the suggested hierarchy. Secondly, they were listed from the most easy to the most difficult as revealed by testing the 'new materials' group. Spearman's rank-difference coefficient of correlation was computed with respect to the fourth and the fifth year pupils. Table No. 8.8.A below shows the results of that computation.

Pupils and ideas	Spearman's p	Significance
1. Fourth year: diffusion and osmosis	0.72	Sig. at 1%
2. Fifth year: diffusion and osmosis	0.621	" " "
3. Fifth year: water potential	0.441	" " 10%

In the first two cases, one can reject the null hypothesis (i.e., no true correlation existed), but with the third one it cannot be so easily rejected. Here the matching between the difficulty order of the ideas of water potential and their logical order on the proposed hierarchy has an unacceptably low level of significance. One or more of the following reasons could be responsible for this.

1. Being considered by the researcher to be logically the most difficult, the higher level ideas on the hierarchy received fuller treatment in the new learning materials compared to the other ideas. As a result, many pupils managed to understand them relatively well.

2. The lower level ideas on the hierarchy could not have been completely appreciated by the biology teachers

involved in the study, since those ideas are mainly drawn from the domains of chemistry and physics. Those teachers could have provided their pupils with alternative explanations for the higher ideas, though not all were completely correct. Making an analogy between a concentrated solution and a 'sponge'(an alternative lower idea) might have helped pupils to have a superficial understanding when they were asked to determine the direction of water flow between solutions (a higher idea). On the other hand, when the same pupils were asked to recognise the effect of solute on the free movement of water particles (a lower level idea), they failed to do so.

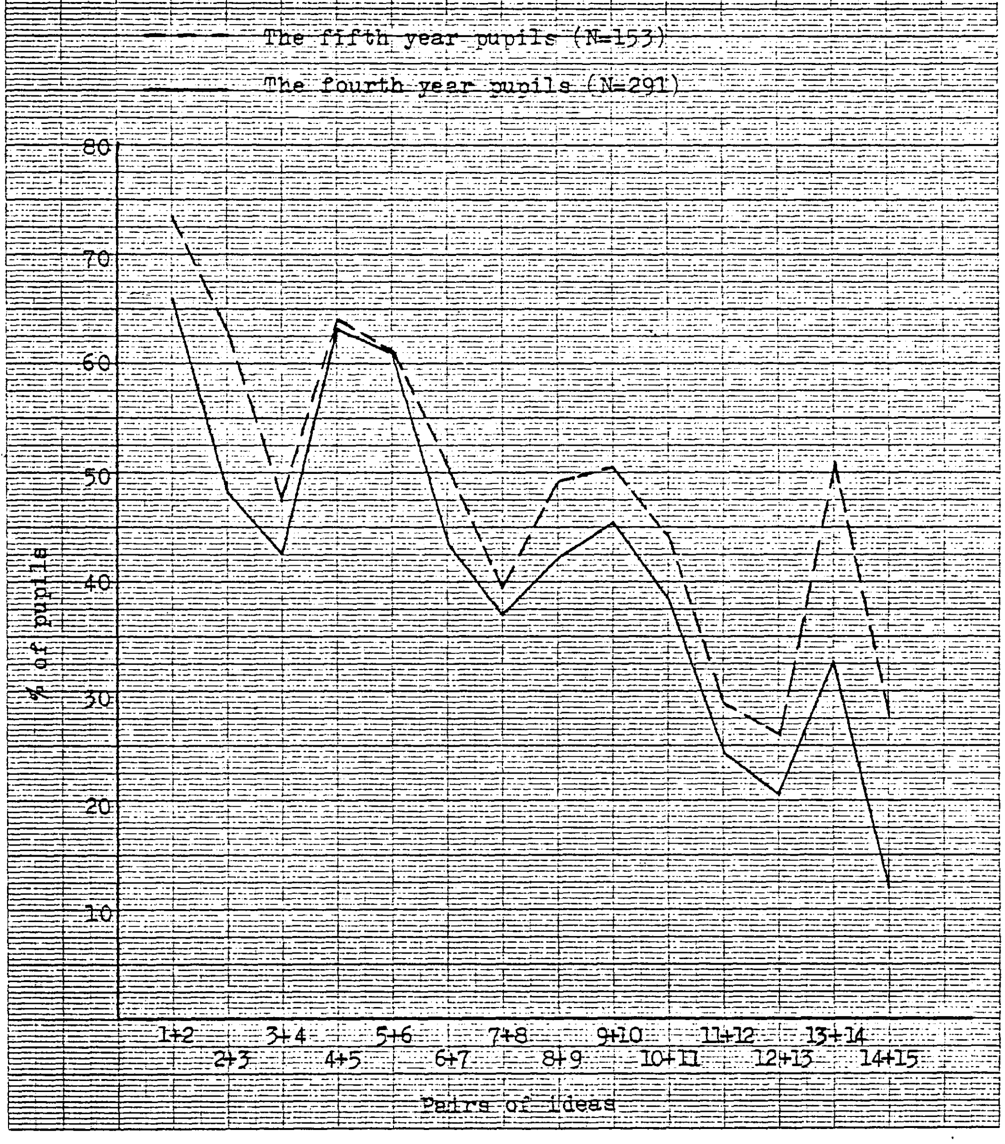
3. The lower level ideas on the logically-structured hierarchy could contain a greater amount of abstraction in them compared to some of the higher level ones, hence being psychologically more difficult for some concrete-oriented pupils (the Piagetian theory). Or, they have no relevant subsumers in the pupils' cognitive structure to be anchored to them. Or, the pupils had the relevant subsumers, but did not realise their relevance (the Ausubelian theory).

To answer the second question about the possible alternative arrangement of ideas, the researcher tried to investigate the links between each successive pair of ideas on the hierarchy. For this to be carried out, he counted in groups the number of pupils who showed understanding of idea no. 1 plus no. 2, idea no. 2 plus no. 3, and so on. It was thought that where the number of pupils was high it could mean that the first idea had led the pupils to the one next to it. Postulating that the tests were administered to a normally distributed sample of pupils on the learning ability dimension, it was anticipated that a smooth curve extending downwards from the first idea to the last one would be obtained if those ideas were initially arranged from the easiest to the most difficult. If not so, the dips on the curve would pinpoint the most suitable sites for making alterations in the arrangement of ideas in the hierarchy. The curves obtained are shown in figures nos. 8.8.A and 8.8.B.

One would have expected to obtain a steady fall-off of the curves since the learning hierarchy assumes that each idea is easier to learn than the one above it. It also assumes that the learning of each idea is facilitated by the learning of the one below it. But since the experimental figures had discontinuities superimposed upon their steady fall-off, one may attribute this to either or both of the following reasons:

1. Many pupils have found some way round the hierarchy proposed according to an adult point of view. That alternative way enables pupils to jump from one lower idea to another one which appears later in the hierarchy, skipping the intermediate ones. For example, it was found that, of the fifth year sample pupils, 62% grasped idea no. 1 as well as idea no. 4 (see Figure 8.8.C). This direct route gave a higher success rate in going from no. 1 to no. 4 than any other routes such as $1 \rightarrow 2 \rightarrow 4$, or $1 \rightarrow 2 \rightarrow 3 \rightarrow 4$, or even $1 \rightarrow 3 \rightarrow 4$ (see Table No. 6.5.A for details). A similar phenomenon appears between ideas 5 and 9. Here the direct link was successfully made by 58% of pupils, whereas any other route or combination of routes gave less success. The same pattern was also observed with the fourth year pupils. On examination of these topics in detail, the strongest route through the hierarchy is from idea no. $1 \rightarrow 4 \rightarrow 5 \rightarrow 9 \rightarrow 10 \rightarrow 14$, i.e. the route most closely following a smooth fall-off curve. This might be a satisfactory route for the less able pupil requiring only the essentials of the topic to meet examination requirements. The alternative routes (followed by many other pupils) are almost certainly the desirable routes for the more able ones aiming for sound learning.

Figure 8.8.A Percentage of pupils from the 'new materials' group who understood successive pairs of ideas (diffusion and osmosis)



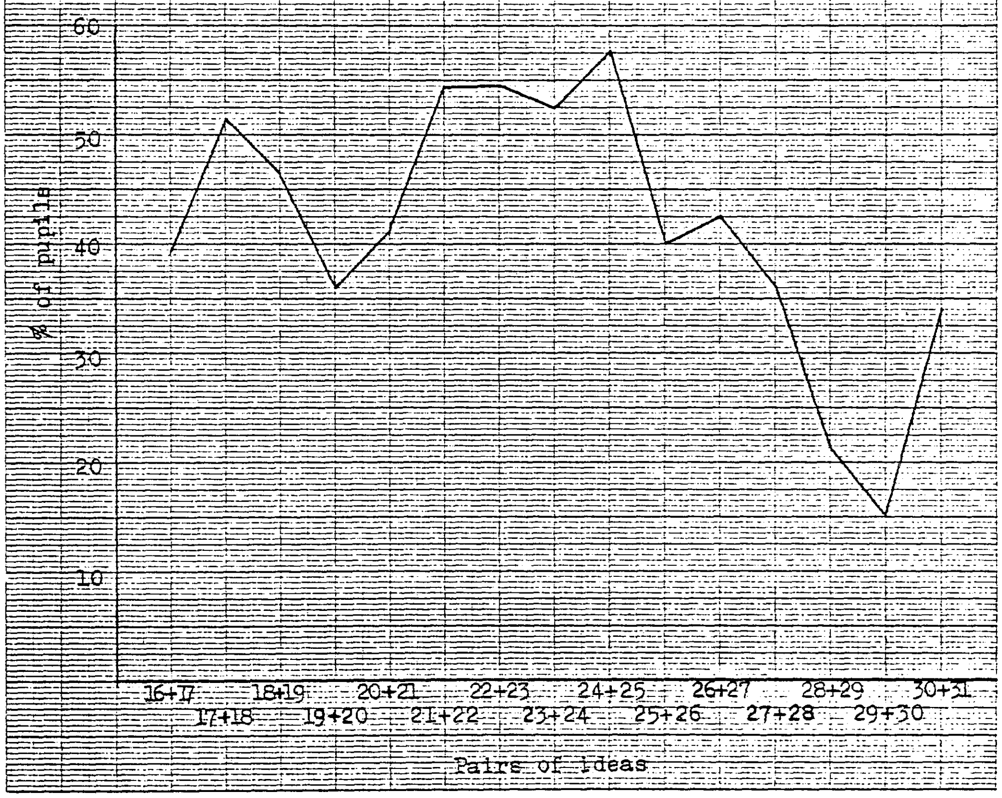
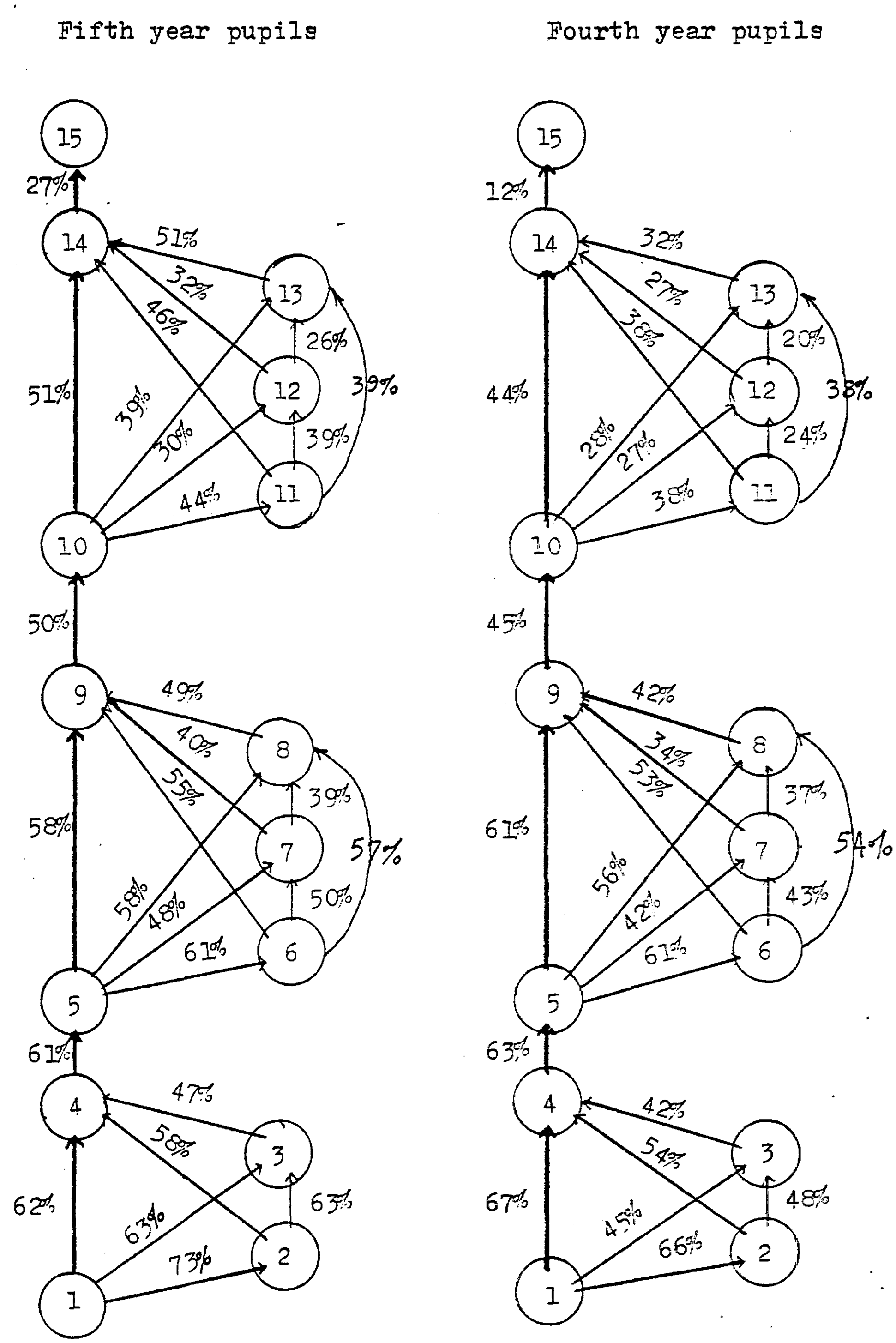


Figure 8.8.B Percentage of fifth year pupils from the 'new materials' group who understood the successive pairs of ideas (water potential)
(N=153)

Figure 8.8.C. Linkage between the ideas included in the learning hierarchy of diffusion and osmosis (the percentages refer to pupils who knew the pair of ideas linked by each arrow)



2. Teachers who are under constant time pressure because of an overloaded syllabus may have to accept an 'essentials' treatment of the topics and this may account for the strong strand in figure 8.8.C. The 'weaker' alternative routes have probably been generated by the film and printed material and have been incorporated by the more able pupils as an extra to the basic treatment given by their teachers.

In spite of the fact that full meaningful learning of the topics almost certainly requires the subsumers lying along the 'less efficient' routes, one has to consider the consequences which such experimental findings have for the teaching situation. This may give us empirical evidence for the necessity of a 'core plus options' structure for science teaching, particularly in mixed ability classes. In this case, the core might be the main route shown in figure no. 8.8.C and the options could be the 'discontinuity' loops. This flexible plan would enable the more able pupils to achieve a complete meaningful learning of the topic, on which they could build in later study, while allowing the less able pupils to obtain a nodding acquaintance with the topic but on correct bases still. Since the majority of the latter group would not be taking the subject further, this level of learning might be quite adequate for them.

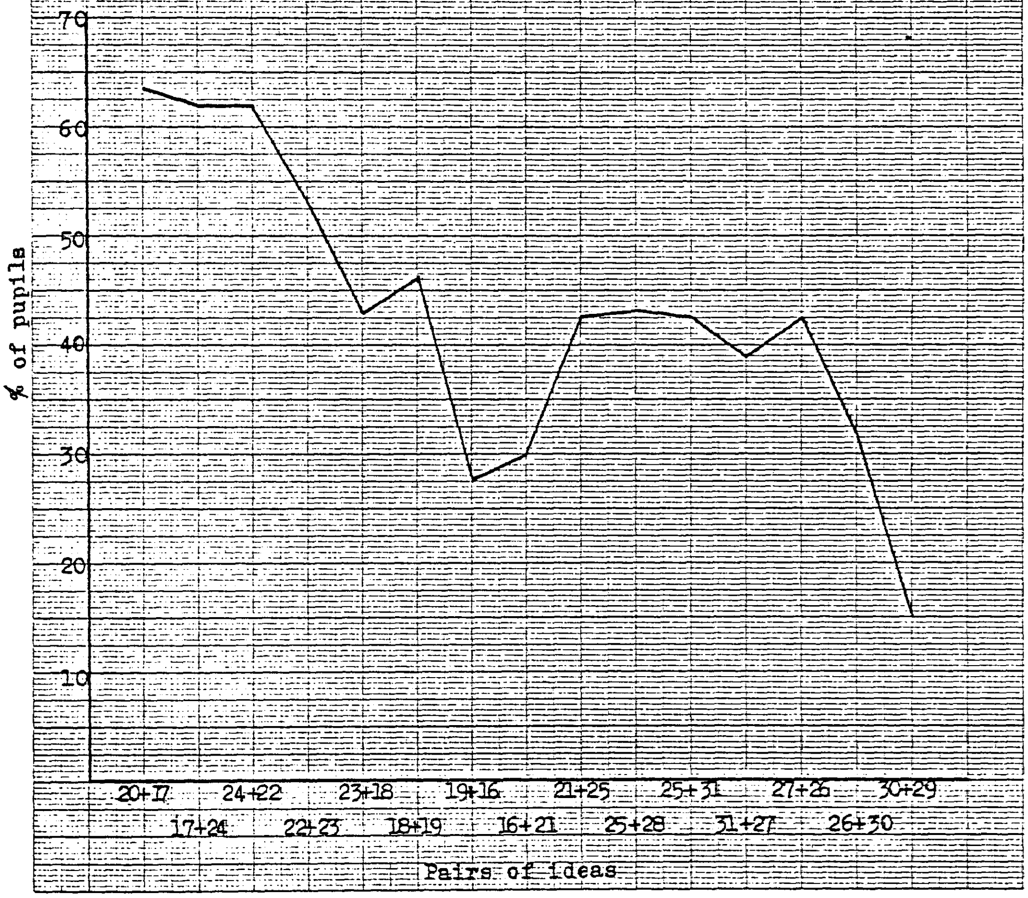
With regard to the ideas included in the water potential study the linkage between them did not reveal any clear pattern. This could be due to difficulty inherent in the topic which made teachers from different schools explain it in different ways to each class of pupils. A new arrangement of the ideas included in that topic could be based, to some extent, on the difficulty order of each single idea, as revealed by figure 8.5.E. In this case, one would have to find a compromise between the logical order of adults and the learning difficulty order according to pupils' assessment.

One of the possible teaching sequences could be as follows:

Idea no.	
20	Effect of water inflow on the cell wall pressure.
17	Effect of the concentration of solute on the amount of the free particles of water causing pressure in solution
24	Effect of the concentration of solute on the direction of water flow between solutions.
22	Effect of the amount of solute on the water potential of a solution.
23	Effect of the concentration of solute on the water potential of solutions.
18	Effect of the amount of solute on the osmotic potential of a solution.
19	Effect of the concentration of solute on the osmotic potential of solutions.
16	Effect of solute concentration on the osmotic pressure of solutions.
21	Differences between pure water and solutions in their osmotic properties.
25	Computation of (Ψ) values from its components.
28	Significance of (Ψ) as indication of the relative concentration of the free particles of water.
31	Direction of water flow between cells, and between cells and pure water.
27	Ranking (Ψ) values in order of magnitude to identify the lowest.
26	Ranking (Ψ) values in order of magnitude to identify the highest.
30	Significance of (Ψ) components as an indication of water gain and loss from cells.
29	Significance of (Ψ) components as an indication of the state of cells.

Figure 8.8.D shows the links between the pairs of ideas according to this possible sequence. Though the fall-off of the curve is not an ideal one, it indicates a reasonable pattern still. The dip on this curve corresponds the relation between solute concentration and both osmotic potential and pressure. It shows that

Figure 8.8.D Percentage of pupils from the 'new materials' group who understood the new successive pairs of ideas (water potential)
(N=193)



understanding osmotic pressure did not depend on, or facilitate the understanding of osmotic potential under the scheme of treatment adopted in the schools (see page 155). If the up-to-date scheme is adopted, one would expect that the existing confusion will be reduced.

8.9 Correlation between the Pupils' Scores on the Tests and Those on Other Measurements

With the absence of standardised biology tests for the Scottish Secondary School pupils, the researcher sought the available scores of the 'new materials' pupils on two other measurements. The first was the 'Preliminary School Tests', the second was the 'Verbal Reasoning Test' (V.R.T.).

The biology preliminary tests are usually carried out on a local basis in each school. Principal teachers construct them guided by questions which appear on the national examination papers. Pupils' scripts are marked by teachers of the same schools, with the aim of reaching an estimate of the pupils' performance in the final external examination. The results of such preliminary tests could give a reasonable assessment of the pupils' level oflearning of biology, although absolute standards might vary from school to school.

On the other hand, the V.R.T. which was prepared by a special unit at the Moray House College of Education in Edinburgh aims to estimate the reasoning abilities of the pupils during their last year of study in primary schools. That test contains elements of reasoning set around letters, words and numbers. With the help of the special unit in Edinburgh, the pupils' raw scores are converted into their equivalent standardised scores, referred to as 'V.R.Q.'. Though several years have passed from the time a pupil's 'V.R.Q.' is computed until he reaches his fourth or fifth year of the secondary school, it is believed that a very limited change happens to that computed value. A pupil's 'V.R.Q.' could reveal the extent to which he can think and reason in different situations. A pupil with high V.R.Q. is most likely to keep his rank among his cohort if tested on a subject. Conversely, a good pupil on a biology test is most likely to be comparatively good when he is asked to reason verbally.

Bearing in mind the limitations just mentioned above, the researcher found it still worth correlating the test scores of the 'new materials' group with the scores obtained by same pupils on those two measurements. Table No. 8.9.A below shows Pearson's Coefficient of Correlation as computed between the pupils' scores on the tests constructed and marked by the researcher and their scores on the biology preliminary tests constructed and marked by their teachers. The formula used for that computation was:

$$r_{xy} = \frac{\sum' xy}{\sqrt{\sum' x^2 \cdot \sum' y^2}}$$

where $\sum' xy = \sum xy - \frac{(\sum x)(\sum y)}{n}$

$$\sum' x^2 = \sum x^2 - \frac{(\sum x)^2}{n} \text{ and}$$

$$\sum' y^2 = \sum y^2 - \frac{(\sum y)^2}{n} \qquad (179)$$

TABLE NO. 8.9.A

Pupils & tests \ Schools	1	2	3	4	5	6	7	8
1 Fourth year: Diffusion & Osmosis	$\underline{\underline{0.75}}$ (25)	0.35 (20)	$\underline{0.54}$ (14)	$\underline{\underline{0.47}}$ (53)	$\underline{\underline{0.55}}$ (31)	$\underline{\underline{0.34}}$ (60)	0.29 (20)	$\underline{0.25}$ (68)
2 Fifth year: (i) Diff.& Osmosis	0.23	$\underline{0.76}$	$\underline{\underline{0.59}}$	$\underline{\underline{0.52}}$	0.18	$\underline{\underline{0.58}}$	0.54	$\underline{\underline{0.62}}$
(ii) Water Potential	0.14	0.53	$\underline{0.51}$	$\underline{\underline{0.56}}$	0.13	$\underline{\underline{0.61}}$	$\underline{0.81}$	$\underline{0.35}$
(iii) Total Score on both tests	0.29 (23)	$\underline{0.74}$ (6)	$\underline{\underline{0.60}}$ (20)	$\underline{\underline{0.61}}$ (25)	0.19 (16)	$\underline{\underline{0.67}}$ (25)	0.74 (5)	$\underline{\underline{0.57}}$ (33)

N.B. (1) Figures in brackets represent the number of pupils in the sample. (2) The single underlined values are significant at the 5% level, whereas the double underlined are significant at the 1% level.[194]

In most of the cases, one can therefore reject with 95% or 99% confidence a hypothesis that the correlation obtained has occurred by chance.

From the Table above, one can also notice the following:

1. There are positive correlations between the scores of pupils on each of the constructed tests and the assigned external criteria.

2. The level of significance of such correlation varies from one school to another. This could be attributed to a difference between the specific objectives which were considered in constructing the researcher's tests and the school tests. While the researcher was keen to assess the understanding of concepts at a meaningful learning level, some school teachers might be more committed to the assessment of a rote type of learning.

With regard to the V.R.Q., the researcher was able to get the data from only four schools, since the other four schools preferred to keep such information confidential. With respect to the available data, Table 8.9.B below shows the correlations between the pupils' scores on the tests constructed by the researcher and their V.R.Qs. Since the latter can be regarded as standardised at a national level, separate computation for each school was not essential in this case.

TABLE NO. 8.9.B

Pupils	Test	r
1 Fourth year	Diffusion & Osmosis	0.30 (162)
2 Fifth year	(i) Diffusion & Osmosis (ii) Water Potential (iii) Total score on both tests	0.31 0.26 0.37 (84)

N.B. (As with Table 8.9.A above)

From the data above, one can notice the following:

1. There are positive correlations between the scores of pupils on each of the constructed tests and their score in terms of V.R.Qs.

2. With regard to the diffusion and osmosis test, the correlation is higher than that of the water potential test. The reason could be because of the controversial nature of the water potential topic. Pupils studying it were provided with various points of view, namely: the views of the school books, the view of the new materials provided by the researcher, the views of teachers as far as they could compromise with the first two sources. This situation could lead to a confusion even with the most able pupil since the information provided could be contradictory.

8.10. Estimation of the Tests Reliability

The researcher investigated the reliability of the tests used in respect with the results obtained from their administration with the 'new materials' group. Three methods are usually followed in such investigations, namely:

(i) Repetition of the same tests.
(ii) Administration of second equivalent forms of the tests.
(iii) Subdivision of each test into two or more equivalent fractions. [195]

Length of biology syllabuses and teachers' commitments to cover them would not have allowed the researcher to repeat the tests for a second run. For this reason the researcher followed the third method, according to which he split up the results from two equivalent halves of the same tests. Since the overwhelming majority of the ideas were tested by more than one question each, one half of each test was made up of one question and the other half was made up of the other question for each idea. With regard to the limited number of ideas tested by one complex question, neither of the two halves included those single questions. Where an idea was tested by three questions, one of them was randomly discarded. This procedure was followed for both tests on diffusion and osmosis, and water potential. The assembled halves of the two tests are shown on Appendix No. 8.10.A. The correlation between the two halves of each test was computed, and the reliability coefficient for each was calculated by substitution in the 'Spearman-Brown Prophecy Formula':

$$r_{11} = \frac{2\, r_{\frac{1}{2}\frac{1}{2}}}{1+r_{\frac{1}{2}\frac{1}{2}}} \qquad (154)$$

The results were as follows:

Test / Pupils	Diffusion and Osmosis		Water Potential	
	$r_{\frac{1}{2}\frac{1}{2}}$	r_{11}	$r_{\frac{1}{2}\frac{1}{2}}$	r_{11}
1 Fourth year	0.76	0.86	-	-
2 Fifth year	0.75	0.85	0.69	0.82

Since the reliability coefficients are better than 0.8, this would suggest that both tests have performed reliably.

A further test of reliability, namely the 'Standard error of measurement', appears on Appendix 8.10.B.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

1. There is a gap in the pupils' learning between the fundamental concepts in the first and second year science and their use in understanding the relevant biology topics in the higher years. Examples of those concepts are: pressure, potential, concentration gradient, diffusion, dissolving in water and molecular movement of both water and dissolved substances. It was clear that pupils were not guided to recall and realise the relevance between such physical and chemical concepts and their present study of biology.[139]

2. As a consequence of this, pupils learned the biology topics by rote rather than by understanding meanings.

3. The learning which took place on laboratory models was not well linked to the relevant plant-soil situation.

4. The biology courses include highly abstract topics, which are beyond the reach of many of the pupils who are studying them. Those abstract topics need some means of making them visualisable in order to help pupils to construct valid mental images.

5. Teachers do not completely appreciate the teaching of the topic of water potential as it is represented by the syllabus, nor the need for furnishing their pupils with the required fundamental ideas from the domains of chemistry and physics.[149][151] Instead of helping their pupils to recall and link the already known ideas to the new topics, some teachers tend to seek the help of misleading analogies.

6. Terminal examinations are affecting the way by which teachers are teaching the topics. The majority of them prefer to treat those topics at a superficial level since the examiners do not usually assess for the learning of supporting or intermediate ideas.

7. Most of the school textbooks as well as the references used by biology teachers are adopting either misleading approaches to the topics, or a combination of old and modern terminology. Where mixed terminology is passed over to pupils, considerable confusion and difficulties arise.[(184)]

8. The observed success of the group of pupils who learned under the materials constructed by the researcher may be attributable to the following:

(a) The area was first of all subjected to careful diagnostic testing.

(b) Suitable media were chosen for the remedial purposes. Since fundamental ideas and concepts were missing from the pupils' cognitive structure, an informative printed material was provided. Also because the relevant subsumers were dynamic and molecular in nature, an animated film was provided to make them visualisable.

(c) The information provided to the pupils started from what they already knew, then developed gradually and gently to the required level. The use of terminology was kept to a minimum, and the learning of the core meaning of concepts was given priority over the mastery of labels. This helped them to integrate the superordinate concepts.

(d) The treatment of the higher level concepts on the new materials always made reference to the relevant basic ideas, which ensured a solid link between each concept and its scientific foundations.

(e) The printed new material presented the ideas in successive separate points, but relevant to one another. Summaries were also provided at the end of osmosis and water potential. This helped the pupils to 'chunk' the high information of these topics into a manageable number of units while learning each meaningfully.

(f) The plant-water relation was demonstrated in the materials by applying what had been discussed on the laboratory models to what was taking place in the plant. As a result they were able to extend learning to the plant-soil situation.

9. Learning hierarchies which are proposed according to an adult point of view do not necessarily coincide with the pupils' favoured routes. Many pupils would usually find an alternative way which enabled them to go directly from one lower idea to a relatively higher one skipping some of the intermediate ideas.

9.2 Recommendations

1. Syllabus designers should be careful in choosing topics where high abstraction is coupled with a large load of information.

2. Greater linkage between what goes on in the physical sciences and biological studies should be emphasised in school syllabuses. All science subjects should be looked on as resources for the development of conceptual understanding and a wide range of skills.

3. Biology syllabuses should be further reduced in length to give teachers time to construct the learning hierarchies properly for their pupils.

4. Biology syllabuses would be more suitable for mixed-ability classes if the treatment of the abstract and high information topics include 'core plus options'. The 'core' part should include the main concepts with

the least amount of explanatory ideas, which are completely consistent with the physical sciences. The 'options' should include more treatment at the different levels in order to provide the able and the less able pupils with suitable extra work.

5. Language used in textbooks should be checked by experts with a view to its drastic simplification. Mastery of sophisticated definitions does not necessarily help in the appreciation of biological phenomena.

6. When a new concept is to be introduced, teachers should anchor it firmly on to the subordinate principles in order to establish a meaningful learning net.

7. Since the new trend in biology education is to teach the subject descriptively as well as analytically,[137] the use of animated pictures should be used whenever appropriate to bridge the gap between the macro and the micro levels of treatment.

8. Criterion-referenced testing and diagnostic interviewing should be carried out in classes at reasonable intervals, especially when a difficult topic is being taught.

9. Remedial short courses should be designed for the least able pupils with respect to specific topics.

10. Biology examiners should aim at assessing pupils' learning up to the meaningful level rather than the superficial attainment of concept labels, definitions and rules in rote forms.

11. Analysis of other areas of high perceived difficulty in secondary school biology should be carried out. The areas of energy usage, genetics and osmo-regulation in living organisms are in need of investigation.

APPENDICES

Appendix No. 4.1.A.

Scottish Certificate of Education Examination Board - Report for 1976

"Presentations and Percentage of Awards on the 'Ordinary' Grade - All School Candidates"

	MALE						FEMALE						TOTAL					
	Present	% A's	% B's	% C's	% D's	% E's	Present	% A's	% B's	% C's	% D's	% E's	Present	% A's	% B's	% C's	% D's	% E's
Biology	5570	23.4	15.7	18.6	15.2	13.5	10526	18.6	15.8	20.6	17.5	15.1	16096	20.3	15.8	19.9	16.7	14.6
Chemistry	14270	32.8	14.3	20.5	13.3	11.3	8779	29.6	14.6	21.7	13.9	12.4	23049	31.6	14.4	21.0	13.5	11.7
Physics	17173	30.5	16.5	18.4	13.6	13.3	4423	34.9	18.6	19.1	12.4	10.0	21596	31.4	17.0	18.5	13.4	12.6

Presentations, Percentage per Grading and Percentage Pass on the 'Higher' Grade - All School Candidates

	MALE					FEMALE					TOTAL				
	Present	% A's	% B's	% C's	% Pass	Present	% A's	% B's	% C's	% Pass	Present	% A's	% B's	% C's	% Pass
Biology	2433	15.9	19.7	26.5	62.1	4061	8.9	17.0	26.6	52.5	6494	11.5	18.0	26.6	56.1
Chemistry	7686	15.2	22.2	32.6	69.9	4188	9.7	19.8	34.5	64.0	11874	13.2	21.3	33.2	67.8
Physics	9377	11.5	20.8	30.5	62.8	2440	10.1	23.4	33.0	66.4	11817	11.2	21.4	31.0	63.3

(Extracted from reference no. 124 p. 50,58)

Appendix No. 4.3.A.

'Objectives in the teaching of biology for Scottish Secondary Schools'

(Extracted from reference No. 47, pp.6-8.)

OBJECTIVES IN THE TEACHING OF BIOLOGY

A In the cognitive domain, the pupils should acquire the ability to:

1. recall (a) specific biological facts
   (b) biological terms
   (c) concepts in biology
   (d) biological principles
   (e) theories in biology
   (f) practical techniques used in biology

2. apply this knowledge to familiar situations and also to unfamiliar situations.

3. recall some of the ways in which biological knowledge is applied in other fields.

4. observe and describe objects and phenomena accurately.

5. recognise the need for measurements, to select appropriate instruments, and to recognise limits of accuracy of such instruments.

6. recognise biological problems: such problems are often characterised by a range of interacting variables.

7. formulate working hypotheses and devise tests for them, using controls where appropriate.

8. interpret data, and to interpolate and extrapolate from them.

9. formulate generalisations in the light of both first-hand and second-hand evidence.

10. communicate, using an adequate scientific vocabulary, and by other appropriate means.

B In the affective domain, the pupils should acquire:

11. an interest and enjoyment in studying living

organisms and their inter-relationships.

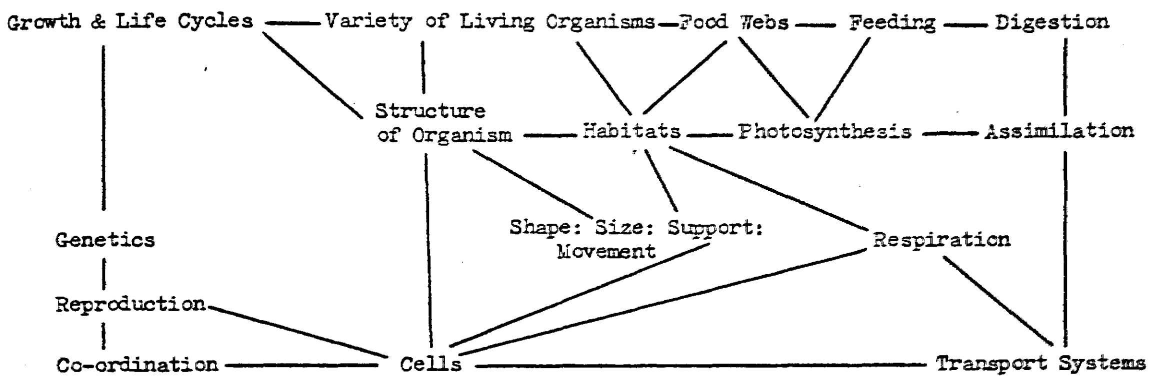
12. a respect for living things, based on an understanding of life processes and inter-relationships.
13. an objective attitude towards evidence.
14. a critical, enquiring mind.
15. an awareness that the body of biological knowledge is not static.
16. an awareness of the need for appropriate safety procedures.
17. an awareness of both the usefulness and limitations of hypotheses in making predictions and describing biological phenomena.
18. an awareness of the interdependence of all branches of science and mathematics in scientific progress.
19. an awareness of the contributions of biologists to the development of knowledge.
20. an awareness of the social implications of biological knowledge and ideas.

C In laboratory skills, including the psychomotor domain, the pupils should acquire the ability to:

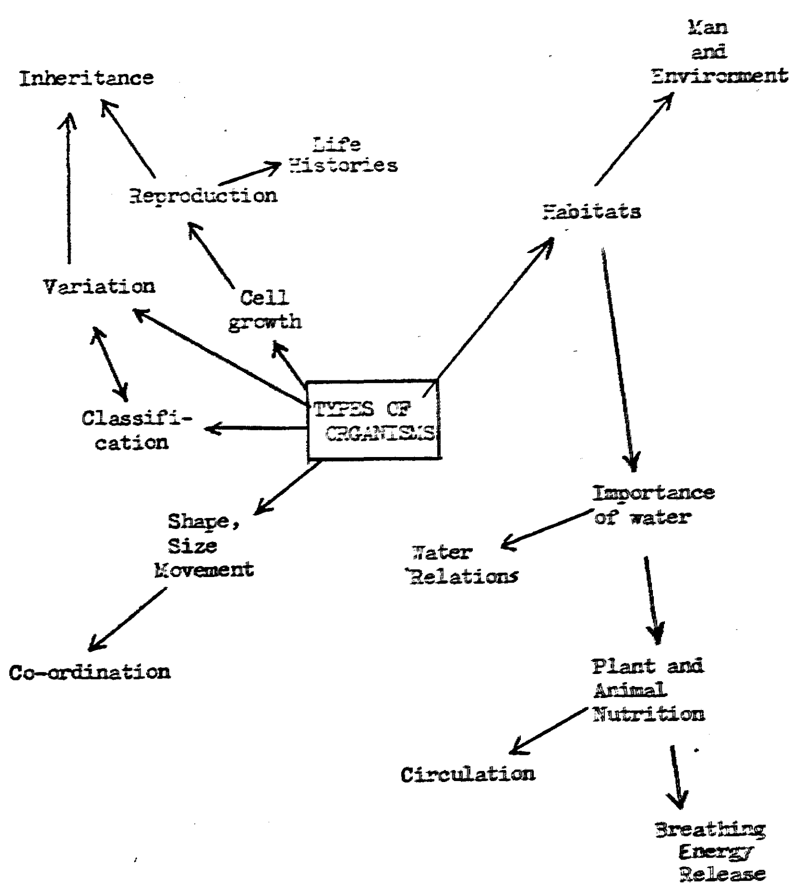
21. use instruments and apparatus to the limits of accuracy appropriate to a given problem.
22. perform common laboratory techniques and handle living organisms with care and safety.

Appendix No. 4.3.B. 'Interdependent nature of the school biology concepts (Extracted from ref. no. 47, pp.9-13).

FLOW DIAGRAM 1. A GENERAL INTER-RELATIONSHIP OF FUNDAMENTAL TOPICS

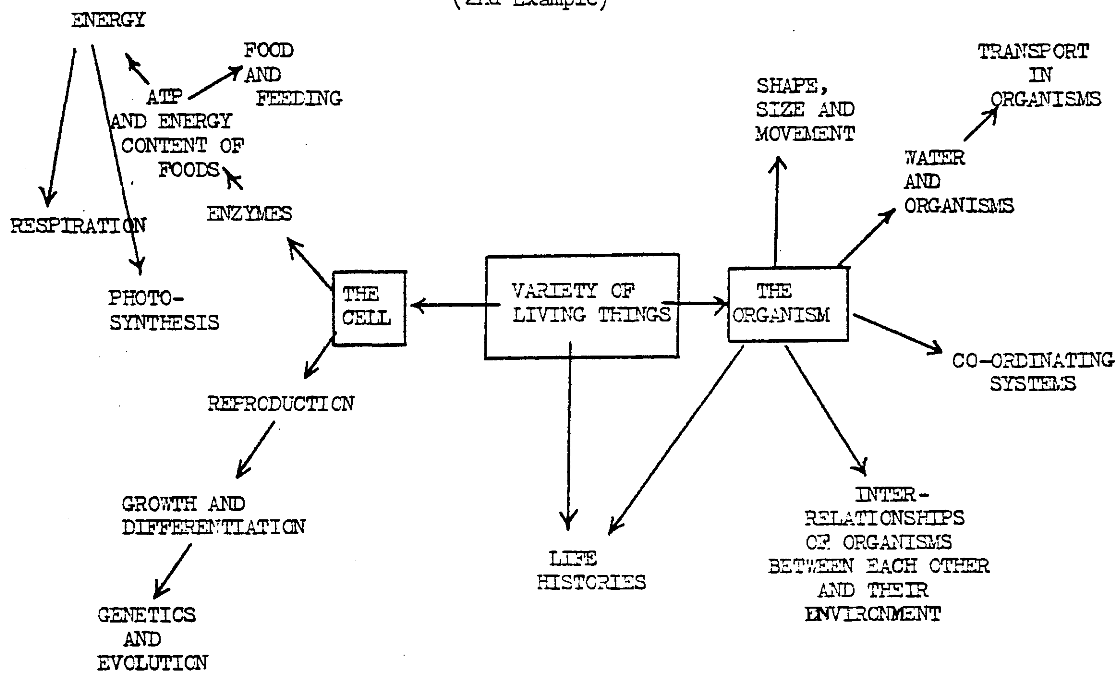


FLOW DIAGRAM 2. POSSIBLE SEQUENCES BASED ON DIVERSITY OF FORM (1st Example)

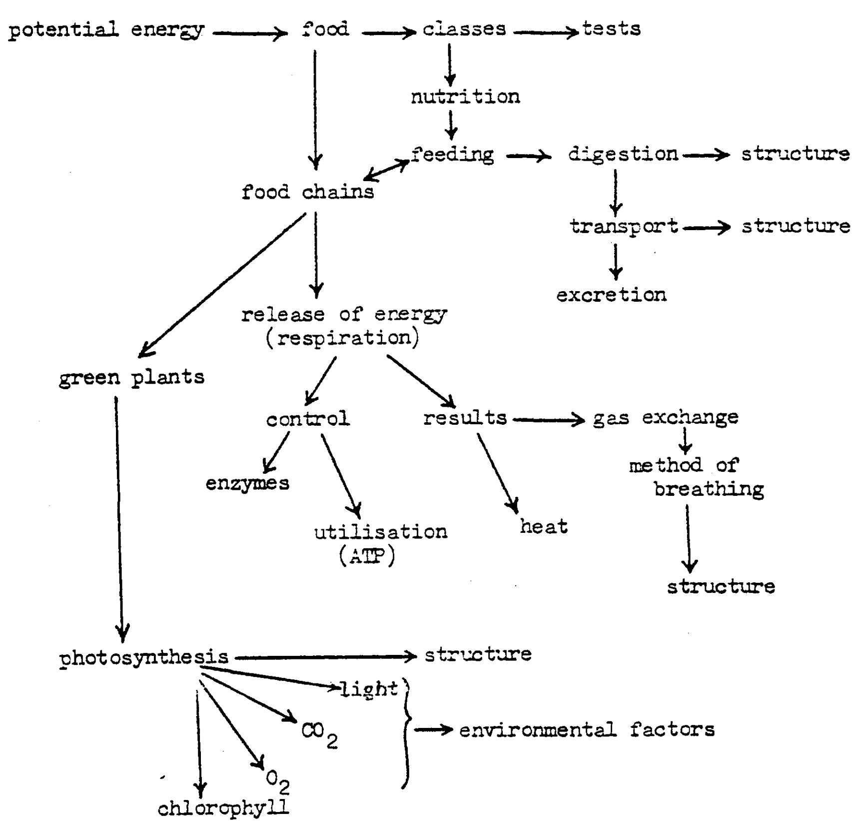


(Continued)

FLOW DIAGRAM 3. POSSIBLE SEQUENCES BASED ON DIVERSITY OF FORM
(2nd Example)



FLOW DIAGRAM 4. POSSIBLE SEQUENCES BASED ON ENERGY AS A TOPIC



Appendix No. 4.6.A.

QUESTIONNAIRE TO THE BIOLOGY TEACHERS

(The questionnaire as appeared on reference no. 148, and the results as gathered from reference no. 149.)

1. The Biology Syllabus is too long to cover adequately in the time available, especially if it is taught "By Inquiry".

Any comment:

Agree	86%
Disagree	11%
No opinion	3%

2. Section IV(7)(a) The first topic should be reworded as follows: "Cleavage and development of embryos up to gastrulation, as seen in one of Echinus, Rhabditis, Planorbis, Pomatoceros".

Any comment:

Agree	86%
Disagree	8%
No opinion	6%

3. Section IV(7)(b) Homeorhesis should be omitted completely.

Any comment:

Agree	59%
Disagree	35%
No opinion	6%

4. Section IV(3)(b) The wording should be changed to:

Solutions and diffusion.	Diffusion of solutes and gases. Importance in cells and organisms.
Osmosis and Cells.	Osmosis as water diffusion. Cells as osmotic systems. Types of cell membranes. Reversible volume changes in cells and tissues established by experiments on varied materials: e.g. Visking tubing models, potato slices. Importance of osmosis, including turgor. Plasmolysis and haemolysis.

Water Potential	A simple treatment of water potential, but excluding measurement and other quantitative aspects. Definition in simple terms. Relationship with osmotic potential. Value of concept in biological systems. Water Potential gradients: e.g. soil-root, leaf-atmosphere.

Any comment:

Agree	75%
Disagree	20%
No opinion	5%

Name:......................

School:....................

Appendix No. 5.2.A

Sample of the check list used during observations of biology lessons inside classrooms.

Lesson: .... School year: ....

I Experiments/practical demonstrations: ( ) needed but not used
( ) needed and used

1. Time devoted: ( ) insufficient
( ) sufficient
( ) exceeded the need at the expense of other activities.

2. Theoretical background relevant to experiment or demonstration:
( ) by-passed
( ) moderately discussed
( ) thoroughly discussed

3. Procedural steps:
( ) mainly dictated by teacher or printed text
( ) moderately discussed
( ) thoroughly discussed and explained

4. Results of experiment or demonstration:
(i) ( ) were determined beforehand
( ) were observed first time as they took place
(ii) ( ) were discussed in a hurry
( ) were moderately discussed
( ) were thoroughly discussed

II Demonstrations on specimens, models, slides and similar A-V aids:
( ) needed but not used
( ) needed and used

1. Time devoted: ( ) insufficient
( ) sufficient
( ) exceeded the need at the expense of other activities

2. Choice of material:

( ) not suitable for the lesson
( ) not suitable for the pupils' level
( ) suitable for both lesson and pupils

3. Usage of material

( ) not suitable for pupils' level
( ) suitable for pupils' level

III Academic knowledge:

1. Time devoted:

( ) insufficient
( ) sufficient
( ) exceeded the need at the expense of other activities

2. Linkage with previously studied knowledge over the years:

( ) not given any concern
( ) given some concern
( ) given all concern

3. Terminology used:

( ) superficially discussed
( ) made simple for the average pupils
( ) made simple for even the least able pupils

4. Discussion of facts:

( ) beyond the level of many pupils
( ) fit with the average pupils
( ) fit with even the least able pupils

IV Evaluation of the learning levels of pupils:

1. Spread over the lesson time:

( ) postponed to the end of the lesson
( ) distributed over the lesson time

2. Points of concern:

( ) the memorisation of sheer facts and the labelling names of concepts
( ) the understanding of ideas and concepts included in the lesson.

Appendix No. 5.4.1.A

The general questionnaire distributed among the biology teachers at 18 secondary schools throughout Scotland.

Dear Colleague,

On this questionnaire we are seeking your opinion on the relative difficulty of each of the topics which are included in the biology syllabuses in hand. Here you find a list of these topics with a column at the extreme right-hand to indicate your estimate of how difficult your pupils find the topic. If you make no entry in this column we shall take it that you mean the topic is average while the notations 'Very easy' (✓✓), 'Easy' (✓), 'Difficult' (X) and 'Very Difficult' (XX) should be used to denote any other shades of opinions. We hope that all the teaching staff in the biology department will participate in filling in this questionnaire.

Many thanks for your co-operation.

Serial No.	Syllabus No.	Topic	Record of the Results					
			✓✓	✓	-	X	XX	Total no. of 'X' & 'XX'
1	I(1)	Diversity of form	1	10	7	0	0	0
2	(2)	Plants classification	1	4	7	4	2	6
3		Animals classification	1	3	8	4	2	6
4	(3)	Types of habitat	1	5	12	0	0	0
5	(4)	Effects of variation in biological habitat	0	5	12	1	0	1
6	(5)	The orderly investigation of living organisms	0	3	11	3	0	3
7	(6)	Variation within an organism	2	7	7	2	0	2
8	(7)	Brief examination of a mammal to show complexity of structure	0	4	13	1	0	1
9		Brief examination of an Angiosperm to show complexity of structure	1	2	13	2	0	2
10	II(1)	Cell structure	0	6	10	1	1	2
11	(2)	Cell division and cell growth	0	2	6	9	1	10
12	(3)	Cell organelles	1	3	9	5	0	5
13		DNA and its replication	1	2	6	7	2	9
14	III(1)(a)	Energy forms and interconversions	0	4	10	3	0	3
15	(b)	Foods and energy, qualitative tests, energy content of foodstuffs	2	8	8	0	0	0
16		ATP	0	2	5	8	3	11
17	(c)	Enzymes, transfer of organic compounds, effects of pH and temperature on enzymes	0	3	9	6	0	6
18	(2)(a)	Solar radiation, energy input into biological systems	0	3	13	2	0	2
19	(b)	Plants as producers of new organic matter	2	6	10	0	0	0
20		Consumers, energy transfer, web of life	3	5	9	1	0	1

Serial No.	Syllabus No.	Topic	Record of the Results					
			✓✓	✓	-	X	XX	Total no. of 'X' & 'XX'
21	III(3)(a)	Photosynthesis, elementary introduction	1	3	7	5	2	7
22		Chemistry of photosynthesis	0	0	4	5	9	14
23	(4)(a)	Respiration and energy release	0	2	6	7	3	10
24	(b)	Chemistry of respiration	0	0	3	7	8	15
25	(5)	Comparison of respiration with photosynthesis	0	3	8	5	2	7
26	IV (1)(a)	Modes of nutrition	2	4	9	3	0	3
27	(b)	Feeding in animals	2	2	11	3	0	3
28	(c)	Digestion and adsorption	2	1	8	7	0	7
29	(d)	Food assimilation	0	2	9	6	1	7
30	(e)	A balanced diet	2	8	8	0	0	0
31		Determination of V.C. content of food using DCPIP	1	6	9	2	0	2
32		Effect of cooking on vitamins	1	6	11	0	0	0
33	(2)(a, b,c,d)	Breathing in man and other animals	0	4	9	5	0	5
34	(e)	Gas exchange in plants	0	4	9	5	0	5
35	(f)	Ecological aspects of gas exchange	0	4	9	4	1	5
36	(3)(a)	Importance of water to life	2	6	10	0	0	0
37	(b)	Diffusion and osmosis	0	2	5	7	4	11
38		Water potential	0	1	2	3	12	15
39	(c)	Water loss or gain by osmosis	0	2	6	6	4	10
40		Role of kidney	0	1	8	8	2	10
41		Water uptake by roots	1	4	9	3	1	4
42		Transpiration	2	4	10	2	0	2
43		Structure of leaves	1	5	9	2	1	3
44		Stomatal mechanism and factors affecting transpiration	0	3	9	4	2	6
45		Water balance in man and in various animals and plants	0	0	6	8	4	12
46	(d)	Inorganic solutes and organisms	0	3	10	3	2	5

Serial No.	Syllabus No.	Topic	Record of the Results					
			✓✓	✓	-	X	XX	Total no. of 'X' & 'XX'
47	(4)(a)	The need for transport systems in plants and animals	1	4	11	2	0	2
48	(b)	Circulatory systems in vertebrates	0	3	10	4	1	5
49		Hormonal and nervous control	0	2	4	10	2	12
50		Types of circulatory systems	0	3	9	5	1	6
51	(c)	Basic plant anatomy	0	4	11	3	0	3
52		Water transport in woody shoots as an enquiry	0	2	12	4	0	4
53		Movement of solutes, ringing experiments	0	4	10	4	0	4
54		Evidence from radio-active isotopes	0	4	8	6	0	6
55	(5)(a, b)	Shape and support in different plants and animals	1	4	11	2	0	2
56	(c)	Locomotion in animals	0	4	12	2	0	2
57	(d)	Movement in plants	2	4	12	0	0	0
58	(e)	Size and surface area	0	4	10	4	0	4
59		Skin structure and function	0	4	13	1	0	1
60		Adaptation of animals and plants in cold and hot climates	0	6	11	1	0	1
61	(6)(a)	Asexual reproduction	0	4	12	2	0	2
62		Vegetative reproduction in animals	0	5	11	1	1	2
63	(b)	Sexual reproduction in plants	0	2	12	4	0	4
64		Sexual reproduction in animals	0	3	11	5	0	5
65	(7)(a)	Growth and differentiation in embryos	0	0	7	7	4	11
66		Growth and differentiation in meristems	0	1	9	7	1	8
67	(b)	Control of development by hereditary material	0	1	7	7	3	10
68		Effect of environment on development	0	2	8	8	0	8

Serial No.	Syllabus No.	Topic	Record of the Results ✓✓	✓	-	X	XX	Total no. of 'X' & 'XX'
69		Glands, growth substances and hormones	0	2	9	6	1	7
70	(c)	Life histories	0	2	10	6	0	6
71	(8)(a)	Human skin, eye and ear	0	3	13	2	0	2
72		Photoreceptors and chemoreceptors	0	3	13	2	0	2
73	(b)	Response to environment, simple experiments	0	4	14	0	0	0
74		Photoperiodism, cyclic responses, behaviour	0	3	11	4	0	4
75	(c)	Mammalian kidney and excretion	0	0	12	4	2	6
76		Osmoregulation in Paramecium and fish	0	0	10	4	4	8
77		CO_2 and regulation of breathing	0	1	11	6	0	6
78		Hormones	0	3	11	4	0	4
79		Central nervous system in man	0	1	9	4	4	8
80	V(1)(a)	Variation within a species	1	5	11	1	0	1
81	(b,c)	Gametes as vehicles of inheritance and pattern of inheritance	0	0	7	6	5	11
82	(2)(a,b c)	Mendel's factors, DNA and RNA, linkage and crossing over and mutation	0	0	5	7	6	13
83	(3)(a,b c)	Evolution	0	2	9	4	3	7
84	VI(1)	Properties and importance of soil	3	4	9	2	0	2
85	(2)	Ecosystems	2	2	10	4	0	4
86	(3)	Man and micro-organisms	0	4	10	4	0	4
87	(4)(a)	Uses and abuses of pesticides	4	7	7	0	0	0
88	(b)	Crops soil and competition	4	7	7	0	0	0
89	(c)	Control of environmental pollution	10	6	2	0	0	0
90	(d)	Aspects of land use	10	6	2	0	0	0
91	(e)	Conservation	10	6	2	0	0	0

Appendix No. 5.4.2.A

"The second concentrated questionnaire distributed among the biology teachers at nine secondary schools in the Greater Glasgow Area."

Dear Colleague,

On this questionnaire we are seeking your opinion on the relative difficulty of each topic on the attached lists. You are requested to indicate your estimate of how difficult your pupils find the topic. If you make no mark opposite to a topic, we shall take it that you mean the topic is average while the notations 'Very easy' (✓✓), 'Easy' (✓), 'Difficult' (X) and 'Very difficult' (XX) should be used to denote any other shades of your opinions. We hope that all the teaching staff in the biology department will participate in filling in this questionnaire.

Many thanks for your co-operation.

UNIVERSITY OF GLASGOW

"A Questionnaire on The Secondary School Biology Syllabuses"

List of Topics

I. Ordinary Grade:

( ) 1. Plant and animal classification.
( ) 2. Cell structure and cell division.
( ) 3. Chemical energy and energy from food.
( ) 4. Enzymes in general.
( ) 5. Photosynthesis.
( ) 6. Aerobic and anaerobic respiration.
( ) 7. Feeding and digestion.
( ) 8. Breathing and gas exchange between living organisms and their environment.
( ) 9. Diffusion, osmosis, turgor and plasmolysis.
( ) 10. Control of water content inside living organisms.
( ) 11. Size, surface area and heat loss in animals.
( ) 12. Development of insects and birds from egg to adult.
( ) 13. Central nervous system, hormones and co-ordination inside the human body.
( ) 14. Gametes.
( ) 15. Alleles, genes and Mendel's work.
( ) 16. Different types of soil and nitrogen cycle.

II. Higher Grade:

( ) 1. DNA and RNA.
( ) 2. Cell structure and cell division.
( ) 3. Chemical energy.
( ) 4. Chemistry of photosynthesis.
( ) 5. Chemistry of respiration.
( ) 6. Gas exchange between living organisms and their environment.
( ) 7. Osmosis and water potential.
( ) 8. Role of the kidney.
( ) 9. Water balance problems and osmo-regulation in living organisms.
( ) 10. Reproduction and growth in living organisms.
( ) 11. Hormones.
( ) 12. Gametes.
( ) 13. Genes.
( ) 14. Evidence for evolution.
( ) 15. Mechanism of evolution.

Appendix No. 5.4.2.B

UNIVERSITY OF GLASGOW

A Questionnaire on The Secondary School Biology Syllabuses

Pupil Instructions

We are interested in having your views about the biology course you have been studying. On the next sheet there is a list of topics and you will be asked to judge each one for difficulty. You can be sure that the answers you give will not be held against you in any way and so you can be quite frank in your opinions.

To complete this questionnaire you will need

(1) One pink computer card
(2) A soft pencil
(3) A number (your teacher will give you). This number will have three digits. If you are number nine, shade C09. If you are number 36, shade 036.
(4) The code number for your school (your teacher will tell you it).

How to fill in the card:-

The computer cannot read normal writing and so you have to show your choice by shading one of the oval spaces in each column. The shading should be done with a soft pencil and it should be marked until the oval looks glossy.

(a) Fill in the left hand part of the card as shown in the diagram.
(b) Ignore the lower part of the right hand side of the card.
(c) If you want to change your answer, rub out the pencil mark with an ordinary rubber and shade in another oval.
(d) Attempt all the questions and answer them quickly. Your first impression will probably be the right one. Answer the topics in the numbered columns in the middle section of the card.
(e) i) If you think a topic has been easy to learn (that is, you understood it first time) shade in the oval marked E (for easy).
   ii) If you think a topic was of average difficulty (that is, you had to work at it to understand it) shade in the oval A (for average).
   iii) If you think a topic was difficult to learn (that is, you had to struggle with it and you are still not clear) shade in oval D (for difficult).
   iv) Shade in oval B when you face a question on a topic which you have not yet studied in the school. You will have to consult your teacher in such a case.

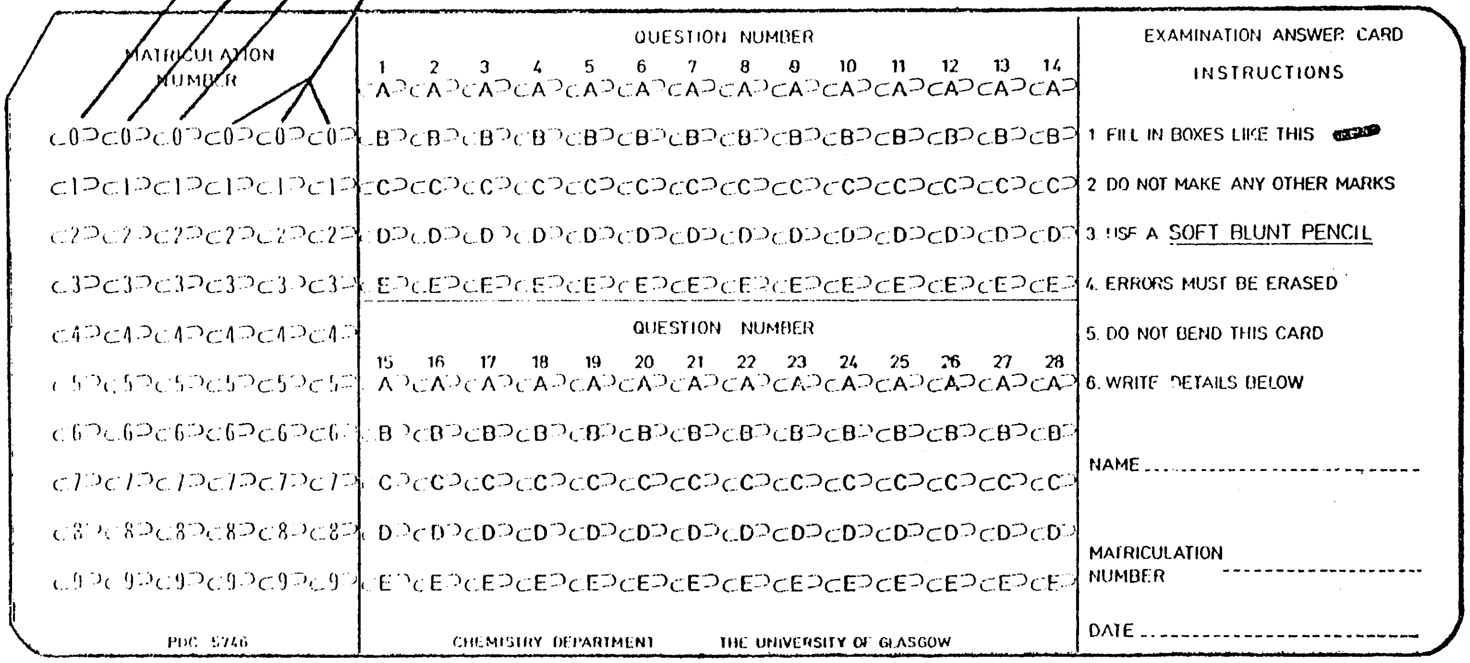
Don't use ovals marked C in your answers.

Column for your school code number (your teacher will tell you)

Column for your year of study (shade either oval 4 or 5 as suitable)

Column for your sex (shade oval 1 for a boy, or 2 for a girl)

Columns for your serial number on the class list



UNIVERSITY OF GLASGOW

"A Questionnaire on The Secondary School Biology Syllabuses"

List of Topics

I. Ordinary Grade:

( ) 1. Plant and animal classification.
( ) 2. Cell structure and cell division.
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( ) 4. Enzymes in general.
( ) 5. Photosynthesis.
( ) 6. Aerobic and anaerobic respiration.
( ) 7. Feeding and digestion.
( ) 8. Breathing and gas exchange between living organisms and their environment.
( ) 9. Diffusion, osmosis, turgor and plasmolysis.
( ) 10. Control of water content inside living organisms.
( ) 11. Size, surface area and heat loss in animals.
( ) 12. Development of insects and birds from egg to adult.
( ) 13. Central nervous system, hormones and co-ordination inside the human body.
( ) 14. Gametes.
( ) 15. Alleles, genes and Mendel's work.
( ) 16. Different types of soil and nitrogen cycle.

II. Higher Grade:

( ) 1. DNA and RNA.
( ) 2. Cell structure and cell division.
( ) 3. Chemical energy.
( ) 4. Chemistry of photosynthesis.
( ) 5. Chemistry of respiration.
( ) 6. Gas exchange between living organisms and their environment.
( ) 7. Osmosis and water potential.
( ) 8. Role of the kidney.
( ) 9. Water balance problems and osmo-regulation in living organisms.
( ) 10. Reproduction and growth in living organisms.
( ) 11. Hormones.
( ) 12. Gametes.
( ) 13. Genes.
( ) 14. Evidence for evolution.
( ) 15. Mechanism of evolution.

Appendix No. 5.5.1.A

Bloom's taxonomy of cognitive educational objectives

1.00 Knowledge:

1.10 K. of specifics:

1.11 K. of terminology, such as scientific terms, symbols, definitions and meanings of scientific words.

1.12 K. of specific facts, such as names of scientists, dates of events and characteristics of an organism or a chemical reagent.

1.20 K. of ways and means of dealing with specifics:

1.21 K. of conventions, such as the ways of expressing the gynotype of an organism or reporting on a reaction between chemicals.

1.22 K. of trends and sequences, such as the cause and effect relationship between temperature and photosynthesis.

1.23 K. of classification and categories, such as the major phyla of animal kingdom and the relevancy of an organism to one of them.

1.24 K. of criteria, such as those used to classify a phylum into subphyla.

1.25 K. of methodology, such as those used to determine the rate of transpiration.

1.30 K. of universals and abstractions in a field:

1.31 K. of principles and generalizations, such as rules of osmosis and laws of heredity.

1.32 K. of theories and structures, such as that of organic evolution.

2.00 Comprehension:

2.10 Translation, such as explaining the meaning of a given gynotype formula or explaining a graphically represented relation in own words.

2.20 Interpretation, such as understanding a scientific report on an experiment and grasping the thought behind it.

2.30 Extrapolation, such as extending a given fact about vital relations between organisms in an echosystem to the effect of introducing a new one to that system.

3.00 Application:

Such as applying his knowledge and comprehension of that knowledge in solving problem situation which is completely new to him. Identification of the direction of water flow between two cells according to the rules of water potential is an example of this category.

4.00 Analysis:

4.10 Analysis of elements, such as distinguishing facts from hypothesis while studying Mendel's work.

4.20 Analysis of relationships, such as that between the evidence revealed through an experiment on the starch content of a leaf before and after a period of illumination and the conclusion about the effect of light on sugar formation and storage.

4.30 Analysis of organizational principles, such as seeing the common techniques generally used in the controlled type of experiments.

5.00 Synthesis:

5.10 Synthesis of a unique communication, such as forming a report of an experiment which was not presented in a book or illustrating a relation between the salinity of a culture and the frequency of the hatching number of toad eggs in a graphical representation.

5.20 Synthesis of a plan of operation, such as designing an experiment to determine the optimum temperature required for the maximum flourishment of a specific kind of yeast.

5.30 Synthesis of a set of abstract relations, such as deducing the rule that governs the relation between the position of an organism on the evolutionary scale and the level up to which his different systems have developed.

6.00 Evaluation:

6.10 Judgments in terms of internal evidence, such as validating the conclusion drawn from an experiment with regard to the precautions taken.

6.20 Judgments in terms of external criteria, such as comparing two theories of evolution one to the other.

(Titles and sub-titles were extracted from reference no. 12, whereas details were constructed by the researcher.)

Appendix No. 5.5.2.A

The Six Sub-Tests

6. Which one of the following organisms carries out photosynthesis?

*A) Spirogyra
B) Mushroom
C) Yeast
D) Mold

7. Which one of the following pairs of statements is true?

	Aerobic Respiration		Photosynthesis
A)	Occurs in all plants and animals all the time without exception.	A)	Occurs in all plants all the time without exception.
B)	Takes place in higher organisms but not in micro-organisms.	B)	Takes place in higher plants but not in microscopic ones.
C)	Oxygen is taken in, whereas carbon dioxide is given out, and the organism gains weight.	C)	Oxygen is given out, whereas carbon dioxide is taken in, and the organism loses weight.
* D)	ATP is formed with the essential help of sugars, then breaks down later.	D)	ATP is formed with the essential help of solar energy, then breaks down later.

8. A plant was undergoing a vital process when the surrounding conditions changed suddenly. Hence, it 'switched' to another vital process. The following two equations show the two vital processes consequently

1. $C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6H_2O$ + Energy

2. $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ + Energy

Which one of the following reports shows the sequence of events correctly?

A) The plant performed photosynthesis, then switched to respiration.
B) The plant performed respiration, then switched to photosynthesis.
C) The plant performed anaerobic respiration, then switched to fermentation.
*D) The plant performed aerobic respiration, then switched to anaerobic fermentation.

9. Which one of the following is true?

A) Maltase is activated in the stomach by hydrochloric acid.
B) Lipase splits up lipids to proteins and fatty acids.
*C) Amylase breaks down starch into sugar.
D) Pepsinogen is the active form of pepsin.

10. For which of the following reasons do bakeries <u>mainly</u> use yeast in their dough?

*A) It produces CO_2.
B) It produces energy.
C) It produces ethanol.
D) It breaks down the sugar content of the flour.

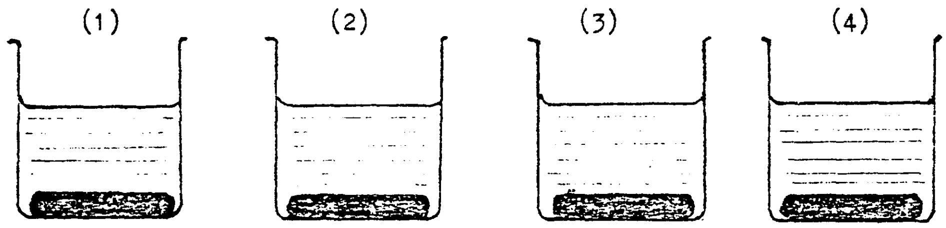
11. Assuming that a runner is not to be supplied with extra oxygen after finishing a hard competition in a long race, which one of the following things would happen to him?

* A) His muscles would suffer from a long term fatigue.
B) Anaerobic respiration would start to take place inside his muscles.
C) Ethanol and CO_2 would accumulate in his muscles causing him a great deal of pain.
D) Oxygen would accumulate in his body but his muscles would not be able to make use of it.

12. Without being stirred, sugar particles can move throughout a cup full of tea until they become evenly distributed. This phenomenon is called

A) plasmolysis
* B) diffusion
C) turgidity
D) osmosis.

13. The following figures show different treatments applied to four slices of beetroots. After being washed thoroughly with tap water, each slice was placed in one of the liquids as below.

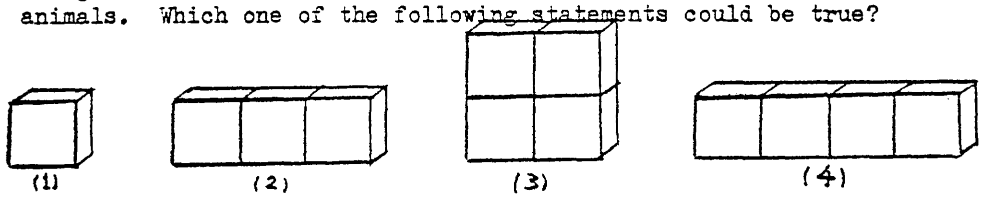


Cold water | Concentrated solution of common salt. | Boiling water | Ether

Which one of the following statements is true?

* A) Red colour flows out of the slice in beaker No.3 because cell membranes have been destroyed by boiling water.
B) Red colour does not flow out of the slice in beaker No. 4.
C) Turgidity occurs in the slice placed in beaker No. 2.
D) Plasmolysis occurs in the slice placed in beaker No. 1.

14. Assuming that the following diagrams could resemble different shapes of animals. Which one of the following statements could be true?



A) Animal No. (1) is the most suitable for cold weather, whereas No. (3) is the most suitable for hot weather.
* B) Animal No. (3) is the most suitable for cold weather, whereas No. (1) is the most suitable for hot weather.
C) Animal No. (4) is the most suitable for cold weather, whereas No. (1) is the most suitable for hot weather.
D) Animal No. (2) is the most suitable for cold weather, whereas No. (4) is the most suitable for hot weather.

15. An insect is said to undergo a complete metamorphosis if it goes through the sequence: egg → larva → pupa → adult.

    Which of the following insects shows complete metamorphosis?

    A) The locust
    B) The dragonfly
    C) The cockroach
    * D) The large white butterfly.

16. Which one of the following sentences is true?

    A) Kidney breaks down surplus amino acids in order to get rid of them directly.
    B) Lungs sense the CO_2 concentration in blood and adjust the rate of breathing accordingly.
    * C) The blood stream carries information to ductless glands, and carries back their secretions.
    D) The liver produces a hormone which stimulates the pancreas to produce digestive enzymes.

17. Which one of the following compounds regulates the conversion of glycogen to glucose?

    A) Bile
    B) Insulin
    C) Secretin
    * D) Adrenalin

18. Which of the following are the human gametes?

    * A) The sperms and ova
    B) The testes and ovaries
    C) The reproductive organs of males and females
    D) The embryos inside the uteruses of pregnant women

19. Which one of the following symbols could refer to a homozygous organism?

    A) Bb
    B) Aa
    * C) AA
    D) Aa Bb

20. With reference to different types of soil, which of these groups of statements is completely correct?

    A) Light soil is the best for aeration
       Heavy soil is the best for withstanding droughts
       Acid soil is the best in general

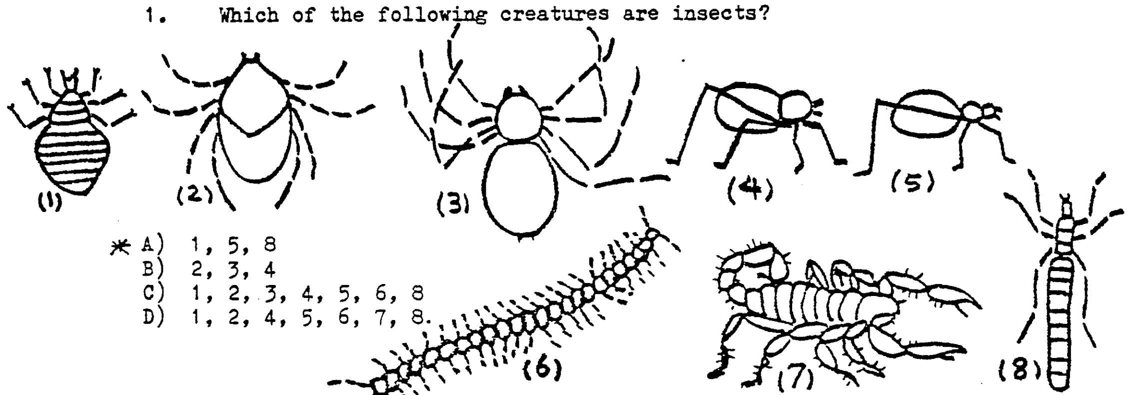
    B) Loam soil is the best for aeration
       Acid soil is the best for withstanding droughts
       Heavy soil is the best in general

    C) Heavy soil is the best for aeration
       Light soil is the best for withstanding droughts
       Loam soil is the best in general

    * D) Light soil is the best for aeration
       Heavy soil is the best for withstanding droughts
       Loam soil is the best in general.

'O' Grade Sub-Test No. (2)

1. Which of the following creatures are insects?

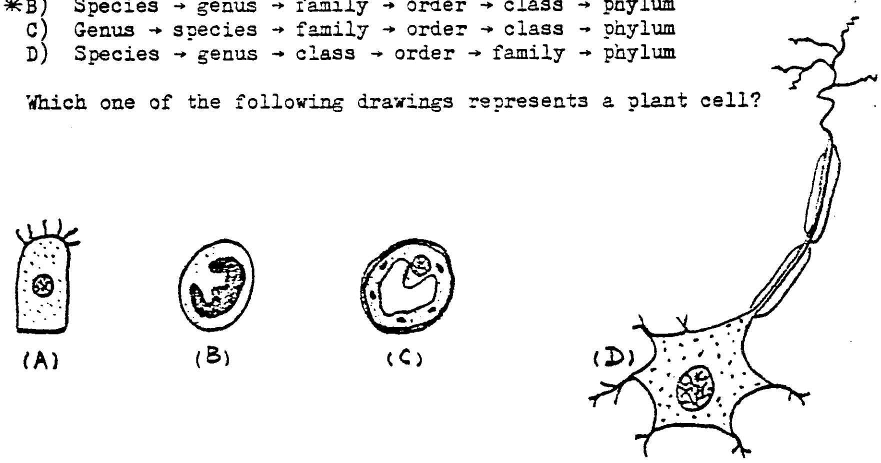


*A) 1, 5, 8
B) 2, 3, 4
C) 1, 2, 3, 4, 5, 6, 8
D) 1, 2, 4, 5, 6, 7, 8.

2. The correct sequence of the groups involved in the scientific classification scheme of living organisms is:

A) Species → family → genus → class → order → phylum
*B) Species → genus → family → order → class → phylum
C) Genus → species → family → order → class → phylum
D) Species → genus → class → order → family → phylum

3. Which one of the following drawings represents a plant cell?



4. Which of the following procedures has to be carried out in order to get the energy required for vital processes?

A) ADP has to be built up
*B) ATP has to be broken down
C) Glucose has to be reduced
D) Fats have to be reduced.

5. Which of the following names is used for a protein compound which acts as a catalyst in a specific chemical reaction inside living organisms?

A) A hormone
*B) An enzyme
C) An auxin
D) Ribonucleic acid

6. A green and white variegated leaf of geranium is taken from a plant grown in bright sunlight. After it is decolourised and treated with iodine the result will be

A) brown all over
B) black all over
* C) black where it was green and brown where it was white
D) brown where it was green and black where it was white

7. Which one of the following pairs of statements is true?

Aerobic respiration	Photosynthesis
A) Occurs in all plants and animals all the time without exception.	A) Occurs in all plants all the time without exception.
B) Takes place in higher organisms but not in micro-organisms.	B) Takes place in higher plants but not in microscopic ones.
C) Oxygen is taken in, whereas carbon dioxide is given out, and the organism gains weight.	C) Oxygen is given out, whereas carbon dioxide is taken in, and the organism loses weight.
* D) ATP is formed with the essential help of sugars, then breaks down later.	D) ATP is formed with the essential help of solar energy, then breaks down later.

8. Which one of the following equations represents what happens during aerobic respiration?

A) $n\ C_6H_{12}O_6 \rightarrow (C_6H_{10}O_5)_n + n\ H_2O + \text{energy}$

B) $C_6H_{12}O_6 + 6O_2 \rightarrow 2C_2H_5OH + 2CO_2 + \text{energy}$

* C) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$

D) $6CO_2 + 6H_2O + \text{radiant energy} \rightarrow C_6H_{12}O_6 + 6O_2 + \text{energy}$

9. A diabetic person has to be treated regularly with insulin. Which of the following functions would the insulin help his body to perform?

A) To split up starch food into simple sugars
B) To oxidize the glucose to produce the necessary energy for work and growth.
C) To absorb already digested sugars from the small intestine into the blood stream.
* D) To make use of the sugar which is absorbed into his blood stream by directing some to be stored as glycogen and other amounts to be oxidized.

10. For which of the following reasons do bakeries <u>mainly</u> use yeast in their dough?

* *A) Because it produces CO_2
* B) Because it produces energy
* C) Because it produces ethanol
* D) Because it breaks down the sugar content of the flour.

11. In respect of breathing and gas exchange in living organisms, which one of the following statements is true?

* A) The smaller the volume of the organism, the more difficulty it finds in fulfilling all its needs of oxygen through the outer surface exchange of gases.
* B) The bigger the volume of the organism, the less extensive its respiratory surfaces.
* C) The dryer the respiratory surface, the easier the exchange of gases through it.
* *D) All respiratory surfaces in all living organisms are moist in order to achieve successful gas exchange.

12. Without being stirred sugar particles can move through a cup full of tea until they become evenly distributed. This phenomenon is called -

* A) plasmolysis
* *B) diffusion
* C) turgidity
* D) osmosis

13. A certain gland disorder causes a person to have high blood concentration because his kidney eliminates too much water. Which gland is affected?

* A) Thyroid
* B) Salivary
* *C) Pituitary
* D) Parathyroids

14. Which one of the following mathematical calculations is used to detect which animal, within a variety of animals, is losing less body heat through radiation?

* A) $\frac{\text{Total body volume}}{\text{Total body surface area}}$ [The smaller the answer the less the heat loss]
* *B) $\frac{\text{Total body surface area}}{\text{Total body volume}}$ [The smaller the answer the less the heat loss]
* C) Total body surface area x Total body volume [The smaller the answer the smaller the heat loss]
* D) $\frac{\text{Total body weight}}{\text{Total body surface}}$ [The smaller the answer the smaller the heat loss]

15. Which one of the following insects shows complete metamorphosis in its life cycle?

*A) The large white butterfly
B) The dragonfly
C) The cockroach
D) The locust

16. Which one of the following statements is correct?

A) Kidney breaks down surplus amino acids in order to get rid of them directly.
B) Lungs sense the CO_2 concentration in blood and adjust the rate of breathing accordingly.
*C) The blood stream carries information to ductless glands and carries back their secretions.
D) The liver produces a hormone which stimulates the pancreas to produce digestive enzymes.

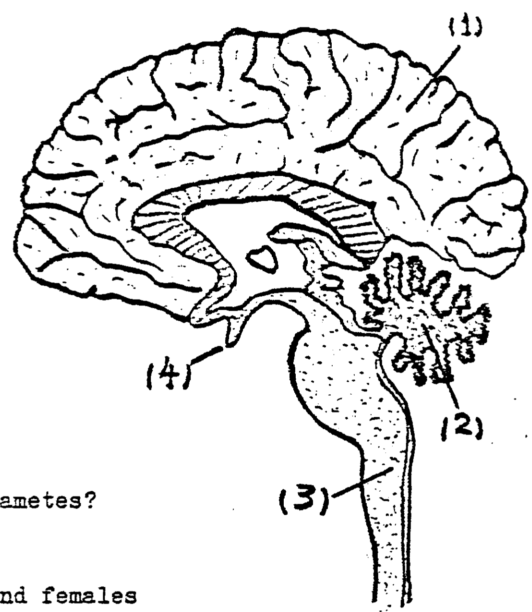
17. The accompanying diagram shows the human brain in a vertical section. Which one of the following sets of information is completely correct?

* A) No.1 indicates cerebral hemisphere
No.2 " cerebellum
No.3 " medulla
No.4 " pituitary gland

B) No.1 indicates cerebellum
No.2 " mid brain
No.3 " pituitary gland
No.4 " spinal nerve

C) No.1 " cerebrum
No.2 " pituitary gland
No.3 " axon
No.4 " synapse

D) No.1 " nerve cell-body
No.2 " dendrites
No.3 " axon
No.4 " ganglion



18. Which of the following are the human gametes?

* A) The sperms and ova
B) The testes and ovaries
C) The reproductive organs of males and females
D) The embryos inside the uteruses of pregnant women

19. Which one of the following symbols could refer to a heterozygous organism?

A) AA BB
B) AA
*C) Aa
D) aa

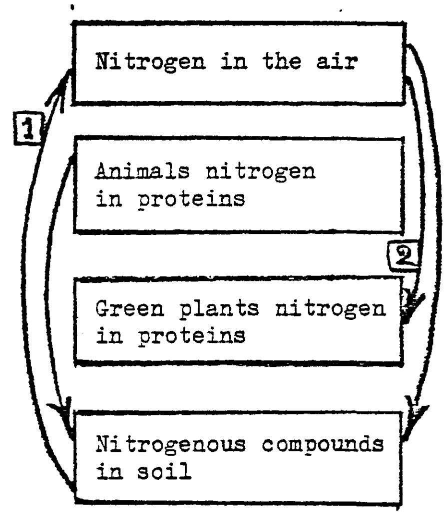
20. Study the accompanying diagram to define which kinds of bacteria are responsible for steps No. 1 and 2.

* A) Step No. (1) is carried out by denitrifying bacteria. Step No. (2) is carried out by nitrogen-fixing bacteria.

B) Step No. (1) is carried out by nitrogen-fixing bacteria. Step No. (2) is carried out by denitrifying bacteria.

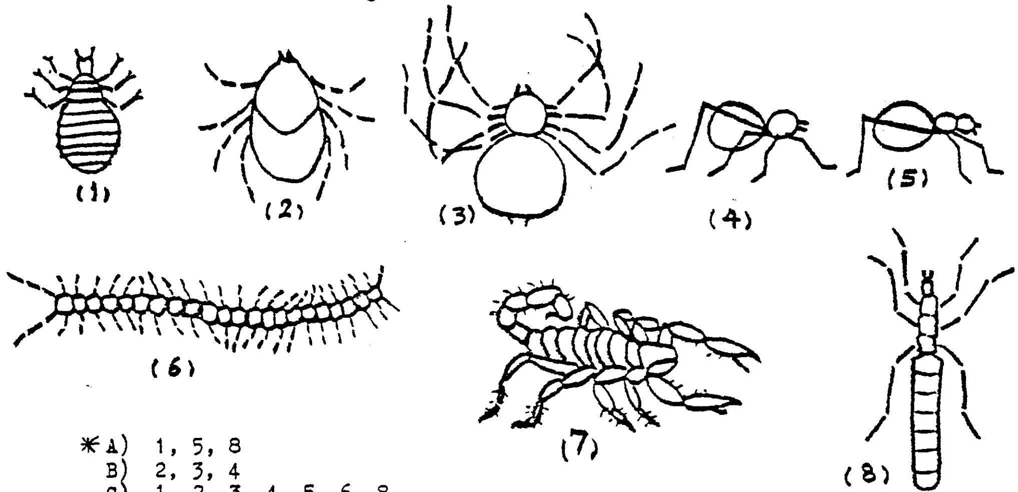
C) Step No. (1) is carried out by nodular bacteria. Step No. (2) is carried out by denitrifying bacteria.

D) Step No. (1) is carried out by nitrogen-fixing bacteria. Step No. (2) is carried out by nodular bacteria.



'O' Grade Sub-Test No. (3)

1. Which of the following creatures are insects?

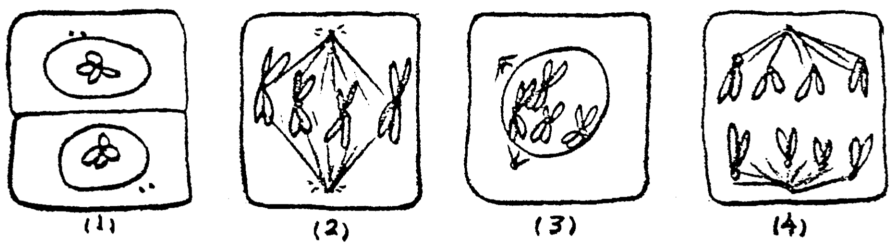


*A) 1, 5, 8
B) 2, 3, 4
C) 1, 2, 3, 4, 5, 6, 8
D) 1, 2, 4, 5, 6, 7, 8

2. Humans eat different parts of plants. Which one of the following lists is completely correct?

A)	Carrot is a stem , Potato is a root , Tomato is a fruit , Cucumber is a stem .
* B)	Carrot is a root , Potato is a stem , Tomato is a fruit , Cucumber is a fruit.
C)	Carrot is a root , Potato is a stem , Tomato is a fruit , Cucumber is a stem .
D)	Carrot is a fruit , Potato is a fruit, Tomato is a fruit , Cucumber is a fruit.

3. The following figures show the various stages of cell division called 'Mitosis'. Which group of the following numbers shows the correct arrangement of these stages?



A) 1, 2, 3, 4
B) 2, 3, 4, 1
*C) 3, 2, 4, 1
D) 4, 2, 3, 1

4. Adenosine triphosphate (ATP) is an important compound to our body. Which one of the following is the correct reason?

   A) It helps to accelerate food breakdown to liberate required energy.
 * B) It helps to store energy released by food breakdown.
   C) It hinders muscles' contractions when required.
   D) It helps to burn food material.

5. In what terms is amylase of great use to a germinating cereal grain?

   A) It stimulates the production of gibberellic acid in the seed.
   B) It promotes tissue differentiation in the seedling.
   C) It induces phloem to grow to a complete plant.
 * D) It alters the complex stored food to simplex.

6. Which one of the following is the best list of requirements for a plant to carry out photosynthesis?

   A) O_2, light, chlorophyll and H_2O
 * B) CO_2, light, chlorophyll and H_2O
   C) CO_2, light, chlorophyll and O_2
   D) Starch, light, chlorophyll and CO_2

7. Which one of the following pairs of statements is true?

	Aerobic respiration	Photosynthesis
A)	occurs in all plants and animals all the time without exception.	A) occurs in all plants all the time without exception.
B)	takes place in higher organisms but not in micro-organisms.	B) takes place in higher plants but not in microscopic ones.
C)	oxygen is taken in, whereas carbon dioxide is given out, and the organism gains weight.	C) oxygen is given out, whereas carbon dioxide is taken in, and the organism loses weight.
* D)	ATP is formed with the essential help of sugars, then breaks down later.	D) ATP is formed with the essential help of solar energy, then breaks down later.

8. Compared with the normal respiration, which one of the following statements would be the result if human cell respiration happened in the absence of oxygen?
 * A) Lactic acid and less energy
   B) Lactic acid and more energy
   C) Carbon dioxide, ethanol and less energy
   D) Carbon dioxide, ethanol and more energy

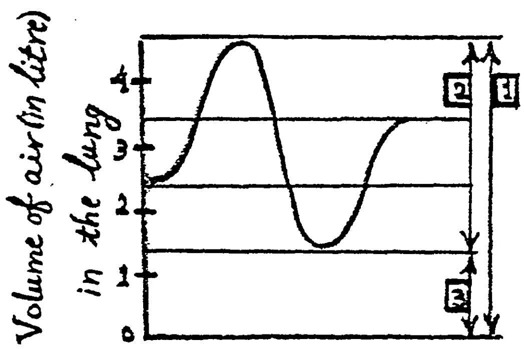
9. An organism which is unable to make its own food from simple materials and has to depend upon other living or non living materials for its food is called an heterotroph.
   Which one of the following living organisms is an heterotroph?

   A) Green algae
   B) Garden peas
 * C) Mushrooms
   D) Leek

10. For which of the following reasons do bakeries <u>mainly</u> use yeast in their dough?

* A) Because it produces CO_2
B) Because it produces energy
C) Because it produces ethanol
D) Because it breaks down the sugar content of the flour

11. The accompanying diagram shows the changes which happened in air volume inside the lung of a young man during normal breathing. The space indicated by arrow No. (1) is the total lung capacity, while that referred to by No. (2) is its usual working (vital) capacity.
To which of the following does arrow No. 3 refer?



A) The breathing at rest volume
* B) The residual air volume
C) The expired air volume
D) The inspired air volume

12. Without being stirred sugar particles could move through a cup full of tea until they become evenly distributed. This phenomenon is called

A) plasmolysis
* B) diffusion
C) turgidity
D) osmosis

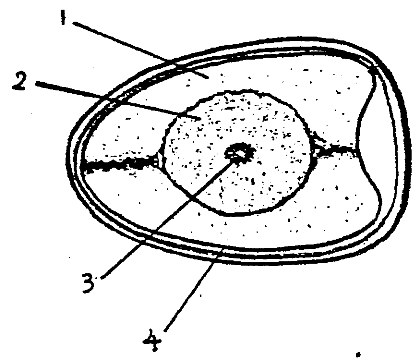
13. If a person's kidneys stopped working, which one of the following could you expect to find in excess in his blood as a result of that defect?

A) Aged red blood cells
B) Complex amino acids
* C) Salts and hormones
D) Glycogen

14. If a mouse, a rabbit, a goat and a cow were kept out in the open on a cold night, which one of them would lose most of its body heat through radiation? (Use the idea of the ratio $\frac{\text{Body surface area}}{\text{Body volume}}$)

* A) The mouse
B) The rabbit
C) The goat
D) The cow

15. Which one of the following sets of labels for the diagram is completely correct?



A) 1. Cytoplasm
   2. Nucleus
   3. Nucleolus
   4. Cell walls

B) 1. Yolk
   2. Albumen
   3. Nucleus
   4. Shell membranes

C) 1. Albumen
   2. Chalaza
   3. Yolk
   4. Shell membranes

* D) 1. Albumen
   2. Yolk
   3. Egg cell
   4. Shell membranes

16. Which one of the following statements is correct?

A) Kidney breaks down surplus amino acids in order to get rid of them directly.
B) Lungs sense the CO_2 concentration in blood and adjust the rate of breathing accordingly.
* C) The blood stream carries information to ductless glands and carries back their secretions.
D) The liver produces a hormone which stimulates the pancreas to produce digestive enzymes.

17. A 17 years old girl produces symptoms of poor secretion of estrogen (oestrogen) hormone. Which of the following symptoms would she produce?

A) Bulging eyes and high blood pressure
B) Physical and mental sluggishness
C) Disordered glucose regulation in the blood stream
* D) Delay in the beginning of her menstrual cycle

18. Which of the following are the human gametes?

* A) The sperms and ova
B) The testes and ovaries
C) The reproductive organs of males and females
D) The embryos inside the uteruses of pregnant women

19. Which one of the following statements refers correctly to a <u>dominant</u> gene?

A) It is found in a homozygote but not in a heterozygote.
B) It is found in a heterozygote but not in a homozygote.
C) It shows up in the individual if it is harmless.
* D) It shows up in the phenotype of a heterozygote.

20. What is the disadvantage for a plant growing in a heavy soil?

* A) Bad aeration
B) High acidity
C) Quick drainage of water
D) Weak holding of soluble minerals

UNIVERSITY
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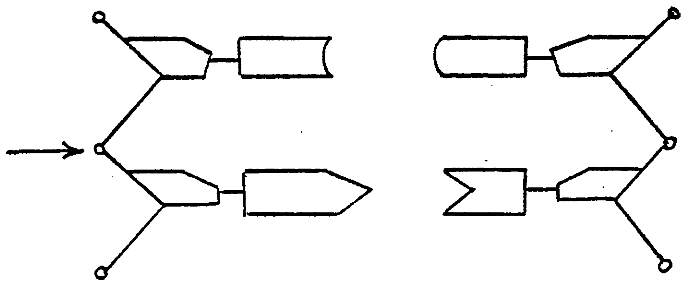
'H' Grade Sub-test No. (1)

1. The following diagram shows a part of D.N.A.
What is the component indicated by the arrow?



A) Ribose
B) Nucleotide
C) Organic base
*D) Phosphate group

2. A centrifuge is an important tool in the study of cells because it enables scientists to

A) study phototropism.
B) study the effect of gravity.
*C) separate different components of cells from each other.
D) mix different components of cells with each other.

3. Which one of the following statements about chemical energy is always true?

It is released:

A) always as heat.
B) only from carbohydrates and fats.
C) always when high energy bonds are broken.
*D) when strong bonds are broken and weaker bonds are made.

4. Which one of the following statements about ATP is true?

A) It carries less energy than ADP does.
*B) It gets its useful energy from glucose or from solar energy.
C) It is found inside plant tissues in daytime but not found at all at night.
D) It is formed in the human body while undergoing aerobic respiration, but cannot be formed while undergoing anaerobic respiration.

5. Concerning the light and the dark reactions in photosynthesis, which one of the following is correct?

A) The light reactions deal with fixing of carbon in a carbohydrate, while dark reactions deal with splitting of water.
B) The light reactions are associated with the conversion of ATP to ADP, while dark reactions are associated with the conversion of ADP to ATP.
C) The light reactions result in the production of sugars, while the dark reactions result in the production of starch.
*D) The light reactions deal with trapping of energy and splitting of water, while dark reactions deal with fixing of carbon in a carbohydrate.

6. In relation to Calvin cycle, which one of the following statements is true?

*A) It is concerned with carbon dioxide fixation.
B) It is concerned with the splitting of water.
C) It occurs only in complete darkness.
D) It occurs only in light.

7. Scientists use chemical inhibitors in order to detect the

A) rate of reactions.
*B) sequence of reactions.
C) factors affecting reactions.
D) sites of different biological reactions.

8. Which one of the following statements about Krebs cycle is true?

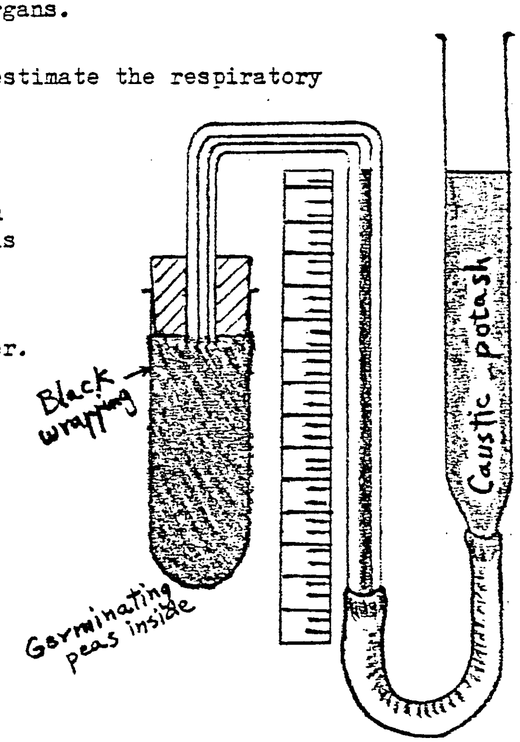
A) It ends with pyruvic acid.
B) It starts with lactic acid.
*C) It leads to the formation of ATP.
D) It is an essential part of anaerobic respiration.

9. Which one of the following statements offers the correct explanation for the fact that insects have no respiratory pigments in their blood?

A) Insects' haemoglobin is colourless.
*B) Oxygen goes straight to all their body tissues.
C) Insects have other pigments in their cuticle which carry on the same function as respiratory pigment of vertebrates.
D) Insects' blood is not confined mainly in vessels but occupies the space between the cuticle and body organs.

10. A pupil wishes to perform an experiment to estimate the respiratory quotient (RQ) for germinating peas. He prepared his apparatus exactly as shown by the accompanying drawing. The pupil, by setting up the apparatus in this way, is making a mistake. Which one of the following statements shows his mistake?

A) Peas should not be wrapped.
B) The peas should be kept immersed in water.
*C) The level of the potassium hydroxide (caustic potash) should be initially lowered.
D) The liquid should not be an alkaline solution, but it should be one of the respiratory inhibitors (e.g. malonic acid).



11. In laboratories, blood cells are kept stored in 0.7 to 0.9 per cent salt (sodium chloride) solution. The <u>main</u> function of this solution with this particular concentration is

A) to act as preservative to blood cells against decay.
B) to prevent white and red blood cells from being precipitated.
C) to provide blood cells with the most important salt needed for maintenance of their life.
*D) to keep blood cells in a concentration similar to the natural one of the plasma.

12. The kidney eliminates excess water from the blood without losing glucose. Which of the following statements is the best explanation for this fact?

A) Bowman's capsules do not pass glucose to the kidney tubules.
B) The narrow bores of kidney blood vessels prevent glucose molecules from passing out.
*C) Kidney tubules absorb back all needed materials, including glucose, from the glomerular filtrate.
D) The pressure filtration process which takes place in the kidney prevents the loss of glucose, as well as other valuable materials.

13. Fish in the sea face problems arising from the surrounding water, nevertheless their bodies can manage to withstand them. Which one of the following statements correctly supports the above idea?

A) Water tends to enter their bodies in great quantities, but their kidneys extract the excess water from the blood and expel it.
*B) Water tends to pass out from their bodies into the sea, but they make it up again by swallowing amounts of water and by minimising water loss through their excretory system.
C) Salt tends to pass out from their bodies, but the body's impermeable covering (i.e. scales and the like) prevents salt from leaking out.
D) Salt tends to accumulate in their bodies, but their kidneys get rid of it in the form of ammonia.

14. Which of the following tissues is responsible for the growth in thickness in tree trunks?

A) The bark.
B) The primary xylem.
C) The primary phloem.
*D) The cambium.

15. A lady who has been complaining from poor maintenance of pregnancy underwent several medical investigations. Lack of a particular hormone was found to be responsible for her case. Which one of the following hormones do you think she is lacking?

A) Oestrogen (Estrogen).
*B) Progesterone.
C) Adrenaline.
D) Thyroxine.

16. Which one of the following statements about Meiosis is correct?

*A) It leads to the preparation of gametes.
B) It takes place in all body cells in plants and animals.
C) It results in the exact repetition of characters of a parent in his offspring.
D) It results in the change from haploid to diploid numbers of chromosomes in the cell.

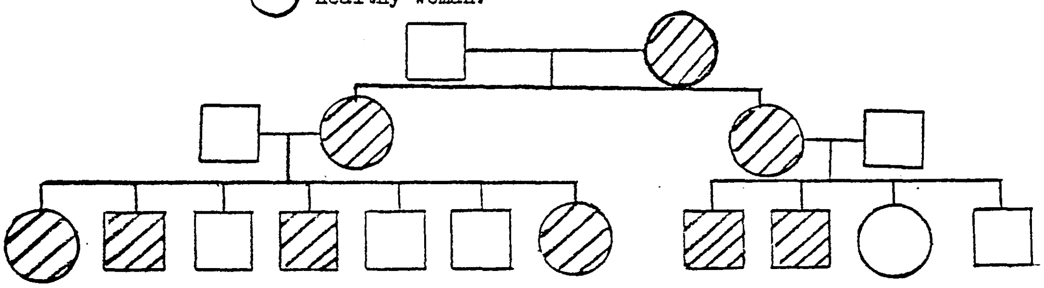
17. Study the diagram below which represents the family tree for one of the families which has some diseased persons.

N.B. The symbols used in this diagram are as follows:

Diseased man. Healthy man.

A woman who does not show the disease but is still carrying the responsible gene.

Healthy woman.



Which one of the following cases do you think the diagram is showing?

A) A case of crossing over.
B) A case of mendelian inheritance.
* C) A case of sex-linked inheritance.
D) A case of mutant gene which appeared in men of the second filial generation.

18. It has been noticed that RNA has an important connection with protein synthesis. In which of the following cells would you expect to find the greater amount of RNA?

A) Cells of a sense organ.
B) Cells of an excretory tissue.
C) Cells of a fat storing tissue.
* D) Cells of an enzyme secreting gland.

19. One of the best examples from which scientists could draw evidence for the gradual nature of evolution is the horse. Which of the following statements is the best reason(s) for the choice of the horse for this study?

* A) It appeared several million years ago and a reasonable number of its fossils exist.
B) It has a special kind of limbs which show similarities with limbs of other animals.
C) It shows natural selection rather than artificial selection.
D) It belongs to the vertebrates to which man belongs.

20. Many years ago there was a kind of moth with roughly equal numbers of yellow and brown. Lately, it has been noticed that the yellow ones are hardly ever found, whereas the brown ones are still found. Which of the following is the best explanation for this observation?

A) Yellow moths have left Britain to avoid their many enemies.
B) Nature has stopped providing moths with yellow colour and shifted to the brown one for areas with sooty backgrounds.
C) Yellow moths have turned brown in order to be less easily seen by their enemies on sooty backgrounds.
* D) Yellow moths being more easily seen on sooty backgrounds, have been killed off, whereas the brown ones have been better hidden.

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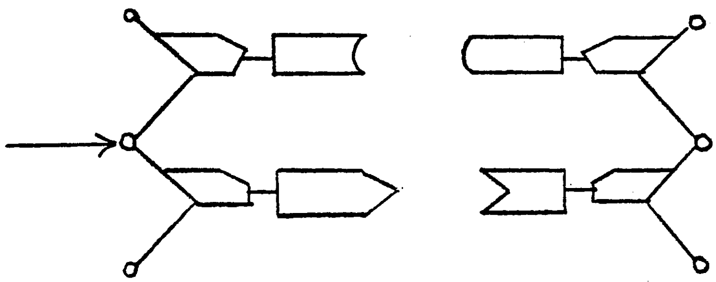
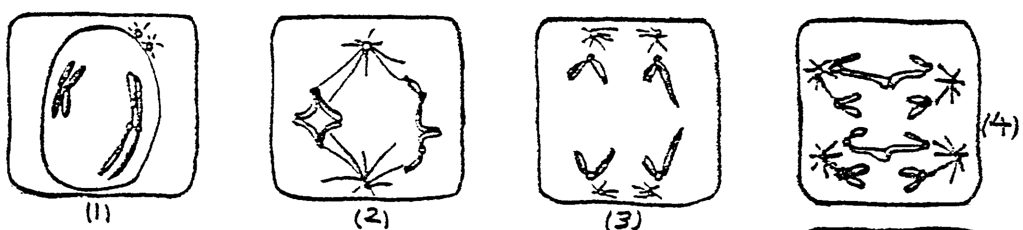
'H' Grade Sub-Test No. (2)

1. The following diagram shows a part of D.N.A. What is the component indicated by the arrow?

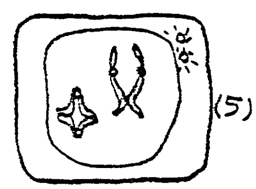


A) Ribose.
B) Nucleotide.
C) Organic base.
* D) Phosphate group.

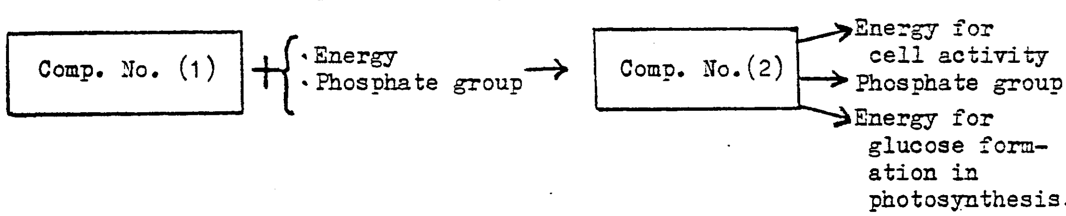
2. The following figures show some stages of the cell division Meiosis. Which one of the following groups of numbers represents the correct arrangement of these stages?



* A) Fig: 1 → 5 → 2 → 3 → 4.
B) Fig: 1 → 2 → 5 → 3 → 4.
C) Fig: 1 → 3 → 4 → 2 → 5.
D) Fig: 5 → 4 → 3 → 2 → 1.



3. Study the accompanying diagram and find which one of the following statements about compounds No. (1) and No. (2) is correct.

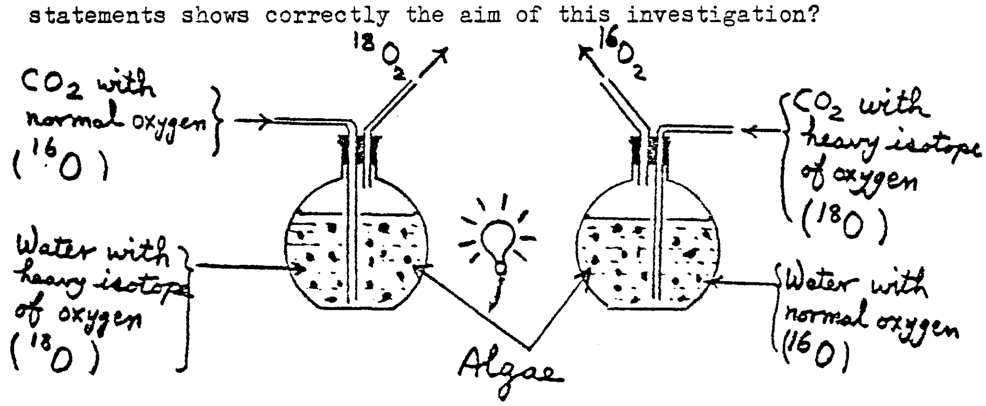


A) Comp. No. (1) is CO_2, while comp. No. (2) is O_2.
B) Comp. No. (1) is DNA, while comp. No. (2) is RNA.
C) Comp. No. (1) is ATP, while comp. No. (2) is ADP.
* D) Comp. No. (1) is ADP, while comp. No. (2) is ATP.

4. Which one of the following statements about ATP is true?

   A) It carries less energy than ADP does.
 * B) It gets its useful energy from glucose or from solar energy.
   C) It is found inside plant tissues in day time but not found at all at night.
   D) It is formed in the human body while undergoing aerobic respiration but cannot be formed while undergoing anaerobic respiration.

5. The following two separate apparatuses were set up by a researcher who was concerned with vital activities in plants. Which of the following statements shows correctly the aim of this investigation?



 * A) To identify the source of the released oxygen in photosynthesis.
   B) To identify the nature of oxygen released in photosynthesis.
   C) To indicate the different factors affecting the rate of photosynthesis.
   D) To investigate the effect of isotopes on the activity of algae.

6. In relation to Calvin cycle, which one of the following statements is true?

 * A) It is concerned with carbon dioxide fixation.
   B) It is concerned with the splitting of water.
   C) It occurs <u>only</u> in complete darkness.
   D) It occurs <u>only</u> in light.

7. In which of the following parts of the human body would you expect to find the greatest number of mitochondria?

   A) The bones.
   B) The sensory organs.
   C) The covered areas of skin.
 * D) The hard working muscles.

8. Which one of the following statements about Krebs cycle is true?

   A) It ends with pyruvic acid.
   B) It starts with lactic acid.
 * C) It leads to the formation of ATP.
   D) It is an essential part of anaerobic respiration.

9. Which one of the following statements offers the correct explanation for the fact that insects have no respiratory pigments in their blood?

A) Insects' haemoglobin is colourless.
*B) Oxygen goes straight to all their body tissues.
C) Insects have other pigments in their cuticle which carry on the same function as respiratory pigment of vertebrates.
D) Insects' blood is not confined mainly in vessels but occupies the space between the cuticle and body organs.

10. In an experiment on two Ganong respirometers one was filled with beans and sodium hydroxide (caustic soda solution), while the other was filled with similar beans and water (or paraffin) as usual. The data obtained were as follows:

The difference between the levels of sodium hydroxide before and after = $20cm^3$.

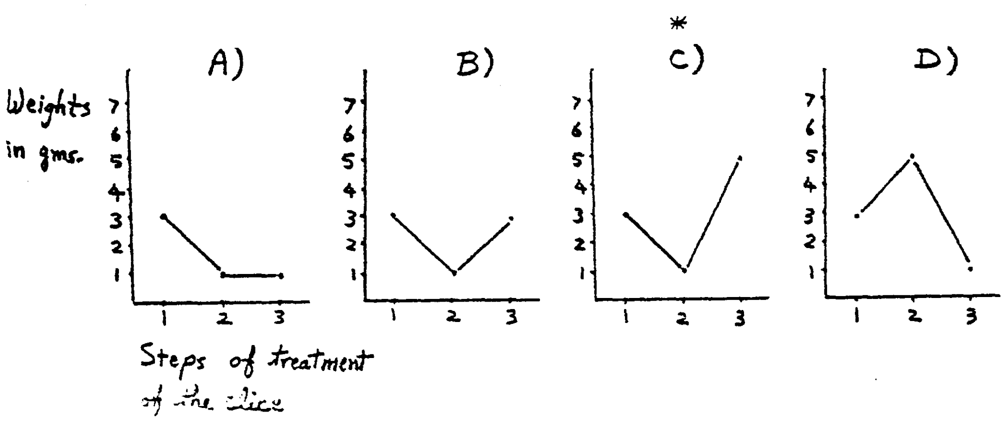
The difference between the levels of water before and after = $5cm^3$.

Which one of the following conclusions is correct?

	Volume of O_2	Volume of CO_2	Respiratory Quotient
A)	20	5	$\frac{20}{5}$
* B)	20	15	$\frac{15}{20}$
C)	15	20	$\frac{20}{15}$
D)	20	25	$\frac{20}{15}$

11. A slice of fresh plant stem was weighed and immersed for one hour in a solution with an osmotic potential <u>greater</u> than that of its own sap. It was weighed again, then transferred into another solution with O.P. <u>less</u> than that of its own vacular sap. The slice was weighed again for the third time.

Which of the following graphs would represent the changes of the slice's weight during that treatment.



12. The kidney eliminates excess water from the blood without losing glucose. Which of the following statements is the best explanation for this fact?

A) Bowman's capsules do not pass glucose to the kidney tubules.
B) The narrow bores of kidney blood vessels prevent glucose molecules from passing out.
*C) Kidney tubules absorb back all needed materials, including glucose, from the glomerular filtrate.
D) The pressure filtration process which takes place in the kidney prevents the loss of glucose, as well as other valuable materials.

13. Which of the following can sense the shortage of water in the body and begin to counteract this problem?

A) Spinal cord.
*B) Pituitary gland.
C) Adrenal gland.
D) Cerebral hemisphere.

14. In which of the following tissues could you expect to find mitosis takes place?

A) The primary xylem.
B) The secondary xylem.
*C) The cambium.
D) The phloem.

15. The thyroid gland would be affected badly if the diet lacks

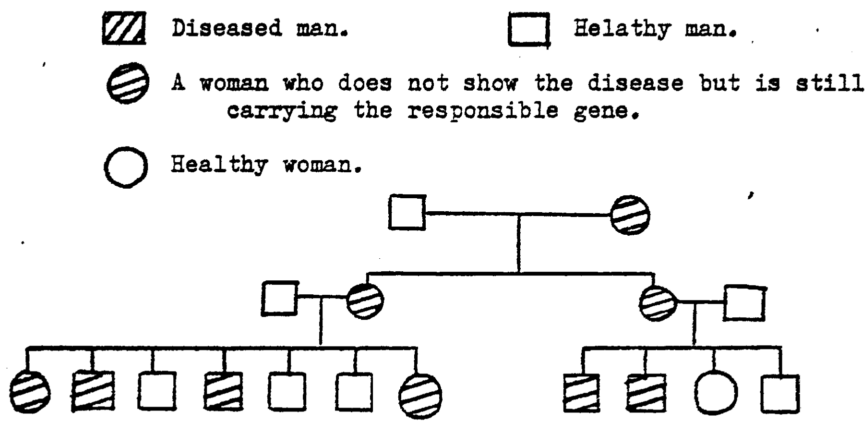
A) iron.
*B) iodine.
C) fluorine.
D) thymine.

16. A cross breeding is made between a plant of 2N = 16 and another of 2N = 18. Which of the following new plants would be the result of such breeding?

*A) A sterile plant with 2N = 17.
B) A fertile plant with 2N = 17.
C) A sterile plant with 2N = 34.
D) A fertile plant with 2N = 34.

17. Study the diagram below which represents the family tree for one of the families which has some diseased persons.

N.B. The symbols used in this diagram are as follows:



Which one of the following cases do you think the diagram is showing?

A) A case of crossing over.
B) A case of mendelian inheritance.
* C) A case of sex-linked inheritance.
D) A case of mutant gene which appeared in men of the second filial generation.

18. In which of the following tissues are the cells expected to contain the greatest amount of RNA?

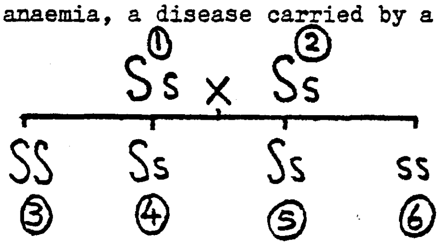
A) Tissues concerned with excretion.
B) Tissues concerned with sensation.
C) Tissues concerned with storing food materials.
* D) Tissues concerned with synthesising protein.

19. One of the best examples from which scientists could draw evidence for the gradual nature of evolution is the horse.

Which of the following statements is the best reason(s) for the choice of the horse for this study?

* A) It appeared several million years ago and a reasonable number of its fossils exist.
B) It has a special kind of limbs which show similarities with limbs of other animals.
C) It shows natural selection rather than artificial selection.
D) It belongs to the vertebrates to which man belongs.

20. The following diagram represents a family showing different degrees of sickle cell anaemia, a disease carried by a recessive gene.



Which one of the following statements is true?

*A) Individual No. (6) will have severe anaemia and will probably die before reaching the reproductive age.

B) Individual No. (3) will have severe anaemia and will probably die before reaching the reproductive age.

C) Individuals No. (3) and (4) differ phenotypically from each other.

D) Individuals No. (1) and (2) are homozygots.

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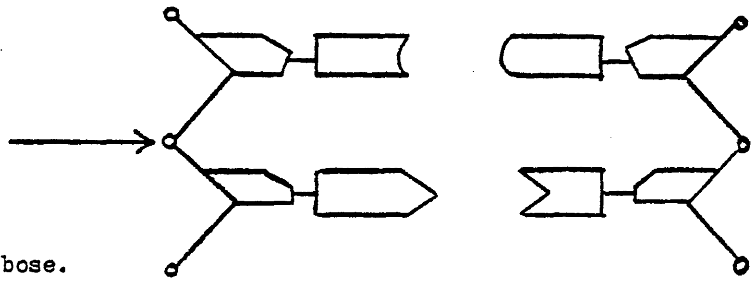
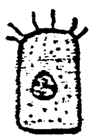
'H' Grade Sub-Test No. (3)

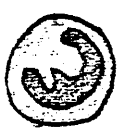
1. The following diagram shows a part of D.N.A. What is the component indicated by the arrow?

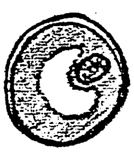


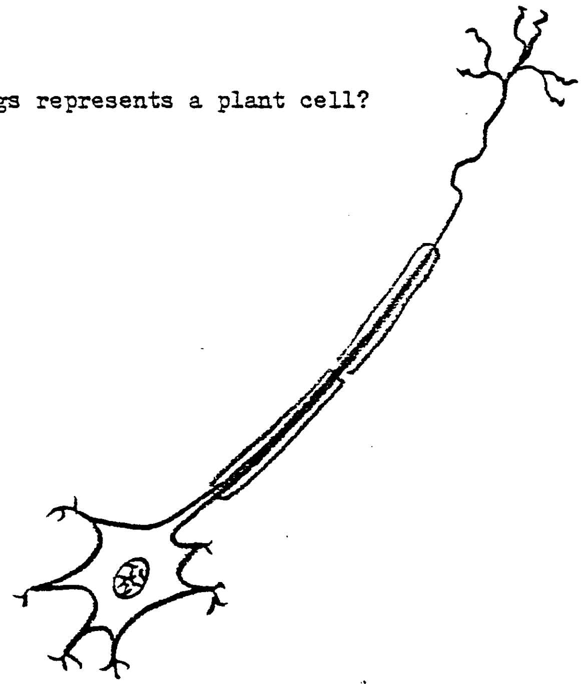
A) Ribose.
B) Nucleotide.
C) Organic base.
* D) Phosphate group.

2. Which of the following drawings represents a plant cell?

A) 

B) 

* C) 

D) 

3. Muscle tissue in man and animals is particularly rich in mitochondria because these organelles are essential to the process of:

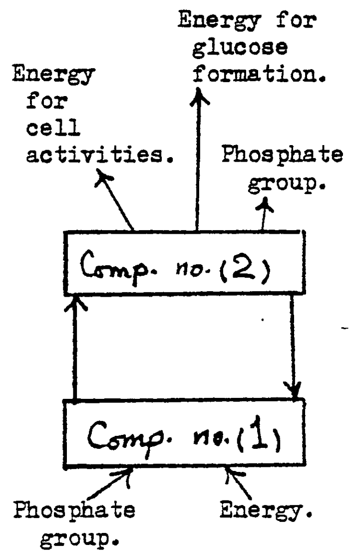
A) inheritance.
* B) synthesising ATP inside cells.
C) distributing O_2 to individual cells.
D) assimilating absorbed food inside every cell.

4. Which one of the following statements about ATP is true?

A) It carries less energy than ADP does.
* B) It gets its useful energy from glucose or from solar energy.
C) It is found inside plant tissues in day time but not found at all at night.
D) It is formed in the human body while undergoing aerobic respiration, but cannot be formed while undergoing anaerobic respiration.

5. Study the accompanying diagram and suggest what could be the compounds No. (1) and No.(2) in the two circles.

   A) Compound No. (1) is CO_2, while No.(2) is O_2 .
   B) Compound No.(1) is RNA, while No.(2) is DNA.
   C) Compound No.(1) is ATP, while No.(2) is ADP.
   * D) Compound No.(1) is ADP, while No.(2) is ATP.



6. In relation to Calvin cycle, which one of the following statements is true?

   * A) It is concerned with carbon dioxide fixation.
   B) It is concerned with the splitting of water.
   C) It occurs <u>only</u> in complete darkness.
   D) It occurs <u>only</u> in light.

7. For what reason is oxygen important for cell respiration?

   A) To balance the CO_2 developed throughout respiration.
   * B) To enable cells to get rid of hydrogen.
   C) To stimulate respiratory enzymes.
   D) To form water for cell use.

8. Which one of the following statements about Krebs cycle is true?

   A) It ends with pyruvic acid.
   B) It starts with lactic acid.
   * C) It leads to the formation of ATP.
   D) It is an essential part of anaerobic respiration.

9. Which one of the following statements offers the correct explanation for the fact that insects have no respiratory pigments in their blood?

   A) Insects' haemoglobin is colourless.
   * B) Oxygen goes straight to all their body tissues.
   C) Insects have other pigments in their cuticle which carry on the same function as respiratory pigment of vertebrates.
   D) Insects' blood is not confined mainly in vessels but occupies the space between the cuticle and body organs.

10. In an experiment on two Ganong respirometers one was filled with beans and sodium hydroxide (caustic soda solution) while the other was filled with similar beans and water (or paraffin) as usual. The data obtained were as follows:

The difference between the levels of sodium hydroxide before and after = $20cm^3$.
The difference between the levels of water before and after = $5cm^3$.

Which one of the following conclusions is correct?

	Volume of O_2	Volume of CO_2
A)	20	5
B)	5	20
C)	20	25
* D)	20	15

11. Which of the following equations is correct about the relation between the factors determining the amount of water which can enter a cell?

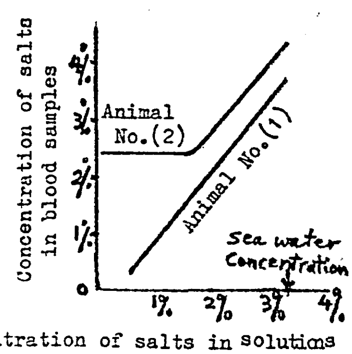
A) $\psi = OP + WP$
* B) $OP = \psi + WP$
C) $WP = OP + \psi$
D) $OP = \psi - WP$

12. The kidney eliminates excess water from the blood without losing glucose. Which of the following statements is the best explanation for this fact?

A) Bowman's capsules do not pass glucose to the kidney tubules.
B) The narrow bores of kidney blood vessels prevent glucose molecules from passing out.
* C) Kidney tubules absorb back all needed materials, including glucose, from the glomerular filtrate.
D) The pressure filtration process which takes place in the kidney prevents the loss of glucose, as well as other valuable materials.

13. Two animals from two different species *were* placed in fresh water and then into successively more salted water up to the concentration of sea water. Before changing the concentration, each time a sample of their blood was analysed separately for salinity.
The following graph shows the data obtained.
Which one of the following statements could be the best conclusion to this investigation?

A) The two animals cannot tolerate fresh water.
B) The two animals cannot tolerate any amount of salinity in water.
C) Animal No.(1) is better adapted to some extent, to life in water in general.
* D) Animal No.(2) is better adapted to some extent, to life in water of changeable salinity.



14. To study fertilization that takes place between sperms and ovum in a laboratory investigation, a pupil tried to collect some Pomatoceros or Rhabditis worms as usual for this study. Being unlucky that day, he did not manage to find any of these worms. A pupil friend advised him to look in neglected rubbish for the larvae of house flies as a substitute for these worms.

Which one of the following pieces of advice would you give him?

A) Both are suitable, but the Pomatoceros or Rhabditis worms are better than the larvae of house flies.
* B) The larvae of house flies cannot be a substitute at all.
C) The larvae of house flies can be a very good substitute.
D) Have no idea.

15. A certain gland disorder causes a person to have high blood concentration because reabsorption of water in the distal kidney tubules is not adequate. Which gland(s) do you think is not functioning correctly?

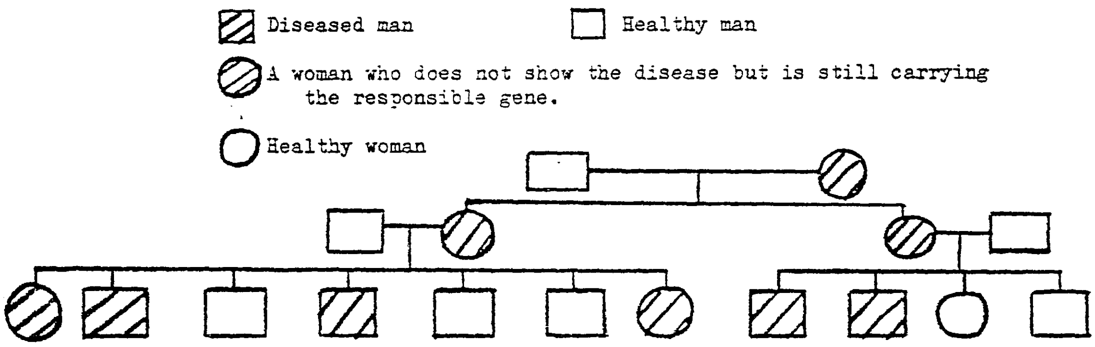
A) Thyroid.
B) Salivary.
* C) Pituitary.
D) Parathyroids.

16. Which one of the following statements is correct?

* A) Meiosis takes place in diploid cells to produce haploid ones.
B) Meiosis guarantees that every new cell will be exactly as the parent cell.
C) Mitosis takes place in gamete producing cells, whereas meiosis takes place in regions of elongation and growth.
D) Mitosis takes place in both plants and animals, whereas meiosis takes place in human beings only.

17. Study the diagram below which represents the family tree for one of the families which has some diseased persons.

N.B. The symbols used in this diagram are as follows:



Which one of the following cases do you think the diagram is showing?

A) A case of crossing over.
B) A case of mendelian inheritance.
* C) A case of sex-linked inheritance.
D) A case of mutant gene which appeared in men of the second filial generation.

18. Where are genes supposed to be located in the cell?

   * A) On chromosomes.
   B) On ribosomes.
   C) On centrioles.
   D) In cytoplasm.

19. One of the best examples from which scientists could draw evidence for the gradual nature of evolution is the horse.

   Which of the following statements is the best reason(s) for the choice of the horse for this study?

   * A) It appeared several million years ago and a reasonable number of its fossils exist.
   B) It has a special kind of limbs which show similarities with limbs of other animals.
   C) It shows natural selection rather than artificial selection.
   D) It belongs to the vertebrates to which man belongs.

20. By which one of the following procedures could haemophilia arise in a family which has no previous history of it?

   A) Linkage.
   * B) Mutation.
   C) Isolation.
   D) Crossing over.

Appendix No. 5.5.2.B

Distribution of the correct answers on the 'Ordinary Grade' three sub-tests.

Sub-test no. (1)

Altern. \ Q.no.	1*	2	3	4	5	6	7*	8	9	10*	11	12*	13	14	15	16*	17	18*	19	20
A	✓					✓				✓	✓		✓					✓		
B		✓	✓		✓							✓		✓						
C				✓					✓							✓			✓	
D							✓	✓							✓		✓			✓

Sub-test no. (2)

Altern. \ Q.no.	1*	2	3	4	5	6	7*	8	9	10*	11	12*	13	14	15	16*	17	18*	19	20
A	✓									✓					✓		✓	✓		✓
B		✓		✓	✓							✓		✓						
C			✓			✓		✓					✓			✓			✓	
D							✓		✓		✓									

* Denotes a question which was included in the three sub-tests.

(Continued)

Distribution of the correct answers on the 'Ordinary Grade' three sub-tests (Continued)

Sub-test no. (3)

Altern. \ Q.no.	1*	2	3	4	5	6	7*	8	9	10*	11	12*	13	14	15	16*	17	18*	19	20
A	✓				✓			✓		✓				✓				✓		✓
B		✓		✓		✓					✓	✓								
C			✓						✓				✓			✓				
D							✓								✓		✓		✓	

* Denotes a question which was included in the three sub-tests.

(Continued)

Appendix No. 5.5.2.B (Continued)

Distribution of the correct answers on the 'Higher Grade' three sub-tests

Sub-test no. (1)

Q.no. / Altern.	1*	2	3	4*	5	6*	7	8*	9*	10	11	12*	13	14	15	16	17*	18	19*	20
A						✓										✓			✓	
B				✓			✓		✓				✓		✓					
C		✓						✓		✓		✓					✓			
D	✓		✓		✓						✓			✓				✓		✓

Sub-test No. (2)

Q.no. / Altern.	1*	2	3	4*	5	6*	7	8*	9*	10	11	12*	13	14	15	16	17*	18	19*	20
A		✓			✓	✓										✓			✓	✓
B				✓					✓	✓			✓		✓					
C								✓			✓	✓		✓			✓			
D	✓		✓				✓											✓		

* Denotes a question which was included in the three sub-tests.

(Continued)

Distribution of the correct answers on the 'Higher Grade' three sub-tests (Continued)

Sub-test no. (3)

Q.no. / Altern.	1*	2	3	4*	5	6*	7	8*	9*	10	11	12*	13	14	15	16	17*	18	19*	20
A						✓										✓		✓	✓	
B			✓	✓			✓		✓		✓			✓						✓
C		✓						✓				✓			✓		✓			
D	✓				✓					✓			✓							

* Denotes a question which was included in the three sub-tests.

Appendix No. 5.5.2.C

Table of specification for the construction of the six sub-tests, with the mean facility value for each topic.

I. The three sub-tests on the 'Ordinary Grade' syllabus:

Ser. no.	Topic	Mean F.V.	Sub-test no. (1)		Sub-test no. (2)		Sub-test no. (3)	
			Ques. no.	Bloom's level	Ques. no.	Bloom's level	Ques. no.	Bloom's level
1	Plant parts and animal classification	52.9	1 2	An Ap	1 2	An Kn	1 2	An Ap
2	Cell structure and cell division	74.5	3	Kn	3	Ap	3	An
3	Chemical energy & energy from food	29.0	4	Kn	4	Kn	4	Com
4	Enzymes in general	53.5	5	Kn	5	An	5	Kn
5	Photosynthesis	46.2	6 7	Ap Ev	6 7	Com Ev	6 7	Kn Ev
6	Aerobic and anaerobic respiration	35.2	8	Com	8	An	8	Kn
7	Feeding & digestion	53.1	9	Kn	9	Ev	9	An
8	Breathing and gas exchange	53.5	10	Ev	10	Ev	10	Ev
9	Diffusion and osmosis	46.7	11 12	Com Ap	11 12	Kn Ap	11 12	Com Ap
10	Control of water content inside living organisms	38.5	13	An	13	Kn	13	Com
11	Size, surface area and heat loss in animals	51.0	14	Com	14	Kn	14	Ap
12	Development of insects & birds from egg to adult	68.5	15	Ap	15	An	15	Kn
13	C.N.S., hormones & co-ordination in the body	32.1	16 17	An Kn	16 17	An Kn	16 17	An Com
14	Gametes	50.0	18	An	18	An	18	An
15	Alleles, genes & Mendel's work	47.2	19	An	19	An	19	Kn
16	Different types of soil and N_2 cycle	57.5	20	Ev	20	Com	20	Kn

(Continued)

Appendix No. 5.5.2.C (Continued)

II. The three sub-tests on the 'Higher Grade' syllabus:

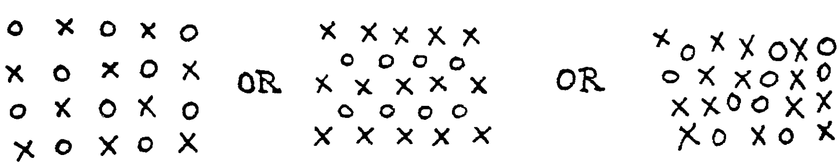
Ser. no.	Topic	Mean F.V.	Sub-test no. (1)		Sub-test no. (2)		Sub-test no. (3)	
			Ques. no.	Blooms level	Ques. no.	Blooms level	Ques. no.	Blooms level
1	DNA and RNA	78.7	1 18	An Ap	1 18	An An	1 18	An Kn
2	Cell structure & cell division	56.3	2 16	Kn Kn	2 16	An Com	2 16	Kn An
3	Chemical energy	50.0	3 4	An Kn	3 4	Com Kn	3 4	Kn Kn
4	Chemistry of photosynthesis	55.5	5 6	Kn Com	5 6	Ev Com	5 6	An Com
5	Chemistry of respiration	57.6	7 8	Kn Com	7 8	An Com	7 8	Com Com
6	Gas exchange between living organisms and their environment	54.8	9 10	Ev Ev	9 10	Ev Kn	9 10	Ev An
7	Osmosis and water potential	25.5	11	Ap	11	An	11	An
8	Role of kidney	85.0	12	Kn	12	Kn	12	Kn
9	Water balance problems and osmo-regulation	75.3	13	Kn	13	Kn	13	Ev
10	Reproduction and growth in living organisms	64.3	14	Kn	14	Kn	14	Ev
11	Hormones	59.7	15	Com	15	Kn	15	Com
12	Gametes	49.3	16	Kn	16	Com	16	An
13	Genes	52.7	17	Com	17	Com	17	Com
14	Evidence for evolution	42.0	19	An	19	An	19	An
15	Mechanism of evolution	54.7	20	Ev	20	Com	20	Kn

Symbols used: Kn = Knowledge, Com = Comprehension,
Ap = Application, An = Analysis, and
Ev = Evaluation.

Appendix No. 6.6.2.A

Samples of the answers given by the interviewed pupils as relevant to the questions listed in the main text of the study.

Q.no.	Most common answers given by pupils
(1)	All substances are made up of atoms/particles.
(2)	Scent evaporates and its particles come to our noses.
(3)	The crystal will break down into very small particles which further moves by diffusion into every place inside water.
	Air bubbles dissolved in water cause the potassium permanganate to spread out.
(4)	Diffusion is the movement of the particles of the solid.
(5)	Particles of potassium permanganate are heavier than those of water and fall first to the bottom of the beaker. Then each particle moves to fill a 'space/a gap' which is already there between the particles of water. This is why the crystal disappears. Their diffusion takes place because of their heavy weight and 'their' movement.
	Particles of potassium permanganate 'reacts' with particles of water, hence the former dissolves the latter.
	Particles of potassium permanganate become liquid as water and mix up with its particles.
	When the solution is formed, the particles of potassium permanganate and those of water are arranged like this:



(6)	(Predictions of the direction of water flow were mainly accurate when water is shown to be placed in the beaker, but not always as accurate when the water is shown to be placed inside thistle funnel.)
	The reason why water flows into the solution side is that because the solution is 'stronger' than pure water therefore the former 'pulls/sucks up' many particles of water.

The particles of sugar block the holes of the s.p. membrane, which prevents the particles of water from moving from the solution side to the pure water side. This does not prevent the particles of water from travelling from the pure water side to the solution side.

There is greater 'amount' of water in this big beaker than it is in this small funnel, so water moves into the funnel to make the two 'amounts' equal.

When pure water is placed in the thistle funnel, and the solution is placed in the beaker, pure water will pull some of the solution to rise up in the funnel until both become of the same concentration.

Water flows across the s.p. membrane to make both sides isotonic with each other.

Water travels one way in this experiment.

A s.p. membrane is that which allows the particles of water to travel across but not the larger particles of the dissolved substances.

(7) Osmosis is the movement of water from where is found in great 'amount' to where it is found in small 'amount'.

Osmosis is the movement of something in water up a concentration gradient.

Osmosis is the movement of water from a pure water side to a solution side.

Osmosis is the movement of water from a weak solution to a strong one.

Osmosis is the movement of water which is pushed by the dissolved substances through a s.p. membrane.

(8) (Predictions of the direction of water flow between the soil and the plant were "correct".)

Water travels one way only from soil to plant, because the root 'sucks' it into the plant.

Water travels into the plant because 'dissolved things' are 'less' concentrated inside the plant than they are outside it.

(9) (Predictions of the numbers of migrating beads were correct.)

Beads tend to migrate from one side of the box to another according to their initial ratio at each side.

Water particles move from soil to plant because they are found in excess in the soil, and because the dissolved substances in soil are heavy and push the lighter water particles into the plant. The root also sucks water into the plant. Also because the root membranes allow water to flow in but not out.

(10) Water rises up the thistle funnel because of osmotic pressure.

Osmotic pressure is the force which pushes water up the funnel.

Osmotic pressure means how much a solution 'needs' water.

Osmotic pressure is that which 'drives' molecules from low to high concentrations.

Osmotic pressure is that which 'pulls' water from solutions.

The rising of the column stops when the solution becomes 'weaker'.

The rising of the column stops when the percentage of water becomes the same both sides, or both sides become isotonic to each other.

(11) (Predictions of the direction of water flow between cells according to their sugar concentration were mainly done accurately by the fifth year pupils, but it was not always the same with fourth year pupils.)

Water flows between cell saps with different sugar concentration in order to level up liquids.

Water is pulled by the cell sap with greater amount of sugar.

Osmotic pressure of concentrated cells moves the particles of water from the other cell into them.

The flow of water will stop when the sugar concentration becomes equal for all cells.

Particles of water will stop moving between cells when equal concentration of sugar is reached.

(12) The amount of water a cell can accept is determined by its osmotic potential.

High osmotic potential means less water in a cell.

Water moves from low to high osmotic potential.

(Predictions of the direction of water flow between cells were not always done accurately by the fifth year pupils.)

(13) A cell becomes turgid when it receives much water.

The cell wall will extend further than usual.

(Identification of the drawing which showed the direction of cell wall pressure was done correctly by only half the interviewed pupils. On the other hand, the identification of the drawing which showed the possible direction of water flow as a result of the cell wall pressure was done correctly by the majority of those pupils.)

(14) Water potential is the 'force' controlling water going into cells.

Water potential is the 'pressure' controlling water leaving cells.

Water potential of a cell shows how much water moves out or into a cell.

(Predictions of the direction of water flow between cells were not satisfactory, whether pupils were provided with the water potential values of the cells or with detailed values of the osmotic potential and the cell wall pressures separately for each cell. Identification of the plasmolysed cell and the one with the highest concentration of solute were correct with only one third of the pupils.)

(15) (a) Three pupils out of twelve indicated correctly that the soil solutions are more concentrated with free-moving particles of water than the different parts of the plant.

(b) Six pupils out of twelve indicated correctly that the shoot system is more concentrated with solute than the root system or the soil solutions.

(c) Two pupils out of twelve indicated correctly that the shoot system has osmotic potential higher than that of the root system or the soil solutions. (This goes well with what is taught in schools in this respect.)

(d) Three pupils out of twelve indicated correctly that the soil solutions have water potential value higher than that of the plant sap.

Appendix No. 6.6.3.A.

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"Diffusion and Osmosis"

(for both fourth and fifth year pupils who are studying biology)

Many pupils and students complain that the ideas of diffusion and osmosis are hard to understand. The purpose of this exercise is to help us to understand where the difficulties lie so that some action can be taken to put things right. Would you, please, be good enough to help us by answering the set of short questions on the attached sheets.

The results will in no way be held against you. However please make an honest and serious attempt to answer the questions. If you are in doubt about an answer, do not guess blindly but indicate that you don't know.

In the box next to each of the following statements write

T - if you think it is true

F - if you think it is false

Dk - if you don't know

On the following pages you will find four laboratory situations followed by a common situation in a plant. Judge the correctness of each statement paying particular attention to the part underlined.

N.B. In the following statements, the word "particles" is used as a replacement of the terms: atoms, molecules, and ions to make it more simple for you.

DO NOT TURN TO THE NEXT PAGE UNTIL YOUR TEACHER TELLS YOU TO BEGIN.

THANK YOU.

UNIVERSITY OF GLASGOW

Situation No. 1

A crystal of salt was placed in pure water as shown by figure No. 1, and was left for some hours without disturbance.

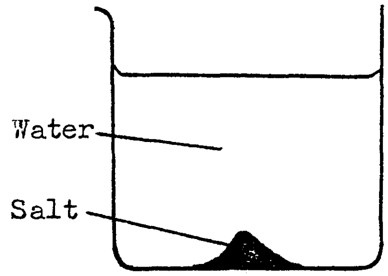


Figure (1)

1. The particles of the salt travel of their own accord in all directions. F
2. The particles of the salt change their positions by being carried by the water particles. T
3. The particles of the water travel of their own accord in all directions. T
4. The particles of the water change their positions by being pushed by the salt particles. F
5. To dissolve in the water, the particles of the salt fit into spaces between the particles of water. F
6. The particles of the water stick to and pull away the particles of the salt. T
7. The particles of the salt and of the water move separately in the solution. F
8. The most likely distribution of these particles is for them to spread evenly throughout the solution. T
9. Distribution and redistribution will continue to occur even after complete mixing between all the particles has been reached. T
10. We can conclude from this situation that the salt spreads out from where it is more concentrated to where it is less concentrated. T
11. We can conclude from this situation that the water spreads out from where it is more concentrated to where it is less concentrated. T

Situation No. 2

A container was divided into two equal compartments by means of a semi (selectively or differentially) permeable membrane. The compartments were filled with equal volumes of two different liquids as shown in figure (2).

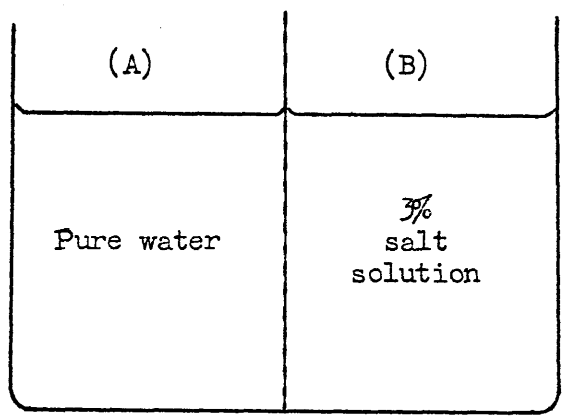


Figure (2)

12. Particles of water move continuously one way only between (A) and (B). F

13. The pressure caused by the free particles of water on the membrane is higher on the (B) side than on the (A) side. F

14. The liquid in (B) will increase in volume because it is the strongest and can draw water from the other side. F

15. Water will flow from (A) to (B) until its amount becomes equal at both sides. F

Situation No. 3.

Another similar container was filled with equal volumes of two different solutions as shown by Figure (3).

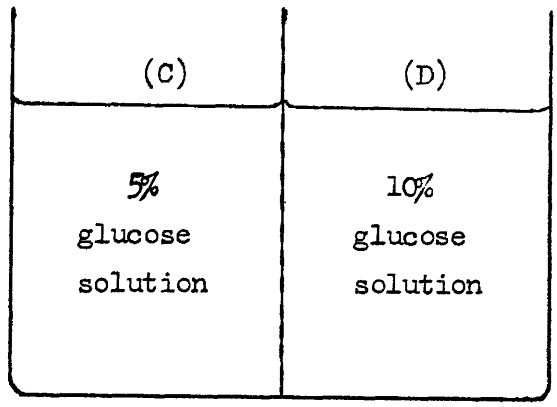


Figure (3)

16. The flow of water from one compartment to the other is due to the suction pressure of the latter one. F

17. The dissolved glucose increases the movement of the particles of water in (D) more than in (C). F

18. Although the volumes are the same, there is a greater number of free water particles striking the membrane at (C) side at any time compared with that at (D) side. T

19. Many particles of water are attached to the particles of glucose and are hindered from moving freely. T

20. When the pressure becomes equal on both sides of the membrane, the state of balance will be reached. T

21. When the amount of the free particles of water becomes equal on both sides of the membrane, the state of balance will be reached. F

22. There will be an increase in the volume in (C) due to osmosis. F

23. Particles of water are moving in both directions between (C) and (D). T

24. The free particles of water in (C) exert higher pressure on the membrane than those in (D) do. T

Situation No. 4

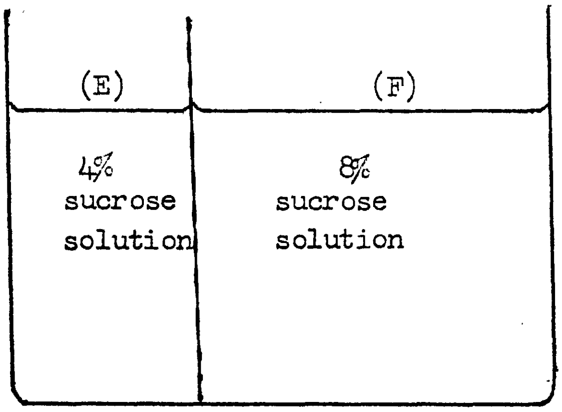


Figure (4)

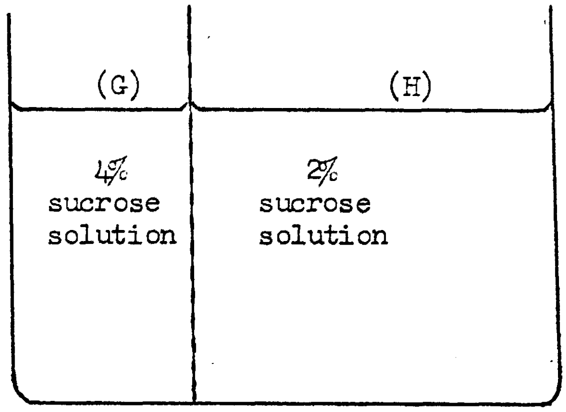


Figure (5)

Two other containers were divided by the same kind of membranes into unequal compartments. The volumes within each container were in the ratio 1:2. The compartments were filled with different solutions as shown by figures (4) and (5).

25. In figure (4), there will be an increase in the volume in (E) due to osmosis. F

26. In figure (4) there is a greater number of free water particles striking the membrane at (F) side at any time compared with that at (E) side. F

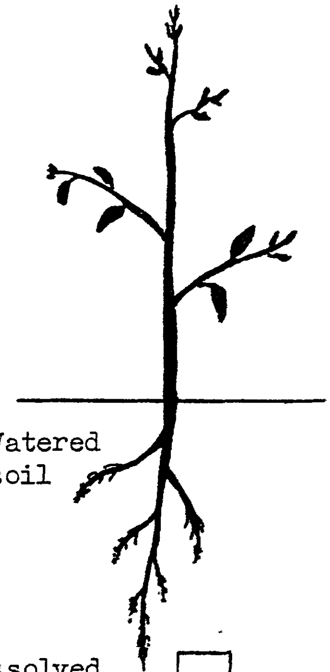
27. In figure (4), the concentration gradient of water increases from (E) to (F). F

28. In figure (5), there will be an increase in the volume in (G) due to osmosis. T

29. In figure (5), when the balanced state between (G) and (H) is approached, the movement of water particles between them will decrease gradually and eventually stop. F

Situation No. 5

A soil with a plant growing in it was watered.



30. The sap of the plant is more concentrated with dissolved substances than the normal soil solution. T

31. There is a continuous exchange of water both ways between the soil and the plant under normal conditions. T

32. The dissolved substances in the sap of the root cells hinder the movement of water particles from the root to the soil. T

33. The heavy particles of the dissolved mineral salts in the soil solution push the water particles on their way into the root. F

34. The osmotic pressure caused by the sap solution of the root hair cells helps the flow of water from the soil into those cells. T

35. There are comparatively more free water particles in the cell sap solution than in the soil one, considering similar volumes of each. F

36. The cells of the root get more water from the soil into them with the help of their wall pressure. F

37. The cell walls exert more pressure after the plant has been watered than before. T

38. The higher parts of the stem have solutions with lower osmotic pressures compared with the lower parts of the root. F

39. The entry of water from the soil to the roof is a case of diffusion. T

40. The loss of water from the cells of the leaves to the atmosphere is a case of osmosis. T

In your own words, give an account describing how water particles leave the soil solutions and accumulate in the root cells.

ANSWER

(Correct answers as well as their rating are shown on Appendix 6.6.3.B)

PLEASE SEE OVER

Now would you please provide us with the following information to enable us to gather some general data for our study.

1. Your name: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ 2. Sex: F/M _ _ _ _ _

3. Date of birth: _ _ _ _ _ _ _ _ _ _

4. School: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ 5. Class: _ _ _ _ _ _ _ _

6. <u>If you are doing 'O' grade biology this year</u>: (delete as appropriate)

   A) Are you doing 'O' grade chemistry as well? Yes/No

   B) Are you doing 'O' grade physics as well? Yes/No

7. If you are doing 'H' grade biology this year: (delete as appropriate)

   A) Are you doing 'H' grade chemistry as well? Yes/No

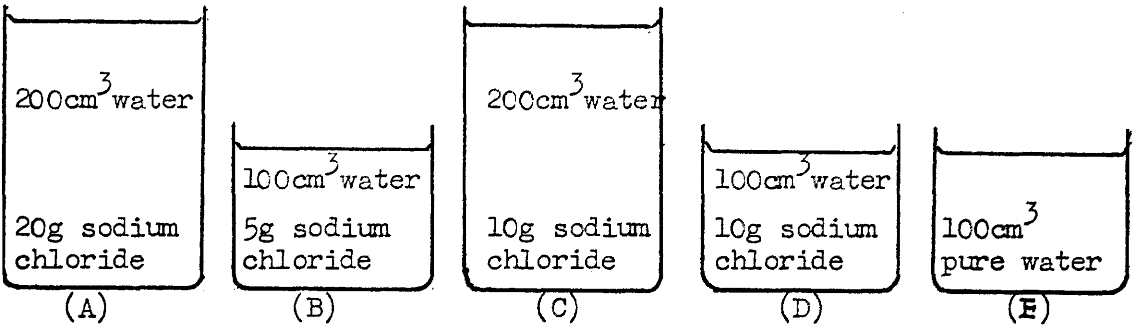
   B) Are you doing 'H' grade physics as well? Yes/No

   C) Have you done 'O' grade chemistry before? Yes/No

   D) Have you done 'O' grade physics before? Yes/No

THANK YOU FOR YOUR CO-OPERATION

"Water Potential"
(for fifth year pupils who are studying the 'Higher Grade' biology)



I. Examine the above diagrams of beakers containing liquids, then read the following statements marking them T, F or Dk.

1. Solution (A) has <u>higher</u> osmotic potential than solution (C) $\boxed{T}$
2. " (B) " " " " " " (D) $\boxed{F}$
3. " (C) " " " " " " (D) $\boxed{F}$
4. " (A) " " " " " " (B) $\boxed{T}$
5. " (A) " " " " " " (E) $\boxed{T}$
6. Solution (B) can cause <u>higher</u> osmotic pressure than (D) $\boxed{F}$
7. " (A) " " " " " " (E) $\boxed{T}$
8. Solution (A) has <u>higher</u> water potential than solution (C) $\boxed{F}$
9. " (B) " " " " " " (D) $\boxed{T}$
10. " (C) " " " " " " (D) $\boxed{T}$
11. " (A) " " " " " " (B) $\boxed{F}$
12. " (A) " " " " " " (E) $\boxed{F}$
13. In solution (C) there are <u>more</u> free water particles available to exert pressure on the walls than in (A) $\boxed{T}$
14. In solution (D) there are <u>more</u> free water particles available to exert pressure on the walls than in (E) $\boxed{F}$
15. From the above information about the solutions, draw heads on the arrows below to show the direction of water flow between each of the following pairs of solutions if each solution was put in contact with the other but separated by a s.p. membrane.

A——C	A——D	A——E	B——D
← OR ↞→	↔	← OR ↞→	→ OR ←↠

nswers:

	Cell A	Cell B	Cell C	Cell D
Wall pressure:	1	4	6	0
Osmotic potential:	5	3	6	2

II. Examine the above data about the wall pressure and the osmotic potential of four different plant cells and calculate the values of the water potential for each. Insert your answer in the following four boxes. (If you don't know the answer insert Dk in the box)

16. | A = -4 | B = +1 | C = 0 | D = -2 |

To answer the following questions insert the appropriate letter in the box provided at the end of each.

17. Which one has the highest water potential of them all? | B |
18. Which one has the lowest water potential of them all? | A |
19. Which one is the most ready to give water out? | B |
20. Which one is the most ready to accept water in? | A |
21. Which one is water movement balanced, if soaked in pure water? | C |
22. Which one is almost plasmolysed? | D |

III. The following boxes show the values of water potential of another four plant cells. Have a look at them, then answer the following questions.

	Cell E	Cell F	Cell G	Cell H
Water potential:	-2	-4	+1	0

23. Draw the heads of the arrows between the following pairs of cells to show the direction of water flow if each pair were put in contact:

Answers: OR OR OR OR

E——F F——G G——H E——H

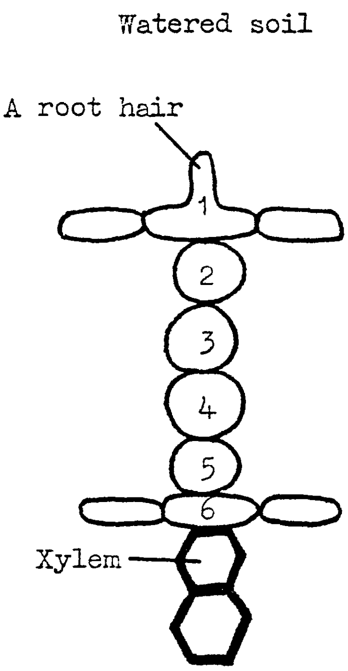
(If in doubt, insert no arrow head)

24. Which one has the highest water potential of them all? | G |
25. Which one has the lowest water potential of them all? | F |

26. If soaked in pure water, which cell(s) is/are going to expand by absorbing water? **E** and F

27. In which one is there more free water particles per unit volume? G

IV. Here you find a diagram which represents the main tissues of a plant root during the active period of the year. To answer the following questions insert the appropriate numbers or words in the boxes below. (If in doubt insert Dk)



"Transverse section in a root"

28. Which cell has the highest water potential? 1

29. Which cell has the lowest water potential? 6

30. Which cell has the highest concentration of dissolved substances? 6

31. Which cell has the lowest concentration of dissolved substances? 1

32. Which cell has most probably developed the highest cell wall pressure? 1

33. Which cell has most probably developed the lowest cell wall pressure? 6

34. Which one has the greater number of free moving particles of water per cubic centimetre: the soil solution or the root hair sap solution? Soil

35. Which one has the power to cause higher osmotic pressure: the soil solution or the root hair sap solution? $\boxed{\text{root}}$

36. With the increase of water flow into the root cells, would they develop higher or lower cell wall pressure? $\boxed{\text{higher}}$

37. Which osmotic potential must be higher to help water to get more readily into the root: that of the soil solution or that of the root hair sap solution? $\boxed{\text{root}}$

THANK YOU FOR YOUR CO-OPERATION

Appendix No. 6.6.3.B

The guide sheet used for the correction of the essay question which reads: "In your own words, give an account describing how water particles leave the soil solutions and accumulate in the root cells."

Score (0): Wrong or irrelevant answer.

Score (1): "Water flows from the soil solutions to the root cells by diffusion/by osmosis/by osmotic pressure/by water potential."

To Piaget: Answer does not give any explanation of the phenomenon, hence does not reveal the pupil's level of thought and reasoning.

To Gagné: Answer does not show more than a verbal association type of learning.

To Ausubel: Answer of cliché type, hence no evidence of meaningful learning.

Score (2): "Water flows by diffusion/by osmosis/by osmotic pressure because its amount is greater in the soil than it is in the plant."

To Piaget: This shows an operational thought at the concrete level since the word 'amount' reveals the use of mental actions which bear directly on observable things. This answer is not more than a statement-of-observation and the pupil sees the phenomenon at its 'macro' level.

To Gagné: This is an inaccurate memorized verbal statement of the concept.

To Ausubel: This shows no evidence of a meaningful learning yet, since the pupil is replacing the correct subsumer 'concentration' by the relatively incorrect one 'amount'.

Score (3): "Water flows because its concentration, or its pressure, is higher in the soil side than it is in the plant side."

To Piaget: This shows an operational thought at the concrete/formal levels interface since the pupil is still bearing on simple relations but in the meantime he refers to the idea of 'concentration' which includes here the concept of ratios between unobservable events.

To Gagné: This answer refers only to one of the subordinate elements of the process making the explanation at its minimum.

To Ausubel: This answer can be taken as an evidence of a meaningful learning, but still lacking some important subsumers which are relevant to the concept.

Score (4): "Soil solutions are more concentrated with solutes compared to the root cell sap, hence the former are more concentrated in the free moving particles of water than the latter. Applying the rules of osmosis, the free moving particles of water tend to travel more readily from the soil to the root across the semi-permeable membranes."

To Piaget: This gives evidence of a formal operational thought since it deals with ratios, atomisation and relation between relations.

To Gagné: This is an evidence of a good learning at the concept level since the answer reveals the understanding of all the required subordinates.

To Ausubel: This answer deals correctly with the concepts which are subsumers of the phenomena, such as the particulate nature of water and solute, concentration and permeability.

Score (5): "Soil solutions are more concentrated in solutes compared to the root hair cell sap, hence the former are more concentrated in the free moving particles of water than the latter. As a result, this kind of particle presses at a higher rate on the s.p. membranes from the soil side than it does from the cell sap side. Eventually, there will be a net flow of water into the root hair cells which will become turgid with a dilute sap and develop a high wall pressure. Both reasons will cause a net flow of water into the next row of cells towards the root centre. By this process being repeated, water leaves the soil and accumulates in the root cells."

To Piaget: This gives evidence of late formal operational thought since the answer deals with more than one variable, and shows a chain of reasoning from the known to the possible with correct application of the role of probability in the redistribution of water particles.

To Gagné: This shows evidence of complete mastery of the concept reaching the rule learning and its application in the given situation.

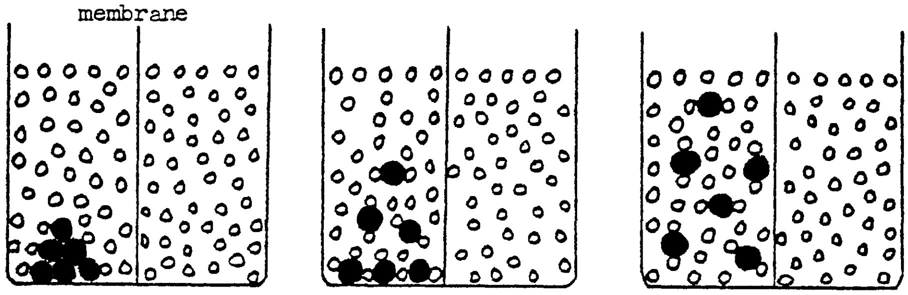
To Ausubel: This answer is highly informative as it anchors correctly all of the relevant subsumers to the given situation. This indicates a meaningful learning at its highest level.

Appendix No. 7.3.A

The 'standard' printed material

PART ONE: "DISSOLVING AND DIFFUSION"

Solid membrane



(1) Water with soluble solid substance | Pure water

(2) Some hours later

(3) Many hours later

Through this part of the film, the pupils are expected to recognise the following facts:

1. Water, as well as the soluble solid substance are made up of tiny building units. (Let us call them particles for simplicity)

2. Particles of water move spontaneously, i.e. they are able to travel from their original places of their own accord. They move very fast (even more than demonstrated by the film). They follow straight line paths until they collide with each other or with any obstacle, e.g. the particles of the solid substance or the walls of the container.

3. Particles of water never stop moving, even after achieving the complete mixing with another substance. It is a continuous movement in all directions.

4. Particles of the solid substance (while in the crystalline state) do not travel from their places but only vibrate (oscillate) around fixed points. As any substance in its solid state, they cannot overcome the internal forces which keep them packed tightly together. As a result, they lie accumulated at the bottom of the container until the particles of water start bumping against them. They do not fit into spaces or fill in gaps.

5. Dissolving means that the particles of water attach themselves to the outer line particles of the soluble solid substance. Being in a continuous movement, the particles of water pull them away into the body of the solution. The then exposed particles of the second line of the solid substance are pulled away in similar manner by other particles of water. As a result, the lump of the solid substance dissociates and disappears to the eye and spreads throughout the solution. Another important result is that a considerable number of the water particles became engaged with the particles of the solid and so are no longer as free as normal water particles. This has some important consequences. It is clear that the particles of the solid substance remain dependent in their travelling with the particles of water. It is a combined slow movement, in which some water is bound.

6. The particles of water and the particles of the dissolved substance spread evenly throughout the solution thus taking up the most probable distribution.

7. As the particles of the solid substance spread from their original location at the bottom of the container we can conclude that they have diffused from where they were more concentrated to where they were less concentrated.

8. As the particles of water gradually move into the spaces initially occupied by the solid substance, we can conclude that water diffused from where it was in higher concentration to where it was in lower concentration.

9. Under normal conditions, distribution and redistribution never come to an end, since the particles of water are in continuous movement, and many of them are attached to the particles of the solid substance. By this means, all kinds of particles are evenly distributed throughout the solution.

PART TWO: "OSMOSIS"

Through this part of the film the pupils are expected to recognise the following facts:

1. At the pure water side the space is almost entirely occupied by particles of water which are moving freely, continuously, and in all directions.

2. Different from that, an equal space on the solution side is shared between (i) particles of dissolved solid substance, (ii) a considerable number of particles of water attached to them without being able to move freely, and (iii) a number of particles of water which are moving freely, continuously, and in all directions. In this sense, we can conclude that a unit volume from the pure water side contains more free-moving particles of water compared with an equal unit from the solution side. Accordingly, it can be said that the concentration of free water in the solution is less than that on the pure water side.

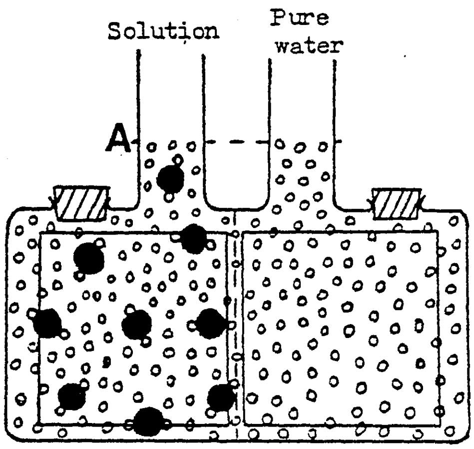
3. If we consider a compartment of pure water in contact with a compartment of solution, then in the pure water compartment there will be more free water particles able to move to the solution compartment than to travel in the opposite direction.

4. The presence of a dissolved substance in a solution has a hindering effect on the particles of water in that solution. This hindering effect can be thought of in different ways:

   a) As they occupy part of the space, there are fewer particles of water facing a given area of the s.p. membrane than there are on an equal area in the other compartment.
   b) Many of the water molecules are busy holding on to the dissolved materials and are not as free to move around as they were before.
   c) As the s.p. membrane does not allow the dissolved particles to pass through, the water particles attached to them are not able to cross either.

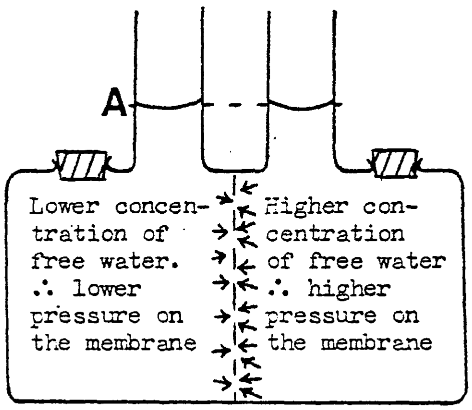
5. Pressure is proportional to the <u>rate of bombardment</u> of particles on a given surface area. Applying this to the osmosis situation would suggest the following notions:

a) As the free-moving particles of water are more concentrated in the pure water side, they cause a pressure on the whole area of the s.p. membrane greater than that caused by their counter-parts on equal area in the solution side.



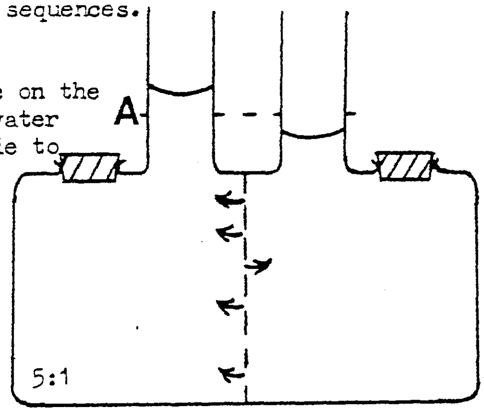
(1)

Comparing the numbers of the free-moving particles of water within two equal areas or volumes on both sides.



(2)

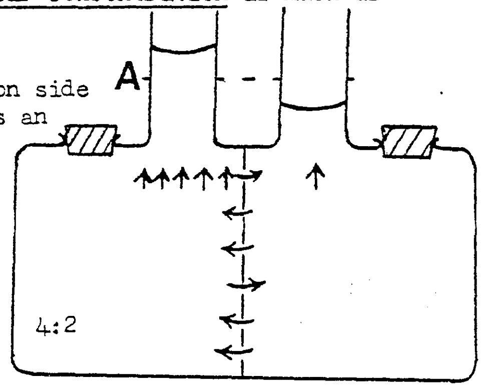
The concentration gradient of free-moving particles of water has its higher end in the free water side. Compare the consequences.



(3)

b) Because of this difference in pressure on the two sides of the membrane, more free water particles flow from the pure water side to the solution, and fewer flow the other way. The result is a <u>net</u> flow of water from the pure water side to the solution side.

<u>Important</u>: It may be obvious now that strong solutions <u>do not cause any suction</u> with respect to pure water or more dilute solutions. Free moving particles of water travel <u>of their own accord both ways</u>. They redistribute themselves between the two sides in an attempt to <u>even up their concentration</u> as much as possible and attain the most probable redistribution.

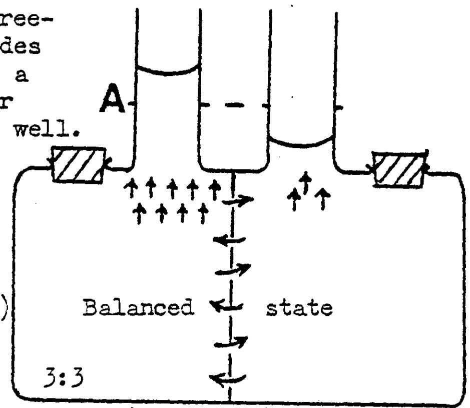


(4)

c) The net flow of water into the solution side creates a continuous force. It causes an increase in the volume of the solution and a corresponding decrease in the volume of pure water. In the former, the pressure generated supports the increasing weight of the growing column of liquid above it. So, the difference in pressure balances the difference in the heights of the columns.

d) The difference in concentration of free-moving particles of water on both sides of membrane gradually decreases. As a result, both the differences in water pressure and water flow decrease as well. The growth of the rising column of liquid on top of the solution becomes slower and slower.

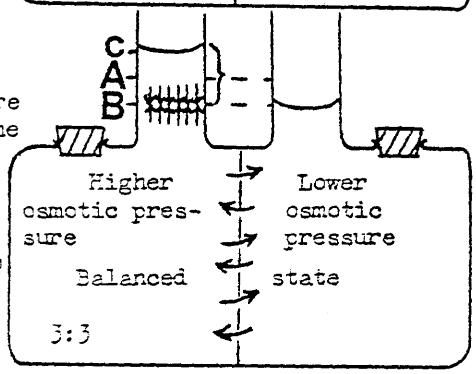
(5)



e) A state of balance is reached when the values of the two opposing pressures become equal:

i) the gradually decreasing pressure of the net flow of water into the solution, and
ii) the gradually increasing pressure caused by the weight of the growing column on top of the solution.

(6)



At that point, the free-moving particles of water keep on travelling equally in both directions across the membrane without any net movement into either side.

Closing note: This phenomenon of water particles diffusion across s.p. membrane is called "osmosis." It is a particular case within the general phenomenon of diffusion. The side with lower concentration of water receives more water particles than it loses, and shows higher osmotic pressure than the side with higher concentration of water. The former can hold a column of extra liquid on its top whereas the latter cannot do as much.

To sum up the main points involved in osmosis:

	Solution side	Pure water side
1.	Lower concentration of free-moving particles of water	Higher concentration of free-moving particles of water

Leads to

2. Difference in the concentration of free-moving particles of water on the two sides of the s.p. membrane

3. Difference in their pressure on the two sides of the membrane.

	Solution side	Pure water side
4.	Lower pressure caused by those particles on the membrane.	Higher pressure caused by those particles on the membrane.

5. Difference in the flow of the free-moving particles of water in both directions.

	Solution side	Pure water side
6.	Smaller number of those particles migrate to the other side during their continuous and random movement.	Greater number of those particles migrate to the other side during their continuous and random movement.
7.	The volume increases gradually.	The volume decreases gradually.
	The solution shows its high osmotic pressure, i.e. higher ability to hold the weight of the liquid column on its top.	The pure water side shows its low osmotic pressure, i.e. lower ability to hold any weight on its top.
	The solution shows lower water potential, i.e. lower ability to send out water and higher ability to receive it from the pure water side. This is simply because all the free-moving particles of water are in continuous movement crossing the membrane in both directions. During this, they redistribute themselves between the two sides. The even distribution is, of course, the most likely one to happen.	The water shows higher water potential, i.e. higher ability to send out water and lower ability to receive it.

8. Because of this, and the difference in pressure on the two sides of the s.p. membrane mentioned earlier, the net flow of free particles of water is into the solution. (No suction takes place!) These crossing particles would try to even up their numbers per unit volume between the two sides. This process can never go to completion because another force appears, i.e., the downwards pressure of the resulting column of liquid at the top of the solution. When the pressure becomes equal on the two sides of the membrane, an equilibrium state is reached. Water particles would keep on crossing both ways but with no net flow in either direction.

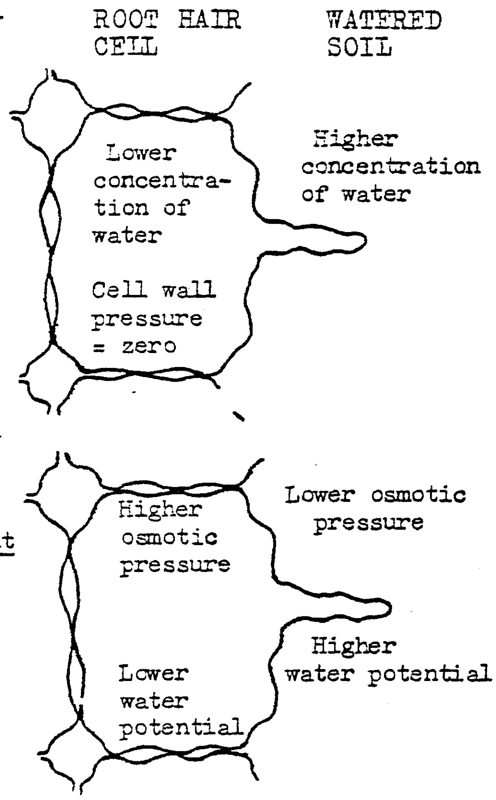
   The same explanation mentioned above could be applied, with few alterations, in the case of experiments with two sides different in free water concentration. Such experiments could involve two solutions, a cell and pure water, a solution and a cell, or two cells. Part III discusses the last two cases.

PART III: PLANT-SOIL SITUATION AND WATER POTENTIAL RELATIONSHIP

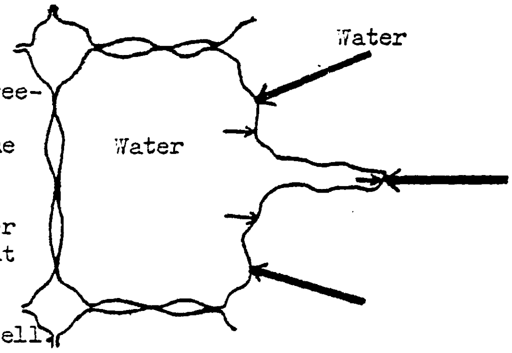
To study the properties of the watered soil solution and the root hair cell sap solution with regard to osmosis, we have to consider equal volumes of the two solutions. Our concern should be with the free-moving particles of water on each side. The following steps could be of help in our study:

1. A wilted plant would show many wrinkled cells, especially those with thin walls, due to the shrinkage in volume of those cells. In normal cases there is initially a greater number of the free water particles per unit volume in the watered soil than in the wilted root hair cell. This is because the plant cell usually contains a solution concentrated with dissolved substances such as salts, sugars, vitamins, organic acids, and the like. A wilted plant would have a smaller amount of water in its cells than a fresh one. This means that the concentration gradient of water has its higher end in the soil, while its lower end is in the root hair cell.

2. As a result, water is more available from the soil rather than from the r.h. cell. This is expressed by saying that the soil solution has higher "water potential" compared to the r.h. cell.



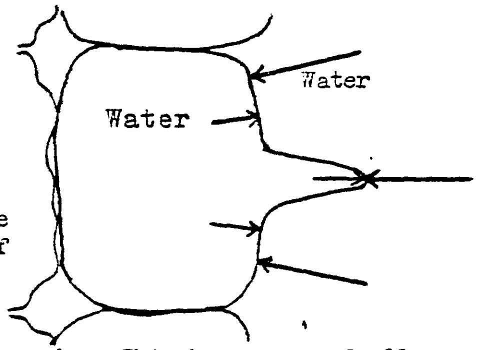
3. The difference in concentration of the free water particles between the soil and the r.h. cell creates a corresponding difference in their pressure on the two sides of the cell wall and s.p. membranes. From part II we have noticed that water flows more readily from the side which:
   a) has higher concentration of the free-moving type of water particles.
   b) shows lower osmotic pressure to the side with the opposite properties.

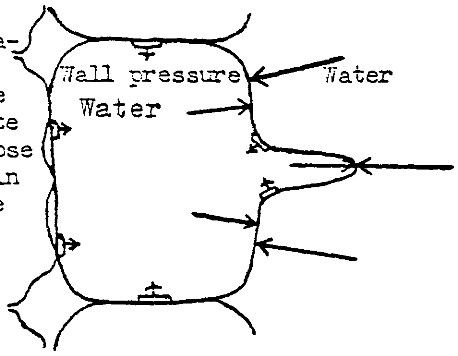


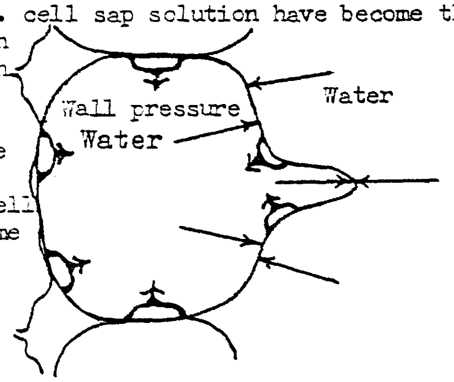
4. As the free-moving particles of water are in a continuous state of movement in all directions, there is always a continuous flow of water both ways between the soil and the r.h. cell.

5. Due to the initial difference in their concentration and the resulting difference in their pressure (bombardment) on the two sides of the cell wall and membranes, more water flows into the r.h. cell, but less flows out to the soil.

6. The results of this difference in water flow would be as follows:
   A) The cell volume grows bigger (recovery from wilting or from plasmolysis).
   B) The concentration of water inside the cell increases. This means the decrease in the osmotic pressure of the cell sap solution.
   C) The cell wall stretches (Turgor commences).
   D) The cell wall reacts by pressing inwards. This happens gradually with the increase of the cell volume. This discourages the flow of water into the cell.
   E) The difference in water concentration between the two sides decreases as the number of the free particles of water which immigrate into the cell is greater than those which leave it. The difference in pressure of this kind of particle becomes less than before.
   F) The cell becomes less able to receive excess amounts of water than before, i.e. its water potential grows higher.
   G) With the decreasing difference in water flow between the cell and the soil, a state of equilibrium is reached. No net flow of water in either direction is recorded. The two values of water potential for the soil solution and for the r.h. cell sap solution have become the same. That state is achieved when the two forces acting against each other become equal, i.e.,
   a) the pressure caused by the net flow of water particles from the soil to the r.h. cell, and
   b) the pressure of the stretched cell wall caused by the growing volume of the cell.
   The first force causes free water particles to flow into the cell, whereas the latter opposes such inflow.







The next step is to trace the movement of water particles between the r.h. cell and the cell next to it, applying the same method of investigation. The initial situation would be as follows:

"CELL NEXT TO ROOT HAIR CELL"

a) Lower concentration of free water particles.

b) Higher osmotic pressure.

c) Lower cell wall pressure (literally nil).

∴ Lower water potential.

"ROOT HAIR CELL"

a) Higher concentration of free water particles.

b) Lower osmotic pressure.

c) Higher cell wall pressure

∴ Higher water potential.

Accordingly, water keeps on travelling deeper towards the centre of the root.

To sum up the main points involved in water potential:

I. In solutions

1. High concentration of the dissolved substance in one compartment ——— leads to ———→

——→ Low concentration of free-moving particles of water ——— leads to ———→

→ Low water pressure on the s.p. membrane on that side towards the other ———→

→ High ability to develop osmotic pressure in that compartment ———→

——→ Low water potential → less water flows out and more flows in.

2. If a solution is exposed to a high mechanical pressure, this leads → to high water potential, i.e. positive value, and can give water to a pure water compartment across a s.p. membrane (such a method could be used in the desalination of sea water).

II. In cells

1. High concentration of free-moving particles of water, i.e. low osmotic pressure, plus high cell wall pressure → high water potential (either positive, or negative but close to zero).

2. Low concentration of free-moving particles of water, i.e. high osmotic pressure, plus low cell wall pressure (or even not found as in a plasmolysed cell) → low water potential (negative and far from zero).

3. If: osmotic potential=cell wall pressure, the result: water potential=zero. If such a cell is placed in pure water, it will receive water particles as much as it gives ∴ No net movement will take place. But if it is placed in a solution, the free water particles which will travel out to the solution will exceed those travelling into the cell. Its wall pressure will decrease for losing volume, its osmotic pressure will increase for losing water, and as a result its water potential will decrease.

Appendix No. 7.3.B. The 'additional' printed material.

WILTED ROOT HAIR CELL	WATERED SOIL

I. The initial situation:

WILTED ROOT HAIR CELL	WATERED SOIL
1. Wrinkled cell wall (cell wall pressure = zero).	
2. High concentration of dissolved substances.	Low concentration of dissolved substance.
3. High osmotic pressure.	Low osmotic pressure.
4. Low concentration of free-water particles.	High concentration of free-water particles.

This leads to:

5. a difference in concentration of the free-water particles on the two sides of the cell wall and membranes.

6. a difference in the pressure caused by those particles on the two sides, i.e., lower at the cell side, and higher at the soil side.

7. a difference in water potential, i.e. the cell sap has lower water potential (e.g., -8) than the soil solution (e.g., -3). The cell is less able to give out water but more willing to receive it.

II. The results:

WILTED ROOT HAIR CELL	WATERED SOIL
1. Fewer free-water particles leave the cell and go to the soil.	Greater number leave the soil to go to the cell.
2. The volume of the cell <u>increases</u>.	
3. The osmotic pressure of the cell sap solution <u>decreases</u>.	Osmotic pressure of soil solution increases.
4. The water potential of the sap solution <u>increases</u>, i.e. its ability to receive water becomes less than before. (The value still negative but much nearer to zero than before, say -6).	Its water potential <u>decreases</u>, i.e. its ability to give water becomes less than before. (The value still negative but further away from zero than before, say -4).

This leads to:

5. The difference in concentration of free-water particles between the two sides <u>decreases</u>.

6. The difference in the pressure caused by them on the two sides of the wall and membranes <u>decreases</u>.

7. The difference in water potential between cell and soil <u>decreases</u>.

WILTED ROOT HAIR CELL	WATERED SOIL
8. The number of free water particles leaving the cell <u>increases</u>.	The number of the free-water particles leaving the soil <u>decreases</u>.
9. A new force appears with the increase in cell volume. While the cell wall is being forced to stretch outwards, it resists by pressing inwards. This opposes the flow of water into the cell. Moreover, it tends to squeeze water out. This new factor helps to <u>increase</u> the cell water potential (e.g., to -5).	

10. The equilibrium state is achieved when the water potential of both the cell and the soil solutions becomes equal. Both still negative values (e.g., -4.5).

<u>N.B.</u> 1. If two amounts of pure free water are separated from each other by a s.p. membrane with equal pressures on them (e.g. atmospheric pressure) no net loss or gain in water will happen. Any factors which would cause the gain of water particles are equalled by factors which cause the loss of an equal amount. For this, the water potential of pure free water is taken as zero. If pressure is imposed from outside on one of the two amounts, its water potential will be higher than zero (e.g. +2).

2. All solutions have negative values for their water potential. The reason is that all of them have many particles of water attached to the particles of the dissolved substance. Those particles of water are no more free in their movement. If such a solution is put against an amount of pure free water, there will be a net flow of water towards the solution. This indicates that the water potential of the solution is less than that of the pure free water, i.e., less than zero (e.g. -2).

3. The greater the number of the free particles of <u>water</u> in a solution per unit volume or unit area, the higher the water potential value for it, i.e., still negative but much nearer to zero (e.g. -1).

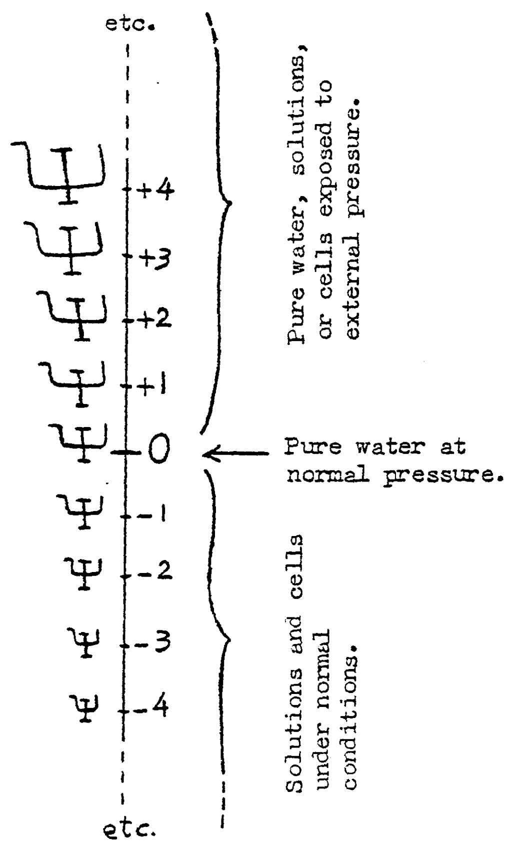
4. The value of the water potential for a cell is the mathematical difference between the factors causing water to flow into it (i.e., the osmotic potential value of the sap solution) and the factors discouraging this inflow (i.e., the cell wall pressure). The equation illustrates the relationship as follows:

Water potential (Ψ) for a cell = its cell wall pressure - the osmotic "potential" of its sap solution.

As the value of wall pressure is usually smaller than that of the osmotic potential of the sap, the result will carry a negative sign.

5. The net flow of water between cells or solutions is always from the one with higher water potential (e.g. -1) to the one with lower water potential (e.g. -2). The greater the difference the more readily the free water particles flow between them. When comparing several values of water potential this scale should be helpful.

If some cells with different (Ψ) are put close to each other, the arrows will refer to the direction of the net flow of water between them according to the corresponding values of (Ψ)



Appendix No. 7.6.A.

" The teacher's guide to the film "

UNIVERSITY OF GLASGOW

A Teacher's Guide to the Film on Diffusion, Osmosis and Water Potential

Introduction and Objectives

In an earlier stage in our research, the topics of osmosis and water potential proved to be of considerable difficulty to the fourth and fifth year pupils in secondary schools.

During the last year, we have been analysing these topics, and investigating the levels at which the pupil understands them. From the data collected by means of several interviews with pupils and two objective tests, we concluded that the majority of the pupils are learning this area by rote rather than by analytic understanding. We suspect one of the causes is that this area was not linked to their previous experience in science. It is clear that these topics are based on several fundamental facts which come from the fields of chemistry and physics. Failure to recall these facts, or to link them up with the relevant corresponding parts in these biological concepts may have led to the results we got from the pupils.

In the present stage of our research, we are attempting to give a picture to bridge between lessons, such as, the particulate nature of matter, the structure of solutions, pressure, dynamic balance, etc., and the biological concepts dealt with in osmosis and water potential. Knowing the shortage in teaching aids suitable for this particular purpose, we've made a 16mm film entitled "Osmosis." The film should help them to construct the mental pictures most needed for a successful understanding of these topics. Besides, it furnishes them with all the required fundamental facts from the physical sciences.

Contents of the Film

Though titled "Osmosis," the film treats many concepts relevant to this title as well. Some are subordinate, others are superordinate to it. The film has three parts, with total running time: 14 minutes.

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Contents of the Film

Though titled "Osmosis," the film treats many concepts relevant to this title as well. Some are subordinate, others are superordinate to it. The film has three parts, with total running time: 14 minutes.

I. Dissolving and diffusion: this part demonstrates the following basic ideas:

1 - The particulate nature of matter.

2 - The formation of aqueous solutions.

3 - The effect of the solute on water.

4 - The diffusion of water and solute.

This part is suitable for pupils doing biology at all levels.

II. Osmosis: this part demonstrates the following ideas:

1 - The concentration gradient.

2 - The hindering effect of the solute on water.

3 - Pressure inside solutions compared to that in pure water.

4 - How water flows more readily from a pure water side to a solution side.

5 - How osmotic pressure is generated in a solution.

6 - The equilibrium state in osmosis.

This part is suitable for pupils doing biology at both 'O' and 'H' Grades.

III. Water potential: this final part demonstrates the following ideas and phenomena:

1 - The initial situation in roots and soil in terms of water concentration and osmotic properties.

2 - How water flows more readily from the soil to the root.

3 - Recovery from plasmolysis, and return to turgidity in plant cells.

4 - Development of cell wall pressure and its effect on the inflow of water.

5 - The cell water potential as a result of the two major factors opposing each other.

6 - How water flows more readily from the root hair cell to the next cell.

This part is mainly intended for the fifth year pupils, but still of great value to the fourth year pupils as it informs them about the plant-soil-water relationships, with the application of what has been learned onthe laboratory models to that situation.

A suggested sequence of presentation

To get the best value of the film, the following sequence is recommended.

1. Printed notes are to be distributed among the pupils a day or two before the day of the projection. Advising them to review the relevant facts previously studied in separate or integrated sciences would be of great help to them later on.

2. A discussion is to follow after this and immediately before the projection. The aim is to reinforce their understanding of the basic factual ideas and to prepare them for the film.

3. The silent showing of the film, with no commentary or questions from all sides. This would help every individual student to grasp as many ideas as possible of his own accord.

4. A discussion of what has been on the screen, in order to receive their reaction and to evaluate the benefit they manage to get out of it. The teacher will need to draw their attention to some ideas concealed from them.

5. The second projection of the film with the teacher's comments. It would be far better if the projection is stopped from time to time to enable the teacher to give a longer talk on some points. The pupils will be able to note every feature on the film and receive the message complete.

6. The pupils' time for enquiry and asking for explanations is to follow. This would help each pupil to remove any conflict between his old background and his new experience. Their understanding of the topic will be much clearer with this enquiry.

7. The teacher's time for asking questions. He could decide whether it is necessary to make a third projection or not. He may find it reasonable to highlight some key points or to refer to some hints which appeared on the screen in order to rectify the understanding of one or more of his pupils.

<u>N.B.</u> Laboratory experiments relevant to these topics are recommended to be carried out prior to the first showing of the film. The film and the discussions that would accompany its showing would furnish the pupils with the explanations for what they have studied earlier in the laboratory.

Appendix No. 7.8.A

"Teachers' opinions about the new learning materials"

THE UNIVERSITY OF GLASGOW

Teachers' impressions of the film "Osmosis" and the accompanying printed material

(to be distributed among biology teachers who have used the film in their classes)

Dear Colleague,

Would you please be kind enough to provide us with your judgment on some points in the film "Osmosis". You can complete one form only, but if you feel that the use of the film with different classes yielded different impressions and reactions, we should be grateful if you complete more than one form.

(18 teachers from eight schools answered this questionnaire.
Fourth year: responses from 18 teachers.
Fifth year: responses from 10 teachers.)

I. General Information

School name: _ _ _ _ _ _ _ _ _ _ _ _

Classes to which the new material was provided:

Serial No.	Section designation	Year of study	Type of class (mixed ability or otherwise)	Had they studied these topics before the showing of the film
1	(21 classes)	(4th year)	(all mixed ability)	(No)
2	(15 classes)	(5th year)	(" " ")	(Diffusion and osmosis while in their fourth year)
3				
4				
5				
6				

II. The factual content of the film

Please tick inside the appropriate box against each enquiry.

1. How do you find the factual contents of the different parts of the film?

(Teachers N = 18)

Part I:	completely correct	12	6	0	0	completely wrong
Part II:	" "	12	6	0	0	" "
Part III:	" "	13	5	0	0	" "

2. How far do you find the screen treatment of each part is suitable in terms of length?

(Teachers N = 18)

Part I:	very suitable	5	10	3	0	completely unsuitable
Part II:	" "	4	11	3	0	" "
Part III:	" "	5	10	3	0	" "

If you have any objections would you please specify: 1. Some animated diagrams are jerky. 2. Part I too long compared to part II and III. 3. Colours are not highly contrasted against the background. 4. Discussion of codes and arrows slightly distracted attention from processes.

3. How far do you think each part could provide the pupils with the knowledge up to the level required?

'O' grade pupils (Teachers N = 18)

Part I:	completely suitable	16	1	1	0	totally unsuitable
Part II:	" "	11	4	3	0	" "
Part III:	" "	5	6	5	2	" "

'H' grade pupils (Teachers N = 10)

Part I:	completely suitable	9	1	0	0	totally unsuitable
Part II:	" "	7	2	1	0	" "
Part III:	" "	3	5	2	0	

If you have any objections would you please specify: 1. Taped commentary needed. 2. Difference between osmotic pressure and osmotic potential was not made clear.

Other comments regarding this section: 1. Chemical facts are not examinable. 2. Thoughtful pupils considered the film very helpful, poor pupils considered it overloaded. 3. Film was better understood by poor pupils when shown twice.

III. The pupils' reaction to the film

1. How far did your pupils require for extra explanation for different parts of the film?

'O' grade pupils (Teachers N = 18)

Part I:	none required	4	9	5	0	great deal was required
Part II:	" "	1	12	5	0	" " " "
Part III:	" "	0	6	7	5	" " " "

'H' grade pupils (Teachers N = 10)

Part I:	none required	6	3	1	0	great deal was required
Part II:	" "	4	4	1	1	" " " "
Part III:	" "	0	3	4	3	" " " "

If they have had any difficulty, please specify: 1. Idea of osmotic pressure is completely new. 2. A few felt that there was much to take in, repeated projection solved the problem.

2. Considering the queries raised by the majority, how far did they seem able to link the ideas explained by the film to their previous knowledge?

'O' grade pupils (Teachers N = 18)

Part I:	easily linked	9	9	0	0	Great confusion was caused
Part II:	" "	9	6	2	1	" " " "
Part III:	" "	3	7	6	2	" " " "

'H' grade pupils (Teachers N = 10)

Part I:	easily linked	8	1	1	0	Great confusion was caused
Part II:	" "	7	2	1	0	" " " "
Part III:	" "	2	6	2	0	" " " "

3. How far do you think that the printed material helped to make the ideas clear to the pupils?

(Teachers N = 18)

Part I:	very helpful	16	2	0	0	Totally confusing
Part II:	" "	11	4	3	0	" "
Part III:	" "	5	8	4	1	" "

If you have any objection, specify here please: 1. Arrows, numbers and coding are slightly confusing. 2. Too much information for the pupils, especially the poor ones. 3. In chemistry, dissolving process is different.

Other comments regarding this section: 1. Osmotic pressure seems to be the best key point to the whole question of osmosis and water potential. 2. The printed notes are very good. 3. The use of the test after the film greatly enhanced their understanding.

Appendix No. 8.10.A

Assembled halves of the tests for the estimation of their reliability

Serial numbers of the 'Diffusion and Osmosis' test items		Serial numbers of the 'Water Potential' test items	
First half	Second half	First half	second half
3	4	6	7
12	23	13	14
9	29	1	2
		3	4
2	1	36	37
		5	12
5	6	8	9
18	26	10	11
		17	24
8	11	18	25
17	19	21	22
14	16	19	20
25	28	23	26
13	24		
15	20	28	29
		30	31
31	35	32	33
30	32	35	34
34	38		
36	37		
39	40		

For detailed wording of the questions, refer to Appendix No. 6.6.3.A

Appendix No. 8.10.B

Estimation of the 'Standard error' of the two tests

For further investigation of the two tests reliability, the 'Standard error of measurement' was computed for each. This is an estimate of the standard deviation that would be obtained for a series of measurements of the same individuals who sat the tests constructed by the researcher in this study. The standard error of measurement was calculated from the reliability coefficient using the formula

$$S_m = S_t \sqrt{1 - r_{11}}$$

where S_m is the standard error of measurement,
S_t is the standard deviation of test scores, and
r_{11} is the reliability coefficient. (154)

The results were as follows:

Test / Pupils	The 'Diffusion and Osmosis' test			The 'Water Potential' test		
	S_t	r_{11}	S_m	S_t	r_{11}	S_m
1. Fourth year	4.71	0.86	1.76	—	—	—
2. Fifth year	4.96	0.85	1.92	5.93	0.82	2.51

From the computed values of (S_m), the researcher would advise researchers and teachers who are going to use these tests of the following:

1. Corresponding to a 95% level of confidence, the true score for a given fourth year pupil on the test of 'Diffusion and osmosis' is within the range $Y \pm 1.96 \times 1.76$ (where Y is the obtained score).

2. The corresponding range for a given fifth year pupil on the same test is $Y \pm 1.96 \times 1.92$.

3. The corresponding range for a given fifth year pupil on the test of 'Water potential' is $Y \pm 1.96 \times 2.51$.[179]

These corrections are within the accepted limits, since '$S_m = 5.7$' is a fair representative of what might be found for intelligence quotients from group intelligence tests.[154]

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