THE DEVELOPMENT OF A PREDICTIVE THEORY OF SCIENCE EDUCATION BASED UPON INFORMATION PROCESSING THEORY

by

HAMDY ABDEL-AZEEM M. EL-BANNA

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ABSTRACT

This thesis describes the establishment of a new predictive theory for science education which can give direction to the improvement and transformation of science teaching at all levels. It is based upon Information Processing Theory. It has the ability to predict performance in science on the basis of independent psychological tests and to provide a framework for understanding how scientific learning takes place.

The development of the theory has resulted from empirical work on 529 school pupils at "O" Grade (age 16) and on 440 Glasgow University students, through two series of experiments in addition to two confirmatory studies in the U.S.A. and Egypt. The first series related to students' performance in individual questions, and the second related to students' over-all performance in conventional examinations.

Throughout this empirical work, a constant pattern has emerged showing that the students' holding-thinking space limited their ability to solve problems of different complexity. As soon as there was an overload on students' holding-thinking space, their performance fell away. In addition, the students' holding-thinking space is considered to be a good predictor for success in the conventional "O" Grade examinations, as well as the university examinations not only in chemistry, but also in physics, biology and mathematics.

Where the theory and the empirical measurements have not agreed exactly, further investigation has been done to examine the disparities. In some cases new understanding has occurred which has allowed the theory to be modified.

This thesis illustrates the importance of the teaching of learning strategies. In fact, it raises the teaching of strategies on to a par with the teaching of content. Three ways of successfully reducing the load on the students' holding-thinking space have been described and tested.

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The effect of the limitation of students' perceptual fields and of holding-thinking space on learning and problem solving tasks is also explored.

The theory, which has been established in this thesis, answered some of the questions that educators have concerning students' limitations in learning and in problem solving. The outworking of this theory in terms of instructional methods, design of computer programs, books and laboratory experiences, is forming the basis of several follow-up studies.

CHAPTER 1

INTRODUCTION - THE PROBLEM

1.1 Introduction

The early 1960's saw the first vigorous movements towards changes in the traditional science curricula in the United States of America. These movements towards change were followed by the United Kingdom and, within a few years, by many countries all over the world. As a result of rapid growth of the body of scientific knowledge, these movements were intended to replace the irrelevant and out-of-date syllabuses with new materials relevant to that time. Since these movements, much has been written about students' difficulties in understanding certain areas in science curricula. Johnstone(1) suggests three possibilities at least by which these difficulties have arisen.

1. The nature of the science itself makes it inaccessible.
2. The methods by which we have traditionally taught, raise problems.
3. The methods by which students learn are in conflict with either or both of the above.

In any attempt to design a new course, enough care should be taken about the nature of both subject content and students' limitations in learning since the level of the content difficulty ought to be appropriate to the students' mental ability. This means that the content should not be too easy so that students lose their motivation to learn, also that it should not be too difficult so that they become unable to deal with it. From this point of view, scientists and educators, as curriculum developers, should co-operate to match the difficulty level of conceptual schemes and the students' mental ability level.

In the field of chemistry, many facts, concepts and theories make up a huge body of knowledge. To overcome the problem of choosing and ordering the content, Johnstone(2) postulates that the shape of the chemistry content falls into at least three categories as follows.

1. Macro - in which tangible objects, substances and phenomena are examined. This is the area of materials science and gross properties.

2. /

2. Sub-micro - this is the molecular level which is used to explain the macro. Here we deal in pictures, ideas, structures and interaction.

3. Representational - here we use symbols to express our thinking in both of the other levels. These may be symbols for atoms and molecules or may have a gross meaning of some bulk of a substance. They are elaborated into equations, balanced or otherwise, and used to explain reactions and form a basis for calculation.

How then do chemistry curricula take into account these levels of the content? How do curriculum developers select and organize the content, bearing in mind the limitations of the students' mental development? Do they take enough care about developmental psychology and the nature of the chemistry itself?

1.2 The First Influential Chemistry Projects

In the United States of America the two major chemistry projects were -

> The Chemical Bond Approach (C.B.A.) and
>
> The Chemical Education Material Study project (CHEM Study).

In the report of the preliminary form of the C.B.A., Strong and Wilson(3) made two comments about the effective relationship between high school and college chemistry courses:

> "Care should be taken to avoid wasteful repetition between the two courses" and
>
> "The performance in freshman college chemistry appears to be little influenced by whether or not the student has had high school chemistry".

It /

It has been argued that the chemistry course in school was too large and factual so that it was only a collection of loosely related topics and yet modern chemistry has developed considerable internal consistency. From this point of view, the C.B.A. developed a new high school chemistry course based on chemical bonding as a central theme. The C.B.A. provides an introduction to chemistry as a modern science, since the chemistry consists of facts connected by imaginative ideas in an intelligible whole with which high school students can cope logically with these ideas and get an introductory view of modern science[(4-5)]. Information supplied by teachers and students led to revision and further improvement of the texts, laboratory manuals and teachers' guides, all printed for commercial distribution in the latter half of 1963[(6)].

Ingle and Ranaweera[(7)] have pointed out that the actual adoption of C.B.A. was limited, but it has had a considerable influence in the United States. In other countries it is well respected but the implementation was limited. It was revised in 1964-1977 with the aim of decreasing the reliance on physical chemistry and lowering the reading level of the materials.

On the other hand, the general objective of the Chemical Education Material Study project (CHEM Study) was to investigate effective ways of teaching chemistry in American high schools[(8)]. This course was based on an experimental approach to the teaching of chemistry. The philosophy for planning this course, as Campbell[(9)] suggested, was to divide it into three parts: the first gives an overview of the chemistry; the second represents an introduction through experiments to chemical generalization which should be covered at the secondary school level and the third part uses these generalizations in more detail to interpret larger chemical schemes.

The course was launched during 1962-1963 using the text "Chemistry An Experimental Science"[(10)] which was prepared over a three year period by a group of university and high school chemistry teachers. Another three versions of this have appeared during 1968-69 from three new groups. Hurd[(11)] has pointed out that the new authors and all members of the original CHEM Study writing team hoped to make the revised versions more teachable. The adoption of the /

the CHEM Study project in the United States has been considerable and its influence in other countries has been widespread and important particularly in Canada and Latin America[7]. However, it is probably no longer taught in its entirety anywhere.

In a revision of both projects, Pode[12] noticed that the C.B.A. as a whole is a course for average students and exceptional teachers. It is difficult to teach and requires a greater degree of commitment and greater mental ability so that intense thought is required. On the other hand, CHEM Study has some educational advantages in the choosing and ordering of ideas from the textbook. It is a much less revolutionary course and is easier to teach than the C.B.A., but both projects contain almost the same material relevant to modern chemistry with different structures and arrangement.

These two approaches are, in some ways, quite similar and Hurd[11] summarized these similarities as follows:

1. They emphasize the principles underlying chemical structure, combination and energy.
2. They establish systematic relations between experiment and theory.
3. They introduce ideas in a tentative fashion and examine them in the light of experimentally derived data.
4. They have an overall internal logical structure for the textbook which makes sampling the book dangerous.
5. They insist upon the value of speculative questions and discussions as a means of promoting and sustaining motivation.
6. They require an inquiry environment in the classroom and teachers who are heuristically inclined.

Once again, Pode[12] has pointed out that the personal performance of the teacher and the degree to which he is prepared to commit himself, govern the choice of one project rather than the other.

To summarize then: despite the noble aims of these two projects, which were designed by highly qualified groups of university professors and high school teachers to prepare well educated chemists in schools, both projects have never been properly linked to any psychological model of learning and little, if any, consideration was given to the limitations /

limitations in student learning. But, both of them did stimulate new thinking on the reform of chemical education in schools in many countries, particularly in Europe.

The Organization for European Economic Co-operation (O.E.E.C.) held an International Seminar on Chemical Education at Graystones, Ireland, in March 1960(13) to investigate the status and development of the teaching of chemistry. Following this conference, new thinking concerning teaching school chemistry was stimulated in Britain.

In England and Wales, the response to these new ideas for the improvement of the teaching of chemistry was in part the setting up of the Nuffield Foundation Science Teaching Project. The first objective for this project was the provision of courses in biology, chemistry and physics for pupils in the 11-16 age range in grammar and technical schools and for more able pupils in secondary modern schools(14). Nuffield O-level chemistry was one of the first chemistry projects to be published in the United Kingdom (see Appendix 1). Among the aims of this project, it was hoped that the pupils should have an understanding of the following:(15-17)

1. knowing how to get new materials from those available;
2. looking for a pattern in the behaviour of substances;
3. using explanatory concepts and knowing how to check theory by observation and experiment;
4. associating energy changes with material changes, and
5. chemistry as a result of enquiry.

The syllabus was interpreted as a "Sample Scheme" which would take five years to complete through three stages -

Stage (I) - for the first two years (age 11 to 12 approximately) which is concerned with the exploration of materials and acquiring basic skills

Stage (II) - for the following two years (age 13 to 14 approximately) in which the focus changes from the /

the exploration of materials towards the exploration of ideas about Atoms, Particles, etc. and practical work to test these ideas

Stage (III) - for the fifth year in which there are a wide variety of topics in optional investigations by which the pupils can develop competence in manipulative and intellectual skills within the framework of chemistry.

Ingle and Jennings[18] have pointed out that the attitude towards the Nuffield schemes had, in fact, started to become polarized in a damaging way even before publication. They summarized three general points as follows:

1. One of the reasons for the scepticism of many teachers about the Nuffield O-level schemes was that some of the work looked so difficult.

2. All the Nuffield O-level schemes were highly specialized so that there was not enough collaboration between sciences or between science and mathematics.

3. The Nuffield schemes included some interesting applications of science in technology and everyday living, but they did not go very far in illustrating the social relevance of science.

On the other hand, they said "teachers or schools responded to the Nuffield projects in one of the following three ways:

1. Some chose to adopt one or more of them, making a substantial use of the publications and entering pupils for the Nuffield examinations.

2. Others preferred to adapt the materials to their own purpose, continuing to enter their pupils for the non-Nuffield examinations with which they were familiar.

3. The remainder largely rejected or ignored the new materials."

The O-level materials were published in 1966, and now the Nuffield O-level /

O-level chemistry project has been completely revised and the publications have been revised, reviewed and reissued in a new format[19-20]. However, the Nuffield schemes have had considerable influence in many countries of the world.

In Scotland, in 1962, the Scottish Education Department introduced Alternative Syllabuses in chemistry and physics for the Scottish Certificate of Education instead of the Traditional ones. In chemistry the fundamental concepts of energetics, chemical bonding and atomic structure had been borne in mind throughout in an attempt to make the approach more logical than in the past, and also many modern topics had been introduced and the out-dated topics omitted in order to make the early part of the work of value to the ordinary citizen[6]. The response to the new syllabus was immediate, so that some teachers and schools decided to start half-way through the syllabus. In 1966, one-third of the pupils taking the Scottish O-grade chemistry sat the Alternative Examination papers; in 1967 about two-thirds of the candidates, and within eight years the Traditional syllabuses ceased to be examined[21-22]. Scottish teachers, therefore, welcomed the new syllabuses and responded enthusiastically.

After the syllabuses had been adopted by all schools in Scotland, the description "Alternative" was omitted in the revised version of the syllabuses published by the Scottish Certificate of Education Examination Board[23]. However, two of the most valuable outcomes of the introduction of the new schemes in Scotland have been the establishment of:

1. An additional syllabus in 1968 for pupils who were staying at school for a sixth year[24] and

2. A course in science for General Education for all pupils in the first two years of Scottish secondary schools (age 12+) and for the less able (age 14-16) group[25]. This course has been adopted by more than 80% of all the secondary schools in Scotland and well adopted abroad[26-27].

Once again, all of these influential chemistry projects strongly emphasized the principles of science but did not give enough consideration to developmental psychology, the pupils' mental ability limits or the /

psychology of learning. Although much money was devoted to these projects which were developed by highly qualified people in science, there are still problems in teaching chemistry, and a lot of areas of difficulty have arisen in the school course. Some other developers began to realize the role of psychology in planning their projects. Projects, such as the Science 5 to 13 Project, the Schools Council Integrated Science Projects in Britain (S.C.I.S.P.) and the Australian Science Education Project (A.S.E.P.) have tended to follow some ideas from Piaget, Bruner, Ausubel and Gagne.

1.3 Early Chemistry Projects Based on Psychology

The Science 5 to 13 Project represents an early project in Britain in which consideration was given to the nature of the learner. In 1969 the Schools Council set up the Junior Science Continuation Project at the University of Bristol as an extension of the Nuffield Junior Science Project. The project team defined stages in children's educational development with similar characteristics to those in the work of Jean Piaget as follows:[28]

1. Each stage extends and builds upon the one before and then forms the necessary foundation for the next stage.
2. Children pass through these stages in the same order 1 - 2 - 3, though the rate at which they pass through them varies between individuals, and,
3. Age is no guide to the stage for a particular child. It is only when referring to the average of a large number of children that a stage can be roughly related to age.

Stage (1) includes some pre-operational and some concrete operational thought, but chiefly describes the transition between the two. In Stage (2), concrete operational thought is the main way of thinking. Stage (3) represents the transition from concrete to formal operational thought.

Parker-Jelly[29] has pointed out that at first the project was directed towards the framework of concepts deemed desirable in the terms of reference, and that his recollection of this period in the project's /

project's life is one of intense mental activity associated with attempts to produce hierarchical network maps of the concepts involved in various science topics appropriate to children in the 5 to 13 age range.

The overall aim of the project was to develop an enquiring mind and a scientific approach to problems. This was then broken down into nine broad aims. These broad aims were further sub-divided into about 150 statements of behavioural objectives appropriate for children, grouped according to the different developmental stages.

The project team emphasized that teachers can best help pupils by choosing activities which match their level of development individually. Two kinds of knowledge are required for matching: firstly, knowledge of the level of development pupils are at and, secondly, knowledge of activities which are appropriate at the different levels[30]. The Schools Council Progress in Learning Science, which was based at Reading University, tried to match the activities to the levels of development of children and the results appeared in a series under the title "Match and Mismatch"[31-33]. However, since the project is not a course, the materials (books) have been produced as a source of ideas for teachers, from which they can identify objectives for their pupils.

The Schools Council Integrated Science Project (S.C.I.S.P.), which was designed as an alternative to the three separate subject O-level projects in biology, chemistry and physics, made another attempt to take into consideration the educational and psychological point of view, but this time these ideas were about the nature of learning itself. The S.C.I.S.P. team took into account Gagne's ideas about the conditions for learning. The project was eventually combined with the Nuffield Secondary Science by the Curriculum and Evaluation Systems in the Integrated Science Project (C.E.S.I.S.) and the materials are being published under the title Nuffield Science 13 to 16[18].

In Australia, a great deal of effort was devoted in the late 1960's and early 1970's to develop new approaches in the teaching of science in the light of psychology. The Australian Science Education Project /

Project (A.S.E.P.) started by asking how science could contribute to the growth and development of a child at a particular stage in his or her life. The instructional strategy, therefore, became the starting point for the materials produced, and the work of Piaget, Bruner, Gagne and Ausubel had direct relevance to the materials produced (34).

Fensham (35) says that the A.S.C.P. materials take the form of a large number of relatively independent units so that teachers or schools or systems have a high degree of choice as to which of the project's units to use and in what sequence. Also, these materials are designed to cater for individual differences in students such as cognitive development, interest and rate of learning. Each unit has a core of study and a number of options, each of which is contained in booklets. Other materials have a self-instructional style, so that students can proceed at their own rate.

Russell (34) indicated that the A.S.E.P. team considered four areas of individual differences as crucial to the development of their materials:

1. Intellectual development
2. Reading ability
3. Student interest
4. Response to visual and aural stimuli.

The materials became available for use in the 1970's in 40 modules and a large number of schools now have these materials.

However, despite all this co-operation between scientists and educators, science education still has difficulties. Does the problem lie in the nature of science itself, or in the content, or in methods of presenting the content, or in methods of teaching, or in the pupils themselves?

1.4 Delineation of the Study

Since the time of the adoption of both the Nuffield O-level chemistry in England and Wales, and the Alternative Syllabus in chemistry in Scotland, work has been carried out to examine the areas of /

of difficulty which have arisen during teaching and learning processes. In England and Wales, Ingle and Shayer[36] have attempted to study the conceptual demands for each topic in the Nuffield O-level chemistry course and classify them according to the mental characteristic requirements of Piagetian stages. This attempt was based on a technique of assessment of science courses according to Piaget's construct of conceptual stages (Shayer[37] and recently, in detail, Shayer and Adey[38]). Two steps were suggested to assess a project course. Firstly, the stages of the course ought to follow the same order of increasing logical complexity as are present in the pupils' own development; secondly, the age range over which the course is taught, should match the age range over which these stages develop.

From this point of view, it is very difficult to assess the success of any course on such purely theoretical assumptions, since it can give only some general guidance in planning the course, but it cannot give any detail about analysing the level of demand of a topic. This is because the level of demand of a topic can depend on the way it is taught[39]. On the other hand, Piagetian stages are too broad within a range of ± 2 years and no sharply defined transformations occur between these stages.

In Scotland, Johnstone[40] started a series of experimental studies in real situations, by identifying areas of difficulty in chemistry. He asked all first year chemistry students entering the universities of Glasgow and Strathclyde to fill in a questionnaire about the chemistry courses they had just completed at school. They were asked in this questionnaire to classify each topic of the course in one of these four categories:

1. Easy to grasp: defined as "understood when the topic was first taught"

2. Difficult to grasp: defined as "understood after considerable effort"

3. Never grasped: defined as "never understood and needs to be re-taught"

4. Never studied.

The results obtained showed areas of difficulty. These areas grouped into three categories:

1. <u>Energetics</u>: including Hess's Law, E^{o} Values and cells

2. <u>Stoichiometry</u>: including writing and balancing equations, ionic equations, ion-electron half-equations and the mole in solutions

3. <u>Organic</u>: including esterification, hydrolysis, condensation, saponification and carbonyl compounds.

The same questionnaire was applied to pupils in their final year in school, and the same results were obtained which revealed the same areas of difficulty even more clearly. A research team then began to examine these areas of reported difficulty in school, without consciously adopting any psychological or educational stance. When Johnstone and Kellett investigated the organic topics(41), an initial hypothesis was formulated on the basis of the study of Short Term Memory (S.T.M.). Their hypothesis was: problem solving ability is associated with student's ability to organize or "chunk" the information provided in a given situation into memorizable patterns and, if the S.T.M. is overloaded with too many pieces of information, the processing of this information cannot take place unless such information can be effectively "chunked". For example, if a person is asked to recall a series of ten disconnected numbers, it is unlikely that he will do so correctly unless he can do some grouping to lessen the load. In the case of a telephone number, the system helps us by providing a grouping or "chunking" method to lessen ten numbers into six or even four numbers. In a similar way, this might be applied to a subject like chemistry.

If this is the case, the size of the S.T.M. for an individual student limits his (or her) ability to carry out learning and problem solving tasks in chemistry. In addition, the nature of chemistry, as it is taught, may be in conflict with the size of the student's S.T.M. To overcome this, it was thought that students could learn strategies which would ease the burden on the size of their S.T.M. and leave space for thought and problem solving. Such strategies are called "chunking devices /

devices".

1.4.1 Concept Understanding and Chunking

Within the context of these working hypotheses research had to take another direction to understand more about the areas of difficulty and their causes. There are three factors in an interactive situation in which the number of pieces of information for the tasks, the existing conceptual understanding and the level of perceived difficulty occur together[41]:

1. The number of chunk units represented by the information will depend on the conceptual understanding.
2. The larger the number of chunk units, the more difficult the material will seem to be, and the poorer will be the results.
3. If the chunk capacity is exceeded, two possible results will appear -
   (i) the pupil will extract no useful information if he tackles the problem as a whole; or
   (ii) if he has some memory saving strategy which allows for sequential treatment, he may succeed in the task.
4. Conceptual understanding leads to an efficient (small number of chunks) organized (sequenced) and converging strategy.

Kellett[42] has made a study of the perception of organic chemical structures, and she suggested that pupils with low levels of conceptual understanding are disadvantaged because of these reasons:

1. they chunk inefficiently, that is, they form chunks of low information content;
2. they may increase the memory load by treating redundant information as necessary; and
3. they are liable to use inefficient or arbitrary strategies in high information contexts.

Kellett demonstrated that these ideas are in no way specific to the organic concepts which were studied. Analysis of the results of three /

three independent studies (one of which was about the mole concept) showed the same patterns. In stoichiometry, the mole concept and its calculations are essential in the study of chemistry for pupils taking the Scottish O-grade syllabus. It has been found across the world that pupils have difficulty in understanding the mole and its related concepts and using it in chemical calculations. It follows that teachers of chemistry do not fully appreciate where these difficulties lie so that these topics remain difficult for pupils to learn and for teachers to teach.

Cervellati, et al[43] investigated the secondary school students' understanding of the mole concept in Italy. They have pointed out that the mole concept is not mastered by most pupils in secondary school. They tried to explain the possible causes of such poor performance in the light of curriculum content, methods of teaching, evaluation of students and teacher training.

The content of that part of the O-level chemistry course which involves the mole concept was analysed to identify a series of underlying concepts which were required for full understanding of the mole concept[44]. Using these concepts an attempt was made[45] to derive a hierarchy by adopting Gagne ideas for two kinds of concepts: empirical concepts (based on experimental observation) and theoretical concepts. In this context, the mole is a difficult concept to learn because it is at the top of the theoretical concept hierachy since theoretical concepts are intrinsically more difficult to learn than empirical concepts.

Ingle and Shayer[36] have classified the mole concept as being at Stage III B (formal operations) of Piaget's stages, and the results from the study made by Novick et al[46] support this view. MacDonald[47] suggested four ideas for teaching the mole concept as follows:

1. The concept should be taught as a counting unit.

2. It should be taught consistently.

3. Related concepts should be defined and used coherently.

4. /

4. Language should be used carefully and correctly.

Duncan[48] has made a study using programmed learning materials to investigate learning processes in difficult areas in school chemistry. Some of the difficulties experienced by pupils in understanding the mole concept have been identified. According to the results of Duncan's study, if one looks at the calculations of the mole quantities in situations such as given formula and atomic weights, and students' attempts to calculate gram formula weights and the weights of mole quantities, it will be found that they presented no difficulty. Some difficulty begins during the calculation from equations using the mole in other than 1:1 relationships. A significant drop occurs in facility values when students were asked to deal with the mole in solution or to provide an equation and then balance it, if necessary, and use it to solve problems.

Once again, Johnstone[49] explained this phenomenon in the light of the working hypotheses, i.e. when the student is being asked to recall more information and at the same time sequence it and use it, he is more likely to get the wrong answer, even if he balanced the equation correctly. He did the calculation as if the stoichiometry were a 1:1 relationship. Could it have been that the form of his perception of the total problem overloaded his Short Term or Working Memory?

1.4.2 Problem Solving and Chunking

In addition to knowledge in examination-type problem solving in schools and universities, two components are required for students to be able to solve the problem. First, an ability to recall the relevant information from the Long Term Memory (L.T.M.), and second, having a strategy to minimize the load of processing. Selvaratnam[50] classified the difficulties associated with both content (as subject matter) and process. The difficulty associated with the content is not merely due to lack of knowledge from L.T.M. but rather the processes involved in the use or application of this knowledge. Therefore, one may have sufficient knowledge but may be unable to choose and recall the relevant information required and organise it. The ability /

ability to choose, recall and organise the relevant information seems to be related to how this knowledge is acquired, stored in the students' L.T.M. and put to use. On the other hand, the difficulties associated with process are due to the use of an incorrect strategy.

Within the context of this type of problem, Frazer and Sleet[51] have made a study of students' attempts to solve chemical problems. The aim of the study was to develop a method for identifying whether or not students could solve every step in a problem when the complete solution is represented as a network, and where the calculation seems to involve a number of steps or sub-problems. An attempt was then made to ascertain why it is that some students who can separately solve all the steps are still unable to solve the complete problem. They have pointed out that the uncertainty experienced by many of the unsuccessful problem solvers put an excessive burden on their working memory capacities and prevent them from recognizing all the steps (sub-problems) in the main problem. On the other hand, with a sub-problem which requires less information to comprehend, a student can more easily see a way of using the fewer items of data to solve the problem.

Kempa and Nicholls[52], in terms of cognitive structure (by which they mean the availability and accessibility in the student's mind of ideas, concepts and the connections between them which are required for a particular problem solving task), have shown that the cognitive structures of good problem solvers are more complex and contain more associations than those of poor problem solvers for given levels of relationships between concepts. From this point of view, if a problem needs a lot of information for its solution, a student with a good cognitive structure can chunk the information into groups to minimize the load on the working memory and, at the same time, he knows which relevant information is required. He knows, therefore, how and where to start. On the other hand, the poor cognitive structure student cannot chunk the information so that this information will exceed his size of working memory. Also, he will not be able to extract relevant from irrelevant information and so he does not know how or where to start.

1.4.3 /

1.4.3 Study Overview

It has been shown[41] that if information is well received and organized, the student's concept will be well developed and he will be able to chunk high information content into a small number of units. He would be expected, therefore, to perform better in a problem solving task. On the other hand, the strategy used by the teacher controls the amount of information and the number of steps required to solve the problem.

The purpose of this study then, was to find answers to these general questions.

1. Is there any relationship between the students' working memory space and their attainment in chemistry tests?
2. Is there any relationship between the students' working memory space and their ability to solve chemical questions which require different numbers of steps?
3. Will students perform better in chemical questions when they are made to organize their thinking before doing the calculation than when they do both together?
4. Will students solve a chemical question better when it is divided into a number of sub-questions than when they have to deal with the complete question undivided?

CHAPTER 2

EDUCATIONAL PSYCHOLOGY ATTEMPTS TO CLOSE THE GAP

2.1 Introduction

It has been suggested in Chapter 1 that there is a gap between science curricula and students' limitations in learning, and some curriculum developers began to realize the importance of applying some of the views of educational psychology in planning the curriculum. They tried to alter their teaching materials in order to make them appropriate to the learners' limitations.

Flavell and Wohlwill(54) have pointed out that a psychological theory of complex behaviour must include two models: a competence model and a performance (automaton) model. A competence model gives a formal representation of what the subject knows or could do in an ideal situation. On the other hand, a performance model represents the psychological process by which the information embodied in competence is actually acquired and put to use in a real situation within the constraints of memory limitations and rapid responses.

In a different approach, Kempa(55) suggests three different levels in which theories can operate. The first is the Descriptive level in which a theory may summarise observations and represent an obstraction of known facts or phenomena without attempting to explain them. A theory in this category would be called a Descriptive one. The second level is the Explanatory level in which a theory may attempt to explain known facts or phenomena by reference to some principle or mechanism intrinsic to the phenomena concerned. Such a theory would be called an Explanatory theory. The third is the Predictive level in which the applicability of a theory of the second level is so widely supported that it can be used in a predictive role. Many scientific theories operate at a predictive level. On the other hand, educational theories, in general, are at the lowest level (descriptive).

Science educators have attempted to take account of educational psychology theories and have tried to link science as a subject to the students' cognitive structure. Although there have been several educational psychology approaches intended to help educators to apply these theories in the educational processes, two major approaches in particular have had considerable influence in the field of science education, namely /

namely, Piaget's theory of mental development and Ausubel's theory of meaningful learning. Despite the fact that these two theories have tended to dominate the curriculum scene, there have been useful contributions from Gagne's model, from the Alternative Framework schools and from neo-Piagetian theory.

2.2. Piaget's Theory of Mental Development

The very well-known theory of Piaget, was built on a life-time of observation of children's ability to think from birth up to 16 years of age. Piaget and his collaborators have had a great deal of influence on science and mathematics curricula in schools, although Piaget was not himself an educator.

Piaget, as a biologist, suggested that, as a child interacts with his environment, he acquires new experiences and learns more about his environment and becomes more adapted to it. To do this, two tendencies are inherent: organization of the experiences, and adaptation to the environment. These two tendencies together form the child's cognitive structures which are known as schemas, susceptible to transfer from one situation to another. The organization is illustrated by a child combining two separate skills, such as looking and grasping, into a more advanced skill, such as picking up something he is looking at(56). The process of adaptation occurs through two complementary processes: assimilation and accommodation. Assimilation is the process by which new experiences are interpreted by the existing mental schemes that the child already has. It affects the growth of the cognitive structures, but it does not develop, alter or modify them. The assimilation which takes place is "the integration of external elements into evolving or completed structures of an organism"(57). On the other hand, the process which explains the development (alteration) of the cognitive structures is known as accommodation. Accommodation is the process of modifying schemes to solve problems arising from new experiences within the environment(58). Novak(59) has suggested that the accommodation process takes place simultaneously with the assimilation process, when the new experiences lead to the modification and alteration of the learner's thought patterns.

Piaget /

Piaget[60] suggested that there are four factors, in an interaction situation, that are related to the cognitive development. These factors are: maturation, physical experiences, social interaction and a general progression of equilibrium. Piaget believed that equilibration is an essential process, so he divided the child's cognitive development into sequence stages according to the qualitative changes which occur as a result of the equilibration process. These stages (3 or 4 on different occasions of the work of Piaget) are further divided into sub-stages, each of them representing a set of levels of equilibration. All children develop mentally through these stages in the same order but not at the same rate. The stage age is only a rough estimate and these ages vary from one person to another and from culture to culture. However, the main four stages of cognitive development are as follows:

1. Sensory-motor stage (birth to 2 years)
2. Pre-operational stage (2 to 7 years)
3. Concrete operational stage (7 to 11 years)
4. Formal operational stage (11 to adult)

Only the latter two stages (3 and 4) are significant in secondary and tertiary education. During the concrete operational stage, pupils develop logical operations and gradually acquire the ideas of conservation of substance, length, number and volume. They can understand the concepts of space, time, speed and basic causality[61]. In addition to this, they become able to classify objects according to their similarities and differences and to arrange them according to size, weight or length.

The formal operational stage is characterized by reaching a high degree of equilibrium. By the end of it, the quality of thought has reached its maximum. There is an ability to use hypothetical reasoning and to handle abstractions. De Cecco and Crawford[62] derived three characteristics for this stage as follows:

1. The adolescent's thinking is basically hypothetico-deductive
2. /

2. Thinking at this stage is propositional

3. Thinking involves combinatorial analysis.

The description of the four principal stages of mental development has made a great contribution to the application of Piaget's theory in the field of science education. A series of studies has been done concerned with how this information might be used to facilitate students' achievements by closing the gap between curriculum development and the Students' limitations in learning. It should be noted that the work of Piaget has been largely devoted to examining the growth of logical thinking(63) and how the basic concepts of mathematics and science develop.

2.2.1 The Educational Utilization of Piaget's Theory

There has been much work done across the world in the light of Piaget's theory (for example: studies reported in Sigel and Hooper(64), Siegel and Brainerd(65), Elkind and Flavell(66)). Some of this work tried to confirm, albeit roughly, the theory using the same techniques and the same tasks as Piaget, or using paper and pencil versions of tests for the same tasks. At the same time, some other studies tried to apply and employ the theory as a guide in the educational process in many learning areas.

Ginsburg and Opper(67) summarized six principles which may guide educational procedures. Firstly, the child's language and thought are different from the adult's. Secondly, children need to act on things in order to learn. Thirdly, children are most interested and learn better when experiences are introduced in a novel form. Fourthly, since social interaction is very important to intellectual growth, children should have the opportunity to talk together in school to argue and debate. Fifthly, the information supplied from Piaget's studies of general development of thinking could be used to determine the limits of children's ability to learn, to evaluate curricula, to develop new learning experiences, and to eliminate the gap between intuition and consciousness. Finally, Piaget's clinical investigation method could be used to help teachers in diagnosis and in assessment.

Beard /

Beard[58] suggested that the teaching method for the majority of pupils in the first two years in secondary school should be suited to children who think in concrete terms, since the capacity of formal operational thinking does not develop until the mental age of about thirteen.

Lawson and Renner[68] used students, who had been classified by using Piagetian tasks into "concrete" and "formal" levels, to interact with tasks in science which they had classified as "concrete" and "formal" concepts. They found that concrete operational students were unable to cope with formal concepts. The understanding of formal concepts did not occur until at least some of the students' responses on the Piagetian tasks reached the level of formal operations. They claimed that a distinction can be made between concrete and formal subject matter.

One of the most important contributions of Piaget's theory is that of the matching model. Rowell[69] defined the objective of optimal matching as tailoring the cognitive demands of coursework to the cognitive abilities of students. He said, "The strategy for doing this makes the following assumptions:

1. that the identification of the Piagetian stage reached by an individual is possible by means of a limited test and that this is useful as an indicator of that person's reasoning in relation to a wide diversity of scientific content;
2. the curriculum tasks can be analysed for their level of cognitive demand, that is, for the stage-related skills required for their understanding, and,
3. that meaningful learning will occur only when the cognitive skills demanded by the task are available to the student."

It has been shown[70] that Piaget's work has been too often interpreted in a negative way in the sense that it tells us what not to do at certain ages and stages. The basic technique of such optimal matching was first proposed by Shayer[37], Ingle and Shayer[36], and in detail by Shayer and Adey[38]. Beistel[71] suggested a syllabus, based on a Piagetian approach, for the first semester of general /

general chemistry designed to stimulate intellectual development, bearing in mind that not all entering freshmen are at the formal operations stage. Kohlberg and Mayer(72) reported that school curricula can be derived directly from Piaget's stages. Sayre and Ball(73) recommended that preservice teachers should develop a greater understanding of Piaget's theory.

Ginsburg(74) indicates, however, that an attempt to base education on the teaching of Piaget's stages leads to mis-application of the theory. He said, "A more useful approach is the modification of the curriculum in line with knowledge of the Piagetian stages, without, however, placing undue emphasis on them and without allowing them to circumscribe one's approach."

Jenkins(75) has pointed out that, as a result of the lack of an agreed definition of the formal operational thought, and the problem of recognising this thought by using experimental criteria, it is very difficult to define the level required to understand a particular topic in a school course.

Phillips(76) agreed that the development of science and mathematics curricula has been influenced by Piaget's theory, but the results have been disappointing, since the stages as outlined by Piaget and his collaborators are, in fact, too broad and lack the prerequisite sequencing necessary for curriculum development. This means that the process of development is gradual and continuous and one cannot say, therefore, that a child's thinking at exactly eight years of age is characterized by pre-operational thought, and on the next day his thought becomes concrete thinking. There is a wider range of time during which the transfer takes place from one stage to another stage. In other words, no sharply defined transformation occurs.

A number of studies have been undertaken to investigate the relationship between the level of the students' cognitive development, measured by various standardized tests based on Piaget's tasks, and their achievement in chemistry, physics and biology. For example, Sayre and Ball(73) have investigated the relationships between scholastic grades in science in junior and senior high school students and /

and their ability to perform formal operational tasks. The findings of this study indicated that formal level junior and senior high school students received significantly higher science grades than non-formal students.

Herron[77] reported that there is a correlation of 0.8 between students' performance on a battery of Piagetian tasks and the total points earned in the chemistry course he supervised. He extended this relation to another sample when he tested freshmen courses using the same battery and correlated their scores in this battery with the scores on a chemistry placement test. The correlation, in this case, was 0.7.

McKinnon and Renner[78] have disproved that students at university level are assumed to have completed their mental development and are able to use an abstract level of reasoning. Their findings indicated that 50% of entering college students tested were operating completely at Piaget's concrete level of thought, and another 25% had not fully attained the established criteria for formal thought. This means that about 75% of college students were not exhibiting formal thinking.

Despite the fact that some studies have claimed to confirm the existence of Piaget's stages of mental development, they have disagreed with it in a number of points particularly the age range. Carpenter[79] and Lunzer[80] agreed that Piaget's stages might be closely related to a subject's mental age rather than his chronological age. Beard's[58] opinion supported these studies. Generally, the chronological ages of these stages obtained by Piaget for Swiss children are earlier by two or three years than those obtained, for example, for British children, and this indicates that the age norms are only approximate. In Shayer's sample[38] only about 30% of pupils are using concrete operations fully at the age of nine years. This percentage rises to above 75% at fourteen years. At the same age (14 years), only 20% are using early formal operations.

On a different line, Kempa[55] has pointed out that Piaget's theory is a descriptive theory. He considers that it describes the child's ability to think and it defines the likely behaviour for each age /

age group. "Assigning a learner to a particular stage of intellectual development does not provide an explanation of his thinking characteristics."

Pascual-Leone[81] and Brown and Desforges[82] agreed that Piaget's theory is a competence model since it defines the ideal behaviours for each stage, and it does not provide an explanation of how the content of mental operations are selected, organized or sequenced, or how performance characteristics, such as memory or attention, limit the child's responses.

Brown and Desforges[82] have attempted to explain two kinds of error when one relates competence (ideal situation) and performance (real situation). If the child has an underlying competence already, his success on the task means that performance is correlated with competence. But his failure is due to factors other than the lack of competence, and here negative errors occur. These errors might be due to demands of the task itself, demands of the response, or lack of comprehension. On the other hand, if the child has not an underlying competence, his success on a task is due to factors other than competence. Here the false positive errors occur which contain various irrelevant aspects of a task which defeat a child. But his failure, in this case, means that performance is correlated with competence.

It has been pointed out[83] that by varying the information processing demands of combinatorial tasks, subjects below the age of formal operations can be made to perform qualitatively like adults, and adults can be made to perform qualitatively like children. Since it could be possible to find a child or adult operating at one level for one concept, and at another level for another concept, it is very difficult to estimate the stage that the child is at. Another problem arises here in using a group of tasks to make judgements about the learner's mental level. The circularity of performance measurements happen in using a student's performance on one task or a set of tasks to predict his likely performance on a similar task[55].

Lovell[84] gives two examples to illustrate the limitations of Piaget's theory. The first is that the theory does not explain why concepts with the same intellectual structure are not all elaborated at /

at the same time. It does not explain why thinking strategies of which the pupils are capable, are not used in certain circumstances. Secondly, it is very hard to specify precisely the tasks that can always be solved by adolescent or adults and never by younger children.

Having surveyed, briefly, Piaget's theory of mental development and its educational utilization, the researcher arrives at the following problems in using Piaget's theory in curriculum design and teaching-learning process:

1. Piagetian stages are too broad, and no sharply defined transformation occurs from one stage to another. The age range, mental or chronological, may be as wide as ± 2 years. This is of the same order as the length of compulsory secondary education and so it is impossible to use it for curriculum planning.

2. To estimate at what stage the child is, he should be tested in a wide range of tasks drawn from many areas of knowledge. This would help to avoid problems of circularity. In addition, one would expect that the child may operate at one level for one concept area, and at another level for other areas.

3. Piaget's theory, as a descriptive competence model, describes the child's capability in an ideal situation. The child's performance may not therefore indicate his capability.

4. It has also been pointed out(39) that, if a pupil gives evidence of having arrived at the formal stage using proportional reasoning in the "equilibrium in a balance" task, the probability of his using proportional reasoning in the classroom tasks is open to question. This leads to the problem of creating a matching model in which teachers should wait until their students are ready to grasp a particular topic, and, in this way, teachers may not aid their students' development through science.

2.3 Ausubel's Theory of Meaningful Verbal Learning

Ausubel, /

Ausubel, as an educational psychologist, was concerned with prior knowledge as a factor influencing learning. The principal idea in Ausubel's theory[85] is that "the most important factor influencing learning is the quantity, clarity and organization of the learner's present knowledge. This present knowledge, which consists of facts, concepts, propositions, theories, and raw perceptual data the learner has available to him at any point in time, is referred to as his cognitive structure".

Since the theory is based on real classroom learning situations, from the view of the learning process, conditions, outcomes and evaluation, Ausubel distinguishes between two kinds of learning processes: reception learning and discovery learning. In reception learning, the content is presented to the students, either by teachers or by written materials in its final form. All that students have to do is to incorporate this content into their cognitive structures to learn it and remember it. Discovery learning, on the other hand, refers to "the situation in which the material to be learned is not presented to the learner in final form but requires that he must undertake some kind of mental activity (rearrangement, reorganization or transformation of the given material) prior to incorporating the final result into cognitive structure". Depending upon what happens after the content to be learned is presented to students' cognitive structures, Ausubel indicated that both reception and discovery learning can be classified either as meaningful or as rote learning.

For meaningful learning, three conditions must be met[86]:

1. The material itself must be able to be related to some hypothetical, cognitive structure in a non-arbitrary and substantive fashion.

2. The learner must possess relevant ideas to which he can relate the material.

3. The learner must possess the intent to relate these ideas to cognitive structure in a non-arbitrary and substantive fashion.

Bearing in mind that meaningful and rote learning are not dichotomies /

dichotomies, the learning will be increasingly rote to the extent that[86]:

1. the material to be learned lacks logical meaningfulness;
2. the learner lacks the relevant ideas in his own cognitive structure;
3. the individual lacks a meaningful learning set.

Any one of these conditions by itself will produce conditions likely to lead to rote learning.

To summarize - "meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Rote learning of the new knowledge occurs when no such interaction takes place"[87].

Rote learning represents one end of the learning characterization continuum scale, and meaningful learning represents the other end. There is a relatively varying degree of meaningfulness of the learning. Ausubel discusses four kinds of meaningful learning, ranging from representational learning to discovery learning. Representational learning can be taken as the lowest level of meaningful learning. It concerns the meaning of the symbols or single words which refer to the objects. For a child, to learn a concept, he has to recognize the critical attributes of this concept. Once these critical attributes of a concept are known, a child would be able to distinguish between an example of the concept from non-example. Ausubel refers to the process of inductively discovering the critical attributes of a class of stimuli as a process of concept formation. When the concept's critical attributes are represented to the students by definition rather than being discovered by them, concept assimilation occurs. A third form of propositional learning is that which concerns the apprehension of the meaning of ideas as groups of words combined into propositions or sentences[88]. Finally, the fourth kind of meaningful learning is discovery learning.

Ausubel has labelled any concept, principle or generalising idea that the learner already knows (which can provide association or anchorage /

anchorage for the various components of the new knowledge) a subsumer[87] and the process of meaningful learning results in subsuming of new knowledge[59].

Since new knowledge is susceptible to be forgotten, Ausubel proposes the concept of obliterative subsumption to distinguish between meaningful learning forgetting and rote learning forgetting. Novak et al[89] have pointed out that in the case of a young learner who has little or no past experience, and so has no available subsumers, the acquisition of new learning may be by rote until enough information is acquired which enables subsuming concepts to be formed. On the other hand, "adults rarely encounter learning tasks where some prior framework of ideas cannot be applied during early learning phases. Subsequent differentiation of new concepts can result in facilitating new knowledge acquisition, and subsumption processes proceed".

In order to facilitate learning, Ausubel has introduced the concept of the advanced organizer. The principal function of the organizer, which is introduced in advance of the material to be learned, is to bridge the gap between what the learner already knows and what he needs to know before he can successfully learn the task at hand[86]. The organizer provides the learner with a subsumer which acts in two ways. Firstly, it gives the learner a general overview of the detailed material in advance before he faces it. Secondly, it provides organizing elements which include the most relevant and efficient information for both the content contained in the material and relevant concepts in the learner's cognitive structure. Barnes and Clowson[90] have attempted to find an answer to the question, "Do advance organizers facilitate learning?", by analysing 32 studies to see if any consistent pattern of results appear, but they found conflicting results.

2.3.1 Research Following Ausubel's Theory

As West and Fensham[87] have pointed out, the obvious relation of Ausubel's theory to the teacher's task makes it eminently worthy of consideration and deserves wider acceptance than any other theory. However, this theory is experimentally difficult to investigate, and therefore, /

therefore, it is less supported by data. "Since Ausubel's theory is based on the part played by the learner's prior knowledge, and how the new knowledge interacts with it to build his cognitive structure, the subsumers that the learner uses for subsumption may not be those obtained by a logical task analysis and may not even be the same for all learners. Hence, the task of deciding what prior knowledge is needed to act as subsumers, and the task of preparing a test to measure them are very difficult."

Novak et al[(89)] reviewed 156 studies in the science education field that might be considered to deal with important parameters in Ausubel's theory, and attempted to use them as external criteria to check some hypotheses consistent with Ausubel's theory. Since few of these studies were designed with reference to Ausubel's theory, the reinterpretation of the data was fraught with difficulties, and they suggest that their conclusions ought to be researched further.

Kempa and Nicholls[(52)] indirectly supported Ausubel's theory in the contribution of prior knowledge subsumers to the learning process. They tried to find the relationship between students' problem solving ability and their cognitive structures represented as cognitive maps by using a "Word Association Technique" for some chemical concepts. Their findings indicated that the students' ability to solve examination-type problems can be explained in terms of their cognitive structures, since they found that good problem-solvers have a more complex cognitive structure than poor problem-solvers. Ring and Novak[(91)] are of the same opinion after having investigated the relative effect of students' existing cognitive structures on the learning of new material in the light of their achievement in college chemistry.

To summarize then, the principal idea in Ausubel's theory is that what you know controls what and how you learn. It is, therefore, based on the students' prior knowledge. However, the theory is experimentally difficult to investigate and is less supported by data. Since both reception and discovery learning can be either meaningful or rote, reception learning need not be rote learning, as it is sometimes thought to be.

2.4 /

2.4 Alternative Framework Schools

It has been shown[92] that pupils and students go to school with ready made explanations for things gained from many sources. Some of these explanations are quite correct and reasonable and others are scientifically wrong. The important point is that, pupils have been shown to hold simultaneously their own explanation and the teacher's explanation.

Driver and Easley[93] and Driver [94-96] used the term "Alternative Frameworks" in the field of science education to indicate cases or situations in which pupils have developed autonomus frameworks to interpret their experience. These naive conceptions, that children develop outside the classroom, influence how they interpret a text, words, a passage in text or the results of an experiment[97].

A number of studies of pupils' misconceptions have been undertaken in science: for example, Novick and Menis[46] about the mole concept, Nussbaum and Novick[97-99] about the nature of matter, Nussbaum and Novak[100] about the children's concepts of the earth, Erickson[101] about the heat concept, Johnstone et al[102] about the concept of chemical equilibrium, and Arnold and Simpson[103] about the concept of photosynthesis.

Regarding the nature of matter, Nussbaum and Novick[97] remarked that the internalization of the particle model of matter is a problem for youngsters (12-14 years of age) as well as for older pupils. They designed two lessons dealing with two basic aspects of the model: a gas is composed of tiny invisible particles, and there is empty space (a vacuum) between the particles. Their findings indicated that these two lessons contributed to the pupils' cognitive understanding in several ways and created very strong motivation for all the lessons on the particle model that followed.

Nussbaum and Novak's[100] findings also indicated that the scientific earth concept was exhibited qualitatively differently by young children. They found five different ideas which were inferred from the children's responses to the interview items. Their method, like most alternative framework researchers, was not that of paper and pencil /

pencil tests, but Piaget-type interviews. Their concern, therefore, is with the students' individual frameworks of knowledge and reasoning strategies(104).

Johnstone et al(102) have attempted to explain the misconception of left and right sidedness in the concept of chemical equilibrium in the light of Ausubel's theory. They realized that many pupils who were failing to anchor the new subject matter to the correct relevant subsumers in their existing cognitive structures may modify the new concepts to make them fit the existing subsumers. Since how students learn is conditioned by what they already know, an alternative framework may provide wrong subsumers for later learning, and hence, the pupils can build a self-consistent "nonsense tower" on wrong alternative framework foundations.

However, the general picture that emerges is of a considerable number of secondary school pupils holding on to certain intuitive notions despite the science teaching they receive in school(39). Nussbaum and Novick(97) argue that it is not a matter of whether or not pupils understand what is taught, but rather of their understanding differently what was intended. To them, the teachers' task is to overcome pupils' alternative frameworks and attempt to create situations which enable pupils to interpret the scientific frameworks that teachers would have them adopt.

Driver(95) suggested implications for classroom practice using students' alternative framework information. Her suggestions are summarized in this way:

1. attention should be given to the structure of the thought of the child as well as the structure of the disciplines in organizing learning experience;

2. teaching programmes may need to be structured so as to be more in keeping with the developmental path in understanding important scientific ideas;

3. activities in science may need to include those which enable pupils to disprove alternative interpretations as well as to confirm accepted ones;

4. /

4. pupils should have opportunities to think through the implications of observations and measurements made in science lessons.

2.5 Gagne's Conditions of Learning

Gagne's model of a learning hierarchy is based on the learner's prior knowledge. While Ausubel's theory is related to the influences of prior knowledge on how learning occurs, Gagne's model is related to determination of what further learning could occur by analysis of learning materials to determine certain prerequisite pieces of knowledge. This model, however, intends 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 schools, and it does not intend to describe a theory of learning[105].

Gagne[106] reviewed various theories of learning and he observed that there had been frequent recourse to certain typical experimental situations to serve as prototypes of learning which represent a variety of kinds of learning. For example, Thorndike was a pioneer in using animals for experiments on learning, then Guthrie, Hull and Skinner tried to follow him by using animal behaviour as the basis of their ideas. Pavlov studied reflexes. Ebbinghaus carried out a set of experimental studies of learning and memorization. Kohler, as one of the Gestalt team, was studying insightful learning in animals. To Gagne, these examples as prototypes, come to be placed in opposition to each other: on one side all learning was concerned with insight, on the other side, all learning involved conditional responses.

Gagne[106] summarized his descriptions of learning conditions as follows: "There are several varieties of performance types that imply different categories of learned capabilities. These varieties of performance may also be differentiated in terms of the conditions for their learning. In searching for and identifying these conditions, one must look, first, at the capabilities internal to the learner and, second, at the stimulus situation outside the learner. The learning of each type of new capabilities starts from a different point of prior learning and is likely also to demand a different external situation."

Gagne /

Gagne proposes a hierarchy of eight inter-dependent progressively complex types of learning as follows:

signal learning; stimulus-response connections; response connections; chaining learning; verbal association; discrimination learning; concept learning; rules learning and problem solving.

He argues that the more advanced kinds of learning can take place only when a person has mastered a large variety of verbal associations, which, in turn, are based on a great deal of stimulus-response learning[56].

Some research has been undertaken in the light of Gagne's learning hierarchies particularly in building teaching materials (Gower et al[45] Howe[107], Howe[108] and Deming[109]). White[110] has pointed out that Gagne's ideas of learning seem to have direct application to classroom learning. Gower et al[45] are of the same opinion. In addition, Deming[109] arrived at the conclusion that Gagne's model is most successful within a single lesson. On the other hand, Copie and Jones[111] and White[110,112], tried to investigate the validation of learning hierarchies. These studies indicated that the procedure of validating learning hierarchies is long, time consuming and difficult.

However, Gagne's model of learning hierarchies are widely criticized. Soulsby[113] says that "Gagne's model describes learning as a whole and it does not cover the learner's affective domain. At the same time, it does not tell educators about the conditions external to learning." The recall and use of the 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 nature under control[114].

2.6 Neo-Piagetian Theory of Development

The weaknesses and disadvantages of the descriptive nature of Piaget's theory led to a search for a theory able to overcome them. In 1969, a neo-Piagetian theory was proposed[115-116]. This theory, first proposed by Pascual-Leone, postulates that a central attention mechanism /

mechanism, or working memory, called the M-operator, is largely responsible for a child's developmental progress through the Piagetian stages. This theory, as a functional theory, describes the mechanisms by which knowledge is acquired and put to use. It is, therefore, considered as an example of a performance model. It attempts to explain a child's cognitive growth by means of a hidden paramater, namely the size of a central computing space M. According to Pascual-Leone's theory[81], a subject's performance on any given cognitive task is a function of three parameters: the mental strategy with which he approaches the task; the demand which the strategy puts on his mental capacity (its M-demand) and the mental capacity which he has available (his M-space). By using these parameters, the qualitative characteristics of Piagetian stages can be accounted for in terms of quantitative parameters. The four major keys of neo-Piagetian theory, briefly, are as follows:

(i) The Repertoire "H"

Within the context of neo-Piagetian theory, a scheme, as a store of knowledge, has two components: a releasing response and effecting response. The releasing components correspond to the semantic perceptual conditions under which the scheme can apply. When this set of releasing response conditions are satisfied, it will activate their corresponding effecting responses. Depending upon the situation, a given scheme can serve a variety of functions: it can represent a state (figurative function), a transformation (operative function), or a control structure (executive function)[117].

Since the subjects are assumed to apply, alter and modify their basic repertoire of schemes, and the total set of schemes activated at any one time represents the content of their thought, Case[118] explains the process of this thought as directed thinking. To him, a subject's first step when he attempts to solve a problem is to activate some general executive schemes. This activation depends upon a number of factors such as the nature of the problem itself, the perceptual field, the subject's past experience of problem solving and his emotional reaction to the situation. It should be noted that, the executive schemes determine what figurative and operative schemes a /

a subject activates. Therefore, once the particular executive scheme is activated, the activation of a sequence of both figurative and operative schemes takes place and represents discrete mental steps to produce a new figurative scheme. Having produced a new figurative scheme, mental efforts are required to activate or rehearse any of these schemes. Since the subject's mental efforts at any one time are limited, the number of schemes which can be activated or rehearsed in any one mental step is also limited. Finally, when a scheme which corresponds to the subject's original objective is generated, the executive scheme directs the response. It should be noted that, if at any time during these processes, two schemes are activated the content of which are incompatible, cognitive conflict occurs.

(ii) <u>The Central Processor "M" (Working Memory)</u>

Pascual-Leone(81), Scardamalia(83) and Case(117) have shown that the information processing capacity, mental effort, M-power, M-space or working memory is defined as the maximum number of items of information, discrete "chunks", or schemes that a subject can hold in his mind while working on a problem. It is, therefore, responsible both for holding items of information for a limited time and carrying out various processing operations(119). In this context, it should be realised that working memory is different from Short Term Memory which is defined as the maximum number of items of information a subject can store and retrieve without any further processing.

The size of a child's M-power has been found to increase linearly with age according to the following scale.

/

Age (y)	Piagetian Substage	Maximum Number of Schemes which can be Co-ordinated Simultaneously
3 - 4	Early Pre-operations	e + 1
5 - 6	Late Pre-operations	e + 2
7 - 8	Early concrete operations	e + 3
9 - 10	Late concrete operations	e + 4
11 - 12	Early formal operations	e + 5
13 - 14	Middle formal operations	e + 6
15 - 16	Late formal operations	e + 7

The symbol e stands for the processing space taken up by the executive scheme and the numbers represent the figurative or operative schemes which can be co-ordinated under the direction of this executive scheme. There is no agreement, however, about whether M-power is a fixed entity for each individual from birth or whether it expands to a maximum with age.

(iii) Information Processing Load: (M-demand)

This is related to the task or the problem, but from the subject's point of view. The information processing load, or the task's M-demand is quantified as the maximum number of schemes that the subject must activate simultaneously, through an attentional process in the course of executing a task [83]. Bereiter and Scardamalia[120] discussed how to determine the M-demand of a task. Since the M-demand depends upon the strategy by which the subject finds the solution, the same task, therefore, may have different M-demands for different strategies used by different subjects. The general method for determining the M-demand of a task is to hypothesize the most efficient strategy that is likely to be available to subjects, then, work through this strategy step by step calculating at each step the number of schemes that must be activated, and finally, note the maximum number which constitutes the M-demand of the task. Case[121] has pointed out that the learning experiences are assumed to improve a subject's performance /

performance by providing him with a mental strategy to decrease the task's M-demand.

(iv) Field Dependence/Field Independence

Witkin et al[122] and Goodenough et al[123] distinguish between field dependent and independent subjects. Subjects who find difficulty in overcoming the influence of a surrounding field, or in separating an item from its context, have a perception which is called field dependent. On the other hand, subjects who are able to distinguish an item from its context, or who easily break up an organized perceptual field, have a perception called field independent. It should be noted that field dependent/independent characterization is not dichotomous, since population performances reflect that they are ranged in a continuum rather than falling into two distinct categories.

Pascual-Leone[81] believes that a subject can very well operate with only a fraction of his structural mental capacity, and the cognitive style field dependence/independence is one of the hidden parameters which moderate the functional M-space. Case and Globerson's[124] findings support this.

2.6.1 Subsequent Studies of Neo-Piagetian Theory

Since the theory was developed, it has been modified and extended by Pascual-Leone and his co-workers. Pascual-Leone[81] designed a new compound-stimuli visual information type of task to test quantitatively the M-space using another kind of stimulus. He tried also to explain the response variability frequently found among subjects belonging to the same developmental stage by means of the hidden parameter M. To him, the degree of familiarity with the task and individual variables such as field dependence/independence were among those moderator variables which could influence the performance level of the subject.

Case[125] demonstrated that the M-values hypothesized to any particular age group could be validated by using a completely different task. He found that the test of "Backward Digit Span" yields identical norms to those obtained in his study using another task to validate the M values. But the norms of the "Forward Digit Span" are either one or two /

two units higher than those of the M values measure.

Results from another study by Case[118] and Case and Globerson[124] indicated that children who are field independent (7 and 8 years of age) managed to acquire a preliminary grasp of the control of variable. To them, according to Piaget, the control of a variables scheme is a formal one. In contrast, according to Pascual-Leone, the same scheme could be considered either formal or concrete depending upon the strategy required to acquire and utilize it. Scardamalia[83] is of the same opinion when examining the combinatorial task. She found that subjects as young as eight years of age constructed a systematic strategy and applied it successfully to the task. In addition, she tried to explain the problem of horizontal decalage (passing certain tasks and failing others that have the same logical structure) in the light of increasing the task's M-demand as a variable which affects the subject's performance in a task.

Case[126] also discussed the relation between cognitive development tasks and classroom tasks. Both are similar in that they are cognitively complex and difficult to teach, but cognitive development tasks are unlike classroom tasks in that they are acquired spontaneously. To him, two sources of difficulty underlying cognitive development tasks are as follows:

(a) Children come to the tasks with reasonable but inappropriate strategies.

(b) The acquisition of a more appropriate strategy places a severe burden on children's working memory.

Both of these difficulties are likely also to be underlying difficulties associated with classroom tasks.

Case[127] has pointed out that the neo-Piagetian theory has the power to make predictions in relatively unconstrained developmental problems, provided that the strategies, which subjects might use, can clearly be specified and provided they can be conveniently assessed. Also, a careful task analysis must be conducted to determine the M-demand required to acquire the strategy, bearing in mind the possible effects of competing strategies and misleading cues. He arrived at three /

three conclusions, after surveying all of the empirical evidence in the light of M-operator, as follows:

1. "Piaget's operational structures can be interpreted as sequences of increasingly complex and powerful executive structures (from Simon's suggestions);

2. simple practice, practice with feedback, cue highlighting and modelling can affect the acquisition of these executive structures (suggested from learning and attention theories);

3. a subject's ability to profit from experience is limited by the limit of his working memory (from Pascual-Leone's suggestions)."

In addition, he summarized his arguments about the implications of a neo-Piagetian theory as follows: (128)

1. "If children have difficulty in mastering new skills, it may often be for one of the following three reasons -

   (a) they are applying a reasonable but oversimplified strategy;

   (b) the instruction is overloading their working memory;

   (c) they are insufficiently familiar with the basic operations which are required."

2. Given that this is the case, it follows that an optimal set of steps for eliminating these difficulties is as follows:

   (a) diagnose the incorrect strategy, demonstrate its inadequacy and model the correct strategy;

   (b) minimize the load on working memory;

   (c) provide massive practice in basic operations.

3. This procedure seems applicable regardless of whether the task is drawn from the literature on cognitive development or from a conventional classroom curriculum.

4. When curricula based on these procedures are developed, the improvement can be quite dramatic in comparison to regular instruction.

Lawson /

Lawson[129] tried to predict science achievement, in three different types of examination: multiple-choice items, computational items and essay items, using five cognitive variables. The five cognitive variables are:

developmental level; disembedding ability;
mental capacity; prior knowledge and beliefs.

The findings indicated that disembedding ability, prior knowledge and belief in evaluation were found to be significantly related to overall achievement. On the other hand, both developmental level and mental capacity were not related to overall achievement. But, the developmental level was found to be the best predictor of performance on the computional items, and the mental capacity was found to be the best predictor of performance on the essay items. Both belief in evaluation and prior knowledge were found to be the best predictors of performance on the multiple-choice items.

After going through these points about neo-Piagetian theory, the researcher has arrived at the following conclusions.

1. All the qualitative characteristics of Piaget's stages can be accounted for as a quantitative parameter related to working memory.

2. There is a limited working memory capacity for an individual. This space increases with age by the rate of one unit every two years starting from 3 years up to 16 years of age.

3. In the light of information processing load, the formal Piagetian tasks have high information requirements. A task's M-demand depends upon the strategy used by the subject. It differs, therefore, from individual to individual according to the number of chunks which an individual can construct with the benefit of his past learned experiences. Within this context, it is a very difficult matter to determine the task's M-demand without knowing the strategy employed by the subject.

4. Developmental psychologists are not yet agreed on how to compute the quantitative load that a strategy places on a child's /

child's working memory, nor are they agreed as to whether the measured growth in children's working memory has a functional or structural basis[126].

5. A subject can operate well with only a fraction of his mental capacity, and it is unlikely that he uses his maximum capacity, since a number of hidden factors affect his functional M-space.

2.7 Conclusion

After this survey of educational psychology being used to close the gap between students' limitations in learning, and science as a subject matter, the researcher has arrived at three interpretations, each of which has different implications for the process of learning science. Firstly, there is an age-dependence. Piaget's theory of mental development gives a description of what a person can do in an ideal situation. The most important educational implication of this stage-theory is the matching model or the readiness model in which teachers must wait until their students arrive at a stage required to teach a particular topic. Secondly, there is also an age-dependent approach, arising from the idea of limited mental capacity, which tells both teachers and educators that there is a limited space of working memory for an individual. It limits his ability to carry out learning and problem solving tasks. This means that any task, which requires a number of mental efforts or steps to be solved greater than the learner's mental capacity, will be impossible to him unless he has instructions or strategies to lessen the burden on his working memory. Thirdly, there is the prior knowledge consideration which either influences the process of learning (Ausubel), or determines what further learning can occur (Gagne). The nature of the cognitive structure that the student already has (alternative frameworks) can be explored by using Piaget-type interviews.

There are some generalizations with which some of these interpretations would seem to agree. Piaget's theory, Ausubel's theory and neo-Piagetian theory try to explore the child's ability to solve problems, from different philosophical points of view. Piaget and Gagne /

Gagne agree that a child develops (learns) intellectual capabilities which are as a result of the interaction between the child and his environment. The acquisition of these capabilities is sequential.

Ausubel and Gagne agree that prior knowledge can influence learning. Piaget and Ausubel also agree that a child's cognitive development occurs in stages are age-dependent while Ausubel's stages happen according to the differentiation and integration of subsumers. Many adults fail to solve some kinds of Piagetian tasks, whereas some youngsters can solve them. Novak[59] explains this by distinguishing between Ausubel's process of subsumption and Piaget's concept of assimilation. The subsumption process occurs when new pieces of knowledge are linked to specifically relevant concepts or propositions. In addition, the changes in the degree of meaningful learning or ability to use knowledge in problem solving, happen as a result of growing differentiation and integration of specifically relevant concepts in cognitive structures, rather than as a result of general stages of cognitive development.

The neo-Piagetian theory, needs to be studied in its educational implications. It gives an indication of a limited mental space for an individual within which he can deal with the teaching materials and problem solving tasks.

Is it possible to create a model of science education capable of helping educators to be more understanding of the learner's limitations, and harmonizing the helpful ideas derived from the various psychological stances examined in this Chapter?

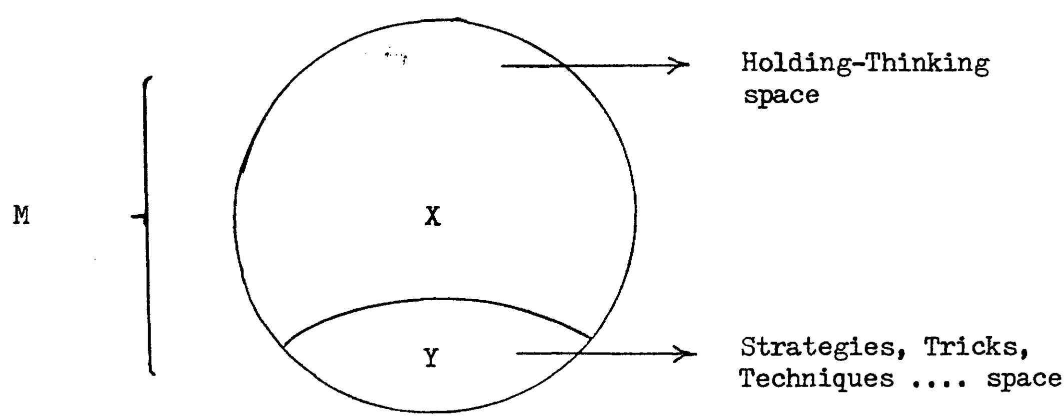
CHAPTER 3

PLANNING THE MAIN STUDY

3.1 A Predictive Model for Science Education

It has been shown in Chapter 2 that Piagetian prediction consists of tests using scientific situations to predict science performance. Ausubelian ideas are exceedingly difficult to verify experimentally and their predictive power in a given teaching situation is very weak. Perhaps neo-Piagetian theory has more predictive power which could be used by educators.

The model outlined here was proposed by Johnstone[130]. The basic construct employed in this model appeared in his earlier work with Kellet[41] and their working hypotheses concerning students' S.T.M. However, since that time, it has been modified and elaborated. The model attempts to explain success and failure in the learning processes in the light of the students' limitations associated with their mental capacities, with particular reference to chemistry situations. The simplified model is given below:



It should be noted that this distinction between X and Y does not mean that the M-space itself is divided into subsystems.

The model suggests that, for an individual, the constant M-space is the total holding-thinking space which is capable of holding the information and thinking about it along with the space taken up by the functional plane on which the items of information can be co-ordinated. Therefore /

Therefore, M-space is said to consist of two components: X + Y. The X component refers to the maximum number of items of information that a student can hold in mind while executing a task. The Y component represents any functional strategy required to organize and process the information together. As a result, if a student has to hold a great deal of information, there will be little, or even no space left for processing. It should be noted that, in addition to knowledge, there are at least three other factors occurring together in an interactive situation: the demand of the problem (task); the student's limited holding-thinking space and any strategy he may use.

3.1.1 Empirical Evidence

In classroom situations, the relationship between overload of working memory and some learning areas which students perceived to be difficult, has been explored.[131-132] Johnstone and Letton[131] give a perfect example to illustrate the overload of working memory and laboratory work in terms of signal (the things the teacher thinks are important), and noise (the things the teacher knows are not important or things which he is unaware of). The laboratory manual says - "Dissolve some ferrous ammonium sulphate in water and add some ammonia solution. What do you observe? Explain your observation. Now add some solid ammonium chloride and shake the mixture. What do you observe? Explain your observation." Three times "ammonia" and "ammonium" occurs, but only once does it have any significance and hence the students are not in a position to distinguish between noise and signal.

Another example of this kind of noisy situation is given by Selvaratnam and Frazer.[133] They tested more than 500 chemistry students in this question.

"3.00 g of phosphorous pentachloride (vapour) are heated in a closed 1.00 dm^3 vessel at 300^oC. The degree of dissociation,, according to the equation

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

is /

is then 0.300. Calculate the density of the equilibrium mixture." They found that more than 75% of students at university level could not solve it despite the solution being very simple:

$$\begin{aligned} \text{Density} &= \text{mass/volume} \\ &= 3.00\ \text{g}/1.00\ \text{dm}^3 \\ &= 3.00\ \text{g dm}^{-3} \end{aligned}$$

They explain this phenomenon in terms of the difficulty of defining the problem. The 'signal' is obscured by four pieces of noisy information - (vapour, 300°C, equation and the degree of dissociation). This then affects the students' ability to define the problem.

In the field of language, Cassels and Johnstone's findings(132) indicated that the language in multiple-choice questions was influencing the thinking processes necessary to answer the question in that the questions posed in a negative form require more working memory space.

The following example illustrates the idea of overloading working memory in examination-type questions.

> "What volume of 1.0 M hydrochloric acid would react with exactly 10 grams of chalk?"

The answer to this question in terms of the number of thought steps, which would be necessary, for the least sophisticated students, are as follows although not always in exactly this order.

1. Chalk is calcium carbonate (recall).
2. Calcium carbonate is $CaCO_3$ (recall/workout)
3. Formula mass = 100 g mol^{-1} (recall/calculate)
4. Therefore, 10 g is 1/10 mole
5. Write equation for reaction (recall products and formulae)
6. Balance this equation (recalled skill)
7. Deduce mole relationship
8. Determine that 1/10 mole $CaCO_3$ = 1/5 mole HCl
9. /

9. Recall that 1.0 M means 1 mole HCl in 1 L.

On the other hand, the same question for the teacher might take three steps as follows:

1. 10.0 g chalk = 1/10 mole $CaCO_3$ (chunked recall by use and familiarity)
2. This requires 2/10 or 1/5 mole HCl (chunked by valency consideration and experience)
3. 1/5 mole of 1.0 M HCl is 100 mL.

It is clear that, for a student, this question might be beyond the working memory space he has to hold, organize, sequence, process and solve it. But a teacher's working memory is already organized in such a situation because of his experience and previously organized knowledge.

By a similar analysis, the researcher examined how well students handled multiple-choice items in chemistry. The Scottish Examination Board supplied 100 items used in 'O' Grade Chemistry Papers along with their pretest facility values. Twenty-four of these were randomly chosen and analysed by a panel of four researchers to establish their demand. A plot of facility values against question complexity (number of thought steps) is shown in Figure 1.

A strong negative correlation between the two variables was expected and obtained ($r = 0.8$). The attempt to find a line of best fit by the method of least squares (see dotted line) was not successful. On further inspection, it was seen that the points fitted an S-shaped curve rather like a pH curve. This was also reminiscent of curves in catastrophe theory. In the graph, the vertical part of the curve comes between 5 and 6 on the x axis (the number of thought steps). This was tantalizingly reminiscent of the number 7 ± 2 mentioned by Miller[134] in his work on short term memory. However, the curve did not quite fit. It neither reached 100% nor dropped to zero, as one might expect in a catastrophe phenomenon, that is, holding up to a level followed by a sudden drop to a lower level.

Up to this point, the researcher dealt with both facility values and /

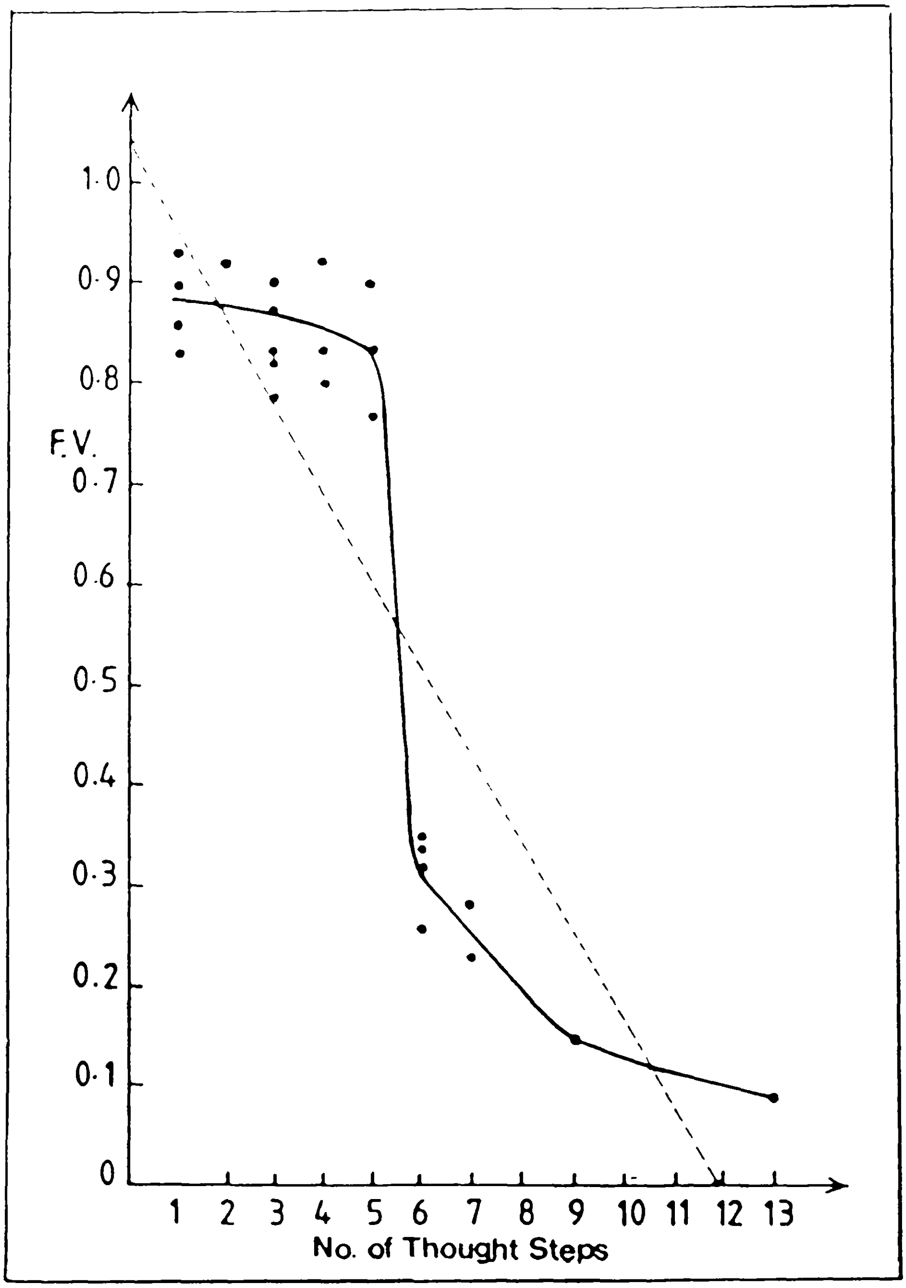


FIGURE 1 A plot of facility value in objective chemistry questions versus the number of thought steps needed to solve the questions. (See Appendix 2)

and the number of thought steps required in considering the following question: "Would it be possible to obtain a series of these S-shaped curves for sub-groups of students with different values of holding-thinking space?" To follow this idea, an independent means had to be used for measuring the holding-thinking space for an individual.

3.1.2 Measurement of Holding-Thinking Space

In order to qualify as a measure of holding-thinking space, the measurement must meet the following requirements:

1. The task used must require some transformation of the input data and operations to ensure that it truly measures both holding and thinking processes.
2. The task must be unfamiliar to the students to ensure that the individual differences in holding-thinking space are not due to strategies or operations used by students rather than to their holding-thinking space alone. If Y is unable to operate, the task measures X only.
3. In order to reduce measurement errors, it is useful to use more than one task with different stimuli to ensure that whatever the stimuli are, the size for holding these stimuli and working through it is the same.

In this study, two standardised tests were chosen to fit these requirements:

(i) digits span backward test - DBT (Appendix 3) and

(ii) figural intersection test - FIT (Appendix 4).

The digits span test usually consists of two parts: digits forward and digits backward. The digits forward part does not satisfy the requirements of measuring the size of holding-thinking space since the subjects are required only to retrieve the given numbers without doing any thinking operation. Therefore, the digits backward part was used. This consisted of reading to the students a set of digits and then asking them to repeat them or write them in <u>reverse order</u>. The students must hold these numbers then reverse them in their mind (process) /

(process) and then retrieve them. The number of digits was gradually increased until the students began to make mistakes. Their upper limit of success was taken to be a measure of their capacity X.

In the figural intersection test, developed by Pascual-Leone[116], there are two sets of simple geometric shapes, one on the right and the other on the left of a page. The set on the right contains a number of shapes separated from each other. The set on the left contains the same shapes but over-lapping, so that there exists a common area which is inside all the shapes. What students have to do is to look for and shade-in the common area of overlap. In this test, as the number of shapes increased, the task became more complex. The upper limit of the student's competence was determined, and only those who obtained identical scores on both tests were selected for this study.

3.1.3. Determination of a Task's Complexity

Having measured the students' holding-thinking space, it should be possible to make chemical performance predictions based on the demand of the question (Z). For questions of a general knowledge or intelligence test type, it may be possible to obtain an intrinsic value of their Z-demand in terms of the maximum number of information pieces to be considered at any one time (although developmental psychologists are not yet agreed on how to compute it). However, the moment anyone starts to use a strategy, this value will fall. The maximum demand, therefore, must come before this, during the process of defining the problem, looking for relationships and so on.

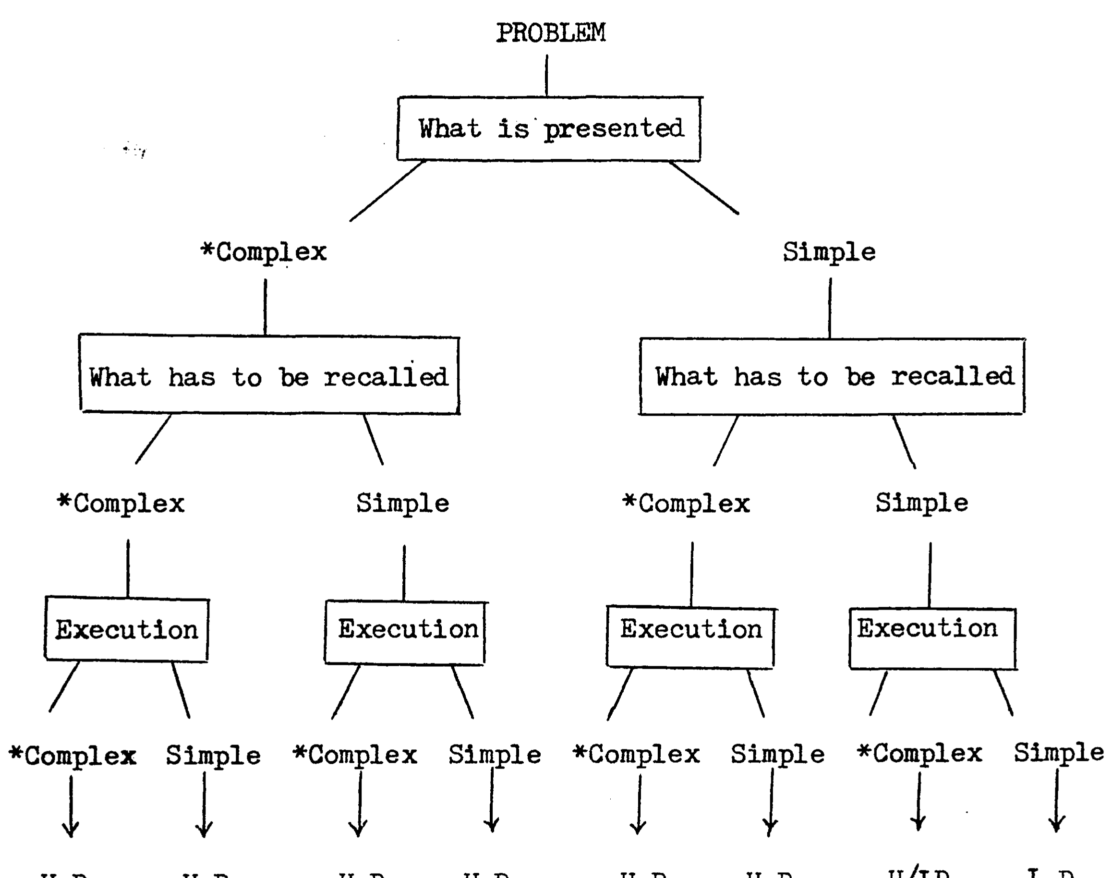
As a working definition, the question's Z-demand is quantified as the maximum number of thought steps which would be employed by the weakest successful student. Students achieving the answer using fewer steps would give evidence of some chunking or organizational strategies. Students attempting to use more steps would be unsuccessful.

The idea behind this is that, during the interpretation of the problem, students try to understand the problem and find the appropriate steps /

steps to arrive at an adequate answer. These steps are retained simultaneously until they arrive at a complete plan even by the help of the "external memory" (a pencil and paper). Students, however, should successfully complete this preliminary stage in order to be able to proceed to the interdependent steps within the plan. In this representation step, students try to link their previous knowledge and past experience with similar and familiar questions, with the actual question which they are facing.

Another Approach to the Estimation of Z-Demand

For any question, there are three factors which could give the maximum demand. These factors are: what is presented in the question itself, what has to be recalled, and the complexity of the executive steps. These are in an interactive situation which is given in the diagram below.



As can be seen, the bulk of the question's demand may lie in the question itself because of its language, negative or double negative forms, the arrangement of the data, or the existence of much irrelevant and unnecessary data. In other cases, the question itself may be simple, but what has to be recalled and sifted may be large. An example would be - "Write an essay on the chemistry of water".

A third possibility may give the maximum demand during the processing. For example -

> "$\triangle G^{o}_{300}$ is -37.5 kJ mol^{-1} and $\triangle G^{o}_{500}$ is 62.5 kJ mol^{-1}.
>
> For this reaction calculate the $\triangle H^{o}$ and $\triangle S^{o}$ assuming that they do not change with temperature."

This contains little information, but requires the insight to see that this can be solved through a chemical parallel to simultaneous equations. The equations then have to be set up and solved.

To summarize: according to the suggested model, the situation between the problem's Z-demand and the students' X-space can be identified when a student of capacity X, is given a question of complexity Z. It is necessary that $Z \leqslant X$ in order to be successful, <u>but this is not a sufficient conditon for success</u>. The sufficiency will depend upon other factors such as previous knowledge, interest, motivation, etc. In addition to this, it is not always possible to retrieve stored items of information. This indicates that limitations in retrieval may sometimes restrict what can be processed.[135] This limitation in retrieval in turn depends upon the relationship between incoming information on one side, and ideas and concepts already held in the students' cognitive structure on the other side. How this information is stored in the students' long term memory will be critical. If the question's demand is greater than the student's capacity, the student will not succeed in this question unless he can operate on Z with a strategy or technique of "chunking" and try to link it /

it with familiar previous questions, to allow the demand to be organized until it becomes less than X.

3.2 The Study's Questions

Having suggested the working model outlined above, the study's general questions stated in Chapter 1, should be presented in the light of the working definition for both the students' X-space and the questions' Z-demand as follows:

1. Is there any relationship between the students' holding-thinking space X, and their ability to solve individual questions of different complexity (Z-demand)?
2. Is there any relationship between the students' holding-thinking space X, and their total attainment score in conventional chemistry examinations?
3. Will students perform better in chemistry questions when they are made to organize their thinking before doing the calculation, than when they attempt to do both together?
4. Will students perform better in a chemistry question when it is divided for them into a number of sub-problems than when they have to deal with the complete question undivided?

3.3 The Study's Hypotheses

In order to attempt to find an answer to the questions stated above, the following hypotheses were formulated.

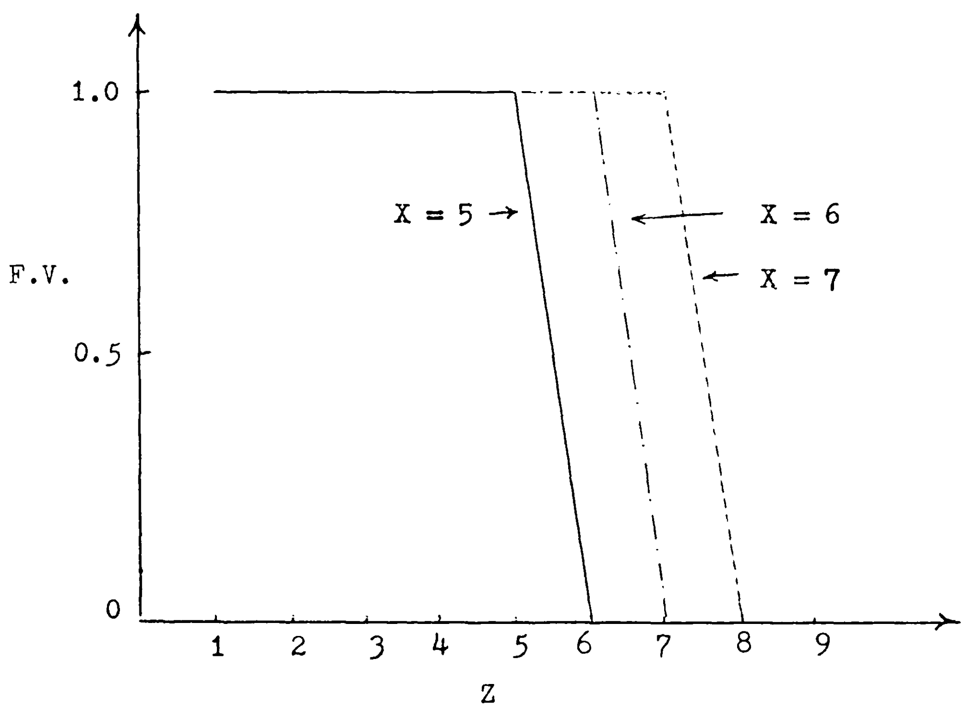
HYPOTHESIS 1

There is a direct relationship between the students' holding-thinking space X, and their ability to solve individual questions of different complexity (Z-demand).

Rationale

In /

In the curve obtained in Figure 1, it was noted that although it had an S-shape, it did not fall completely to zero. This could be explained by the fact that the sample of 20,000 students would be made up of individuals with differing holding-thinking capacities. The S-curve might be a composite resulting from a series of S-curves. The researcher is able to measure X-space for students by means independent of chemical or other science performance. In the light of the working model described earlier, assuming that the Z-demand of the question as thought steps is a sufficiently important factor, and Y is not operating well, students should do well and be able to achieve success in problems of demand $Z \leqslant X$, but should do badly in problems of demand $Z > X$. For example, if the students' holding-thinking space $X = 5$, they might be expected to do well in questions of demand $Z \leqslant 5$, but would do badly in questions of demand $Z > 5$. Similarly, $X = 6$ students would do well until $Z \geqslant 7$, and so on. The hypothetical performance for these three groups of different X-space would be as shown in the diagram given below.



Expected Chemical Performance of Students of Differing X-space in Questions of Different Z-demand.

HYPOTHESIS 2

There is a direct relationship between the students' holding-thinking space X, and their total attainment score in conventional chemistry examinations.

Rationale

Students with lower holding-thinking space would be expected to succeed in fewer questions, assuming that questions of various Z-demand were in the paper, and so would have a lower potential maximum score in the overall examination than those with higher holding-thinking space. Therefore, students of holding-thinking space $X = 5$ would be expected to have a total score in chemistry test lower than those who have $X = 6$ and both would be expected to have a total score lower than $X = 7$ students and so on provided that there were questions of Z values greater than capacities.

HYPOTHESIS 3

Students will perform better in chemistry questions when they are made to organize their thinking before doing the calculation, than when they attempt to do both together.

Rationale

It has been shown in the proposed model that the important point is that the information to be held and the thinking operations, have to share the same limited space. To provide space to carry out the calculation (during the executive step), the student has to plan, organize and sequence the steps required to solve the question in order to group and "chunk" the pile of information. During these processes, it might be that a flash of insight indicates the answer steps. If the calculation is being attempted at the same time, this might be precluded and so result in an unsuccessful attempt.

HYPOTHESIS/

HYPOTHESIS 4

Students will perform better in a chemistry question, when it is divided for them into a number of sub-problems, than when they have to deal with the complete question undivided.

Rationale

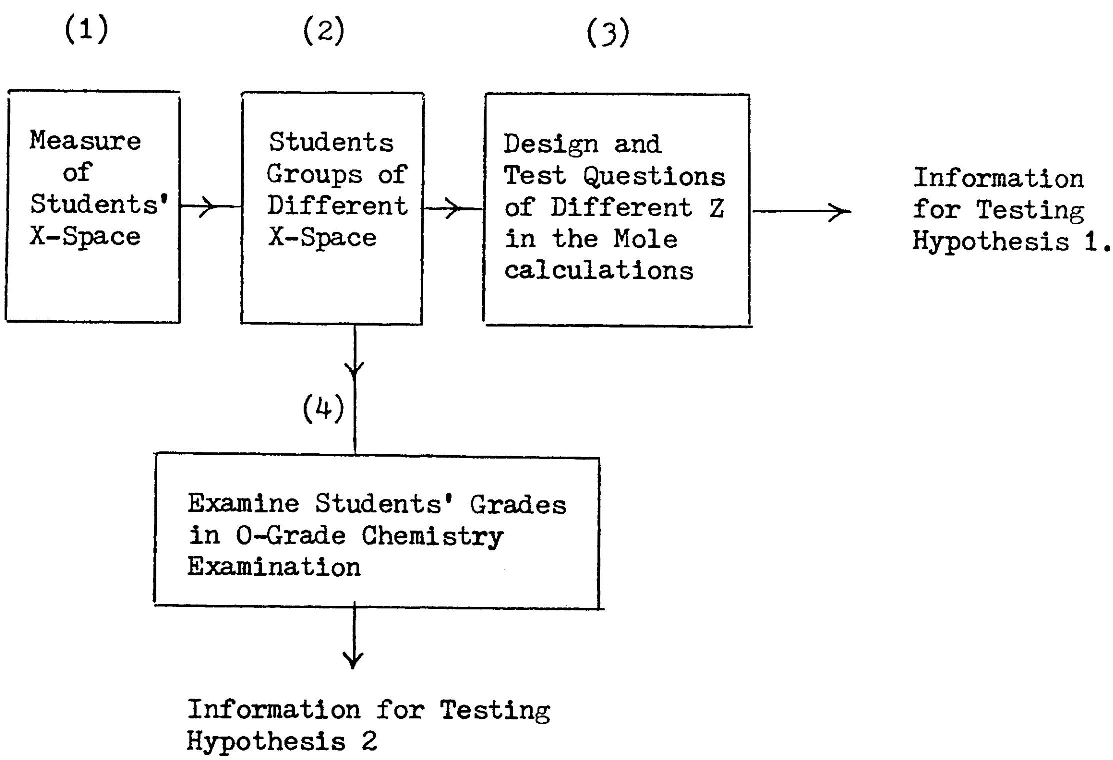
Frazer and Sleet(51) have shown that students could solve separately every step in a given problem, but some of them were still unable to solve the whole problem in an individed form. They emphasized that "teachers need to provide more opportunities for students to practise short problems ... Success and familiarity with such problems will help to develop confidence and ability to recognize sub-problems".

3.4 The Study's Design

These hypotheses were tested over a period of three years in five different schools in Glasgow, Renfrew, Falkirk and Stirling and also with undergraduates in the University of Glasgow. Three stages were proposed as follows:

Stage 1

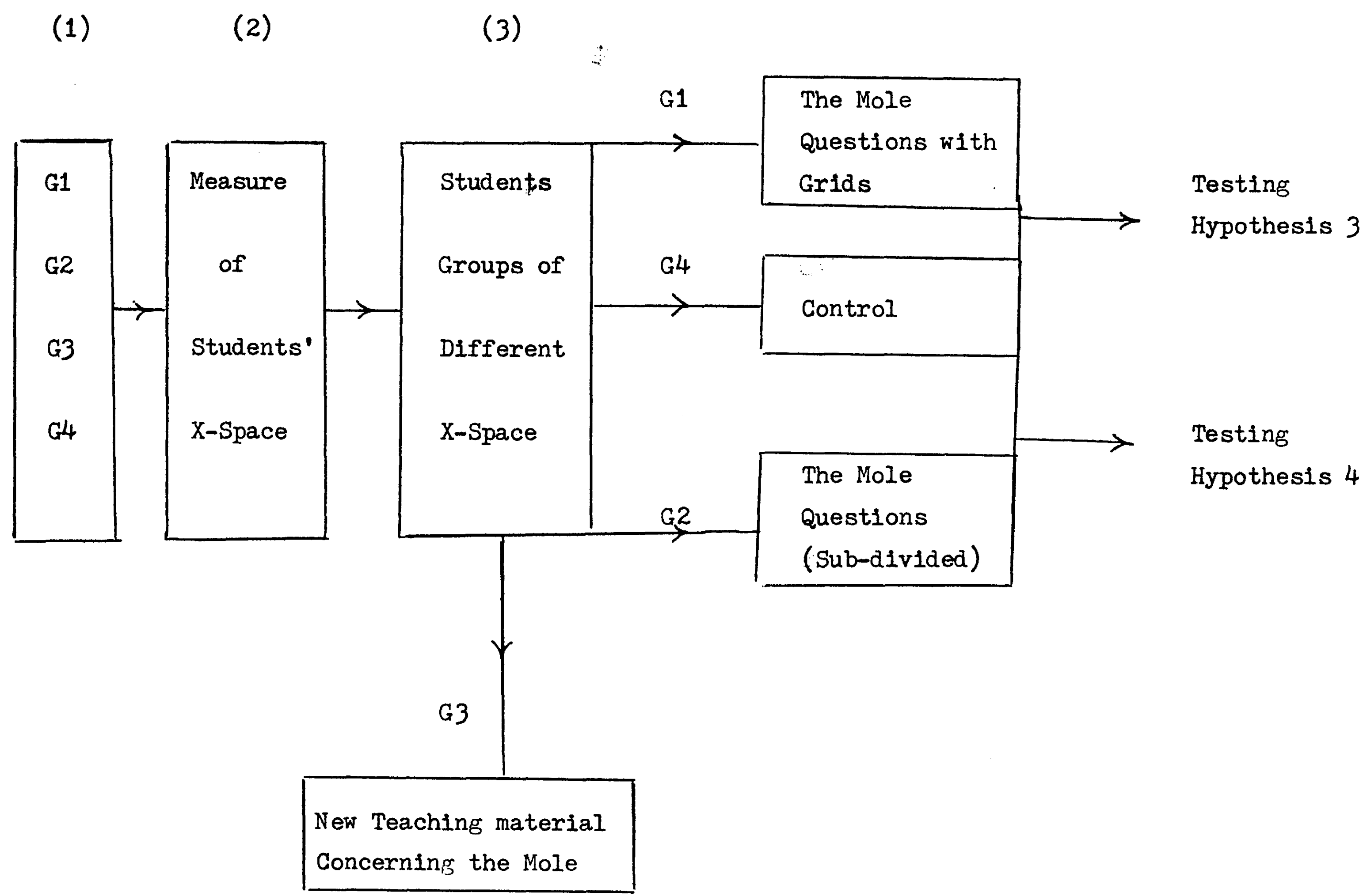
The researcher first tested the validity of the proposed model using the schools sample. The relationship between the students' X-space and their ability to solve individual questions of different Z-demand, as well as their attainment grades in O-Grade chemistry examinations were tested following the diagram below. It should be noted that this Stage was done twice in two following years as replication studies.



Stage 2

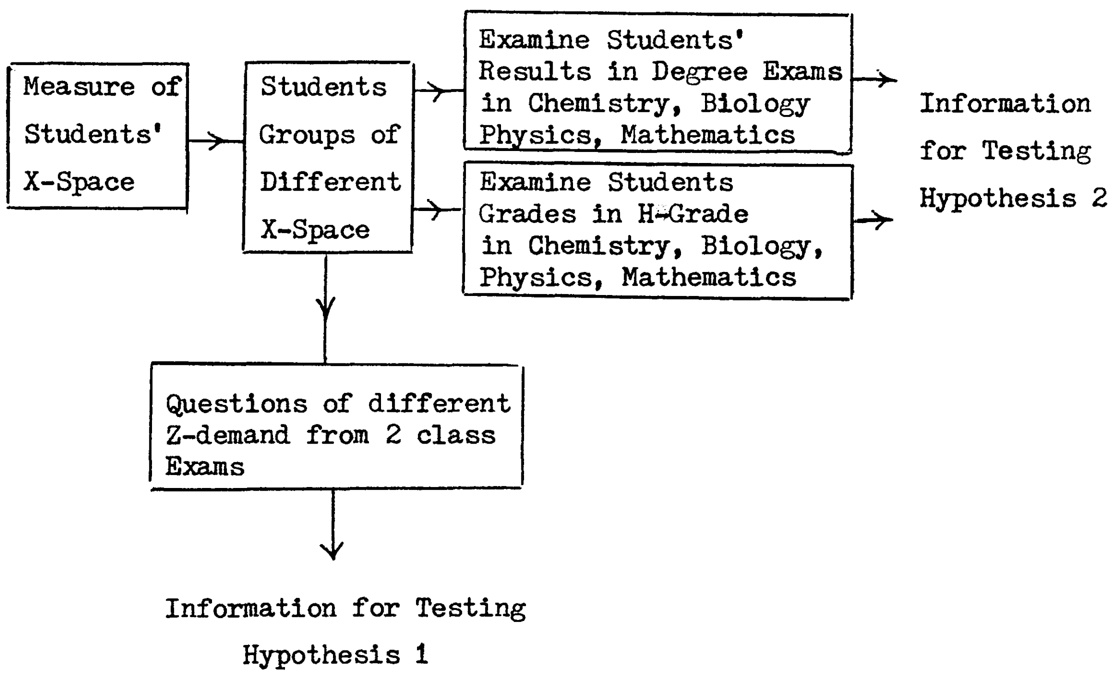
In this Stage, it was hypothesised that, once the model was tested in the light of the relationship between the students' X-space and their ability to solve individual questions of different complexity Z, instructions and methods could be devised to help students of lower X-space to perform better in chemistry questions. Three methods were suggested and tested. The first method was to help students to organize their thinking before doing the calculation by using answer grids. The second method was to divide the questions of high Z-demand into sub-questions each of which has a Z-demand no higher than 5. The third method was to construct and apply written teaching materials incorporating strategies concerning mole calculations.

To test these methods, the pupil sample was divided into three experimental groups (G1, G2 and G3) with an additional control group (G4). Each of these groups were further divided into sub-groups of different X-space. The design of this Stage is summarized in the diagram given below.


(1)
(2)
(3)
G1
G2
G3
G4
Measure
of
Students'
X-Space
Students
Groups of
Different
X-Space
G1
The Mole
Questions with
Grids
G4
Control
G2
The Mole
Questions
(Sub-divided)
Testing
Hypothesis 3
Testing
Hypothesis 4
G3
New Teaching material
Concerning the Mole

Stage 3

It was decided to test the validity of the proposed model by observing university students attempting questions of different Z-demand within different areas in chemistry. This was done by using the university normal class exams for a sample of first year students. In this Stage, the students' results in degree exams in chemistry, biology, physics and mathematics, in addition to their results in these subjects in H-Grade in the previous year, were examined as can be seen from the following diagram.



A further test of the working model has been made to find whether there is a relationship between the students' degree of field dependence-independence and their attainment scores in university chemistry exams.

3.5 The Potential Significance of the Study

It is hoped that this model will begin to answer some of the questions that educators have concerning students' limitations to learn and /

and to solve problems. If shown to be tenable, it must have consequences for all aspects of teaching, learning and testing. The way in which concepts have traditionally been presented may have to be re-examined for their Z-demand to ease students' retrieval in terms of how an individual can process it before storage. This, in turn, depends upon how incoming information reacts with the students' prior knowledge. To do this, greater care may have to be given to the ways in which concepts are interlinked to encourage the development of strategies.

In addition to this, laboratory work may have to be designed to avoid noise and to amplify the signal, keeping Z as low as possible. Also care would have to be given in the preparation and presentation of worksheets, as well as textbooks, in terms of the Z-demand of the task or the lesson. Care would have to be given to the language in any written materials or questions. This would equally apply to teaching presented by computer. Finally, in assessment procedures, the questions of high Z-demand would have to be re-examined.

CHAPTER 4

EXPERIMENT USING SECONDARY SCHOOLS
(A) TESTING THE MODEL

The validity of the proposed model using the school's sample was tested during 1984-1985 in two stages. The first stage was to establish whether there is a relationship between the students' holding-thinking space X, and their ability to solve questions of different Z-demand. The second was to examine students' performance in the external O-Grade chemistry examination. A replication study was done during the following year (1985-86) using the same stages.

4.1 Problems and Hypotheses

In order to test the validity of this part of the model, the researcher considered the following questions:

1. Is there any relationship between the students' holding-thinking space X, and their ability to solve individual questions of different Z-demand?
2. Is there any relationship between the students' holding-thinking space X, and their attainment grades in the O-Grade chemistry examination?

Using the following two hypotheses, it was hoped to find an answer to the two questions asked above.

1. There is a direct relationship between the students' holding-thinking space X, and their ability to solve individual questions of different complexity (Z-demand) as follows:
   (a) There will be a significant difference in the students' performance (within each X-space group) between the questions of complexity $Z \leqslant X$, and the questions of complexity $Z > X$.
   (b) Whenever $Z = X + 1$ for a lower group, there will be a significant difference in the students' performance for that group relative to the other higher group(s).
2. There is a direct relationship between the students' holding-thinking space X, and their attainment grades in conventional O-Grade /

O-Grade chemistry examinations.

4.2 Method Used

4.2.1 Student Sample

The subject were students from five schools. At the time of the investigation, all were currently enrolled in the third year and were then transferred to the fourth year of secondary school (O-Grade). The student population of the schools was drawn from different areas in Glasgow, Renfrew, Falkirk and Stirling. Ages were around (15+) years. In the measurement of holding-thinking space, students in the experimental sample were those who had the same score in both psychological tests, namely, the DBT and FIT. Table 1 shows the comparison of students' scores in both tests.

TABLE 1

COMPARISON OF STUDENTS SCORES IN TWO PSYCHOLOGICAL TESTS

(Schools Sample)

Performance Between DBT and FIT Scores	Number of Students
Identical score	529
Difference ± 1	87
Difference > ± 1	51
Misunderstood the instructions	62
Did not complete test(s)	25
Total	754

The sample used for the subsequent experiments were those students who obtained the same scores on both tests. This sample was subdivided into groups according to their measured holding-thinking space as shown in Table 2.

TABLE 2

SCHOOL SAMPLE USED FOR SUBSEQUENT EXPERIMENT DURING THE TWO YEARS OF TESTING

X- Space Group	N
X = 4	60 *
X = 5	140
X = 6	218
X = 7	111
Total	529

* Only 55 students were able to continue throughout the study.

4.2.2 Independent Variables

4.2.2.1 Holding-Thinking Space X

According to the suggested model, a student's holding-thinking space X, is operationally defined as the maximum number of items of information, or discrete "chunks", that he can hold in mind at any one time during the solving of a problem, assuming that he is not employing efficient strategies. With respect to chemistry, an item /

item of information or discrete "chunk" could be a thought step such as writing a formula, writing an equation, etc. which requires mental effort to complete it.

4.2.2.2 Question Complexity (Z-demand)

In examination-type questions, a question's complexity, Z-demand, is operationally defined as the maximum number of thought steps which would be employed by the weakest successful student. Two assumptions therefore would be made in this definition.

1. Y strategies are not operating well (if at all).
2. Z-demand of the question, in terms of thought steps, is the highest demand.

Within the O-Grade Chemistry Syllabus, the mole concept is an area where Y might be functioning poorly. The researcher set six questions of different complexity (Z-demand) ranging from Z = 3 to Z = 8 thought steps. The student, however, could not attempt the question without some familiarity with the language of the chemistry, and an appreciation of what was being asked. Therefore, the student would have had to be taught and this teaching may have included "here is how to solve questions of this kind".

To establish the questions' demand, all of the questions were shown to twelve chemistry teachers who were teaching the study sample in the five different schools. This was done for two reasons. The first was to ensure that there were no symbols, units or words unfamiliar to their students. The second was to ask them, on the basis of their teaching methods, how they expected their students to tackle these questions. In this way, a variety of possible strategies for the solution of each question was obtained. The researcher took as, the value of Z of a question, either the number of agreed steps required (regardless of strategy) or the maximum number of ideas which have to be processed simultaneously: whichever was the greater. For example, in a question like this:

What /

What weight of potassium hydroxide is contained in 0.2 L of 4 M potassium hydroxide solution?

(At. masses: K = 39, O = 16, H = 1)

There are three different strategies for its solution.

STRATEGY (A)

Step 1 Find no. of moles of KOH: $n = V_{(L)} \times M$

$= 0.2 \times 4 = 0.8$ moles

Step 2 Calculate G.F.M. of KOH: $= 39 + 16 + 1 = 56$

Step 3 Remember that: 1 mole of KOH contains G.F.M. of KOH

i.e. 1 mole KOH $\equiv$ 56 g KOH

Step 4 Calculate the weight of KOH actually required

$= 0.8 \times 56$ g $= 44.8$ g

STRATEGY (B)

Step 1 Calculate G.F.M. of KOH: $= 39 + 16 + 1 = 56$

Step 2 Recognise that:

1000 ml of 1 M KOH solution contains 1 G.F.M. KOH

Step 3 Determine that:

1000 ml KOH solution contains 4 G.F.M. KOH in 4 M solution

Step 4 Determine that:

200 ml KOH solution contains 4/5 G.F.M. KOH in 4 M solution

Step 5 Calculate:

Weight of KOH actually required $= 4/5 \times 56$ g

$= 44.8$ g

STRATEGY /

STRATEGY (C)

Step 1 Calculate G.F.M. of KOH: = 39 + 16 + 1 = 56

Step 2 Recognise that:

1 litre of 4 M KOH solution contains 4 moles KOH

Step 3 Determine that:

0.2 litre of 4 M KOH solution contains 0.8 moles KOH

Step 4 Calculate:

0.2 litre of 4 M KOH solution contains 0.8 x 56 g KOH

i.e. = 0.8 x 56 g = 44.8 g

Strategy(A) was used by 8 (out of 12) teachers, Strategy (B) was used by 3 (out of 12) teachers and Strategy (C) by only one teacher. Both Strategies (A) and (B) consisted of 4 thought steps, and these methods were used by the majority of teachers. The researcher, therefore, considered that the commonest number of thought steps of this question is 4, i.e. its Z-demand = 4.

The common strategy (or strategies) was further analysed in order to count the items of information required to be held for an individual step. Consider this question:

> How many moles of hydrogen ions (H^+) are there in 200 ml of 2 M sulphuric acid (H_2SO_4)?

The common strategy for solving this question required only one step, where:

Step 1 Calculate:

$$\text{No. of moles of } H^+ = V_{(L)} \times M \times \text{no. of } H^+ \text{ in the formula}$$

$$= \frac{200}{1000} \times 2 \times 2 \text{ moles}$$

$$= 0.8 \text{ moles}$$

But this step required, in turn, three items to be held simultaneously /

simultaneously as follows:

1. Remember that volume should be in litres.

2. Determine how many H^+ are there in the formula of the acid.

3. Recall the relationship among the three variables.

In this question, the number of items to be held for an individual step simultaneously was greater than the number of steps. The Z value, therefore, of this question was 3.

In this way, the Z values for all the questions were established before doing any experimental work. (Appendix 5).

4.2.3 Dependent Variables

The dependent variable, the achievement in chemistry, was in two forms.

A - The Mole Concept Questions

For each question the mean score and facility value (the proportion of students answering the question completely correctly), were calculated to test Hypothesis 1. Each question's score was related directly to its Z value. The score of questions of complexity Z = 3, therefore, was 3 marks; the score of questions of complexity Z = 4 was 4 marks and so on. These scores were then converted to a score out of 10 for each question. The possible score on each question, therefore, was 10 marks.

B - Overall O-Grade Results

Students' grades in O-Grade Chemistry Examinations were obtained to test Hypothesis 2. The grades in the first year testing (1984-85) ranged from grade A to grade F. In the second year testing (1985-86) the grades ranged from grade 1 to grade 6 because of a change in the Examination Board procedures.

4.2.4 Procedures

This /

This part of the study was conducted on three separate days at each school. Each day's testing required one normal class period. The first day (in the last week of summer term while students were in their third year) was devoted to the administration of the psychological tests. The digits span backward test DBT and the figural intersection test FIT were used to measure the students' holding-thinking space (X space). At the beginning, students were told that the results of tests would not affect their school assessment in any way. The digits span test was given first. The digits forward test was administered followed by digits backwards. This was done for two reasons. The first was to allow students to become familiar with the calling speed of the numbers and to have practice in writing them immediately after each sequence had been given to them. The second was to allow the testers to answer questions about any misunderstanding of the instructions. Ideally, both tests should have been administered to each student individually, but due to the number of students participating in the experiment, and the time allocated by the schools, the researcher used tape recordings and gave an answer grid to each student on which to make his response. For both tests the digits were called out from the tape,recording at the rate of one digit per second. Students were then given the same number of seconds to record the numbers.

Since the test was given to the whole class at the same time (15-20 students), two testers had to be present during the testing to watch for certain errors which had to be prevented.

1. The possibility of writing the numbers from right to left, within the digits backwards test, rather than turning the numbers around mentally. Students who attempted to do this were excluded from the sample.

2. The possibility of writing the numbers while they were being spoken on the tape recording. Those who attempted to do this were also excluded from the sample.

The digit span test was followed by the figural intersection test. After being given the materials, students were instructed to study carefully all the written instructions and the examples on the second page./

page. Two testers had to be present during the exercise to answer questions and to circulate among the students and watch for certain errors which had to be prevented, but no information about solving the items was given. Errors which had to be watched for during testing included:

1. Multiple shading in more than one area.

2. Outlining the shapes by pen (or even by fingers).

Both tests were marked separately so that no attempt would be made by the researcher "to make them agree". A student score in the digits backwards test was taken to be the highest correct group of digits in either one of the two trials before two unsuccessful trials are made in the following series. This method was used by Case[(125)] and Scardamalia[(83)]. The upper limit of a student's competence determined from the figural intersection test (see Appendix 4), was matched with his score in the digits backwards test. Once again, the sample used for subsequent experiments included only those who obtained the same score on both tests.

Having determined the students X-space, a list of students' names and their scores on both tests was given to an independent researcher to be kept secret from the original researcher. Another list was sent to the Head of Chemistry for each school for independent storage.

The second day of testing was to administer the mole concept questions of different complexity (Z-demand) as soon as each school had finished teaching this concept and had had time for revision: (January-February). After being given the materials (booklet contained six pages; one page for each question) students were instructed to answer all the questions and to record their answers clearly below each question. All necessary data were given at the end of each question. The time allocated was the normal class period.

By the help of the independent researcher, the answers booklets from each school were ordered randomly. Each booklet had been given a number on its cover page. The same number was placed on the first page of the booklet. The cover page was then torn off the booklet. All /

All cover pages were collected and given to the independent researcher so that students names became "unknown". After the researcher finished marking the booklets, the cover pages were placed again according to their numbers and both the independent and the original researchers entered the scores into the computer.

Finally, the third day was used to collect students' results in the O-Grade Chemistry Examinations (August).

4.2.5 Data Analysis

The hypotheses presented earlier in this Chapter were tested as follows:

1. To test Hypothesis 1, the significance of the differences in the case of facility values and students' mean scores have been calculated using the method described by Kellet[42] (Appendix 6).

2. To test Hypothesis 2, the significance of the differences, in the case of students percentage in each grade, have been calculated, also, by the method described by Kellet (Appendix 6).

4.3 The Results: (First Year of Testing 1984-1985)

4.3.1 Testing Hypothesis 1

Date Using the Facility Value

One of the main aims of testing Hypothesis 1, was to find out whether there was a direct relationship between the students' holding-thinking space X, and their ability to solve individual chemistry questions of different Z-demand.

The Facility Value for all the questions of different complexity (Z-demand) for all students' groups of different X-space, appear in Table 3.

TABLE /

TABLE 3

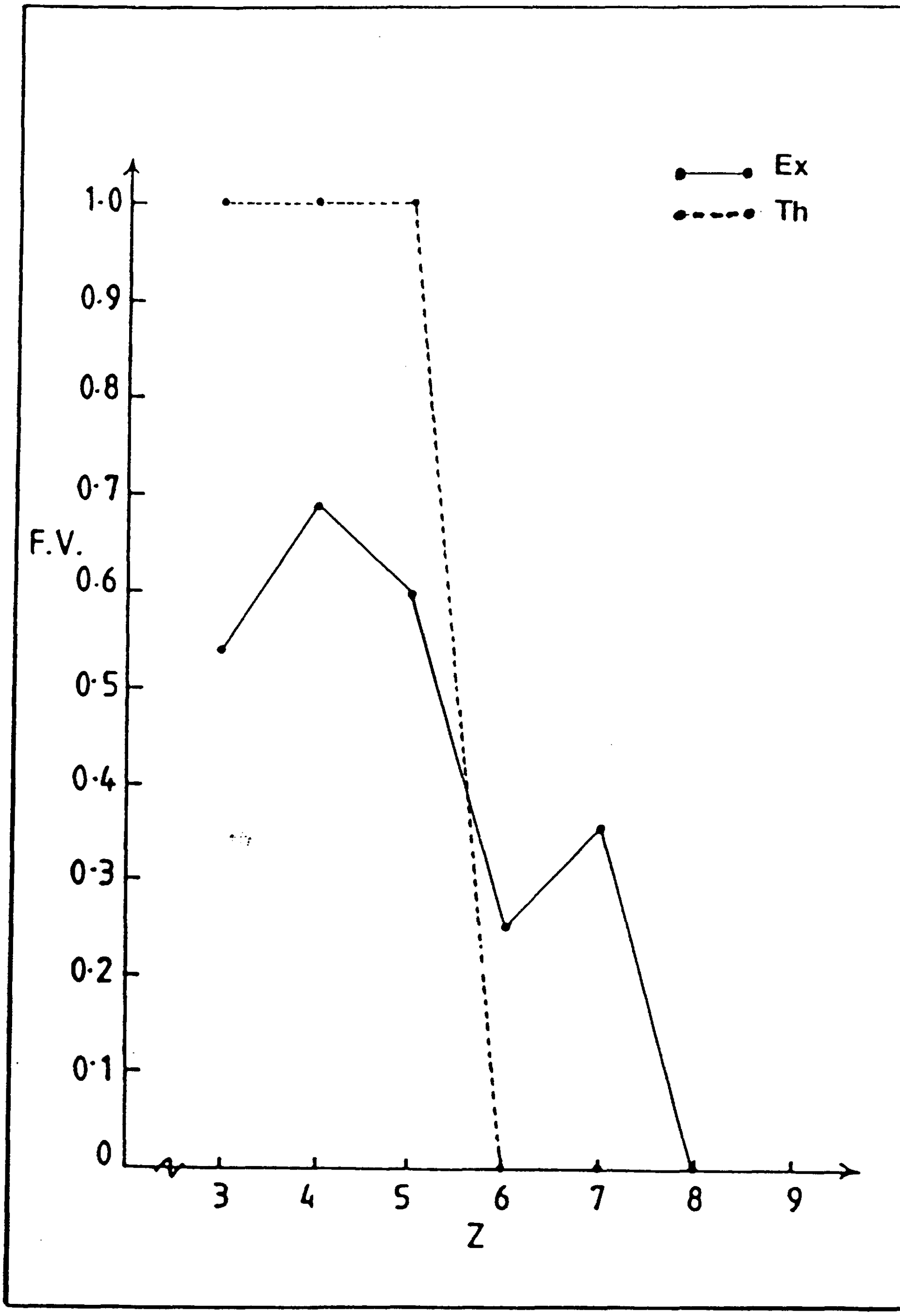
THE F.V. FOR THE MOLE QUESTIONS AGAINST STUDENTS GROUPS

Groups \ Questions	Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 5 (N = 48)	0.54	0.69	0.60	0.25	0.35	0.00
X = 6 (N = 92)	0.57	0.72	0.62	0.65	0.48	0.07
X = 7 (N = 51)	0.71	0.92	0.82	0.78	0.77	0.08

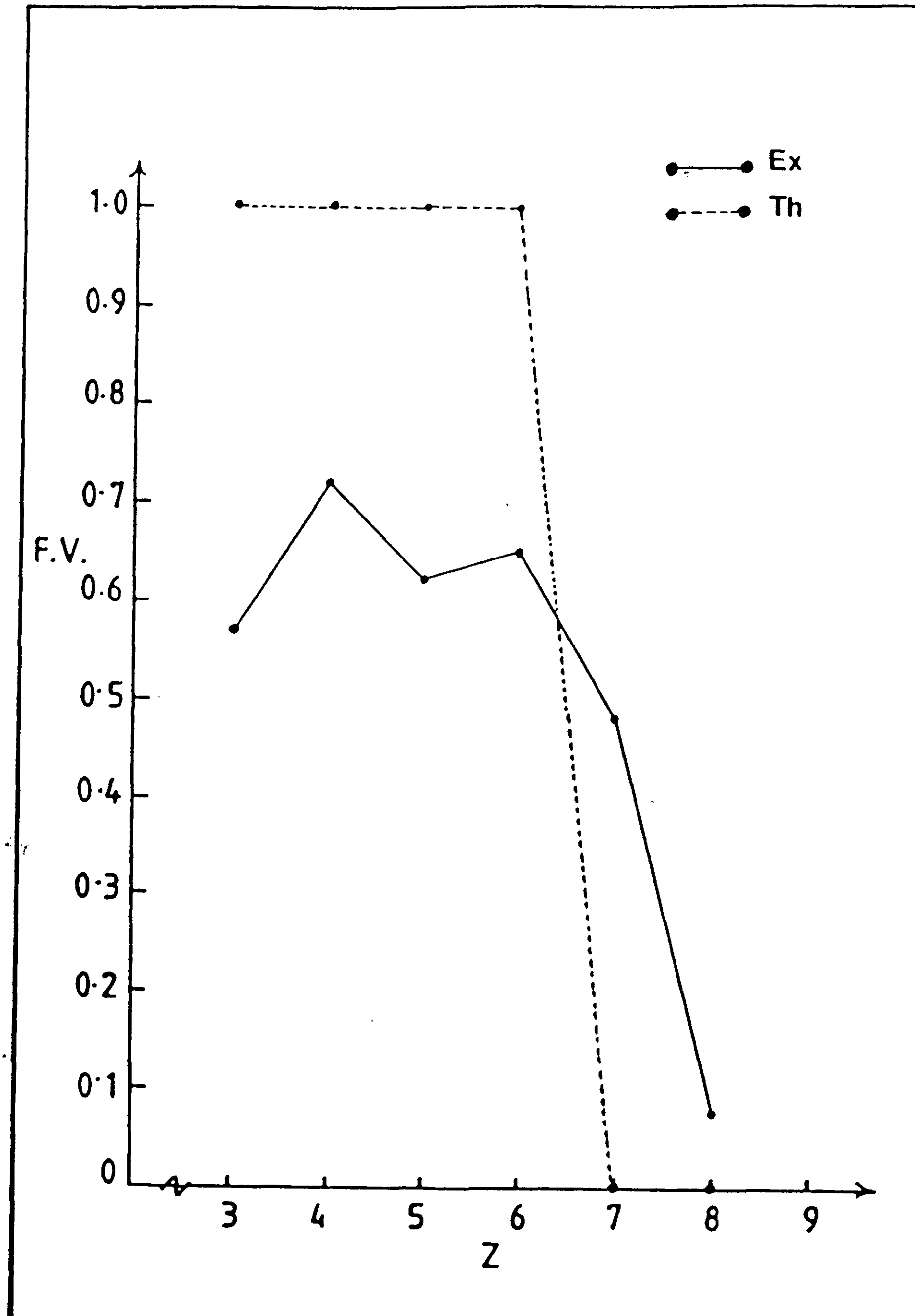
These results, illustrated in Figures 2 through 5, do not conform exactly to the idealised (theoretical) curves (dotted lines), but there are strong similarities. In Figure 2, the X = 5 students maintain a facility value between 0.54 and 0.6 for all questions of complexity Z $\leqslant$ 5, but they fall for the question of complexity Z = 6 (with facility value of 0.25). On the other hand, they make a temporary recovery at the question of Z = 7, and then fall again at question of Z = 8. As can be seen, 25% of Z = 5 students were able to solve a question of Z-demand greater than their measured X-space by 1. Moreover, about 35% of them were able to solve a question of Z-demand greater than their X-space by 2. This led to further investigations.

Figure 3 shows similar trends for X = 6 students. They do quite well up to question of complexity Z = 6. For all questions of Z $\leqslant$ 6 they maintain a facility value between 0.57 and 0.62, but fall away rapidly for questions of Z = 7 and Z = 8. However, 48% of them were still able to solve a question of Z = 7, and 8% for question of Z = 8.

Because /



<u>FIGURE 2.</u> Results from students of X = 5 attempting the mole questions.
(1st year of testing)



<u>FIGURE 3</u>. Results from students of X = 6 attempting the mole questions.
(1st year of testing)

Because of the critical time in the school, it was possible to interview only ten students of X = 5 and X = 6, who solved questions of Z-demand greater than their measured X-space, to find out how they solved these questions. The interview questions were:

1. Have you seen a question like this before?

2. How did you manage to solve this question?

3. Did someone teach you this method or did you devise it yourself?

These questions were asked of the students after they had been given the same questions (of Z > their X) to solve aloud into a tape recorder. The time spent with each student did not exceed ten minutes. Two of these students' answers indicated that they had seen examples like these questions before and they had become familiar with this type of question. The majority (8 students) said that their teachers had shown them a formula for coping with this type of question and they had been taught how to solve them. They were, therefore, able to bring these previous strategies into the answering of these questions.

Successful students who had not been interviewed, had their answers sheets matched with those of their teachers. It was found that these successful students had followed the shortest strategy used by their teachers which effectively reduced the Z-demand of the questions for them.

In Figure 4, the X = 7 students maintained facility value greater than 0.7 for all questions of complexity $Z \leqslant 7$, but plunged to a facility value of less than 0.1 for the question of Z = 8. Putting all the three curves together, Figure 5 shows that, in all questions the X = 7 curve represents better all-over performance than X = 6, and both are better in all-over the performance than X = 5. This indicates that other factors must be involved in all-over performance. In addition to this, when $Z \leqslant X$, there is a good performance, but not as good as 100%. When Z exceeds X, there is a sharper fall in performance for the X = 7 students than for the X = 6 students, and both fall more sharply than X = 5. In all cases, the fall did not reach zero per cent /

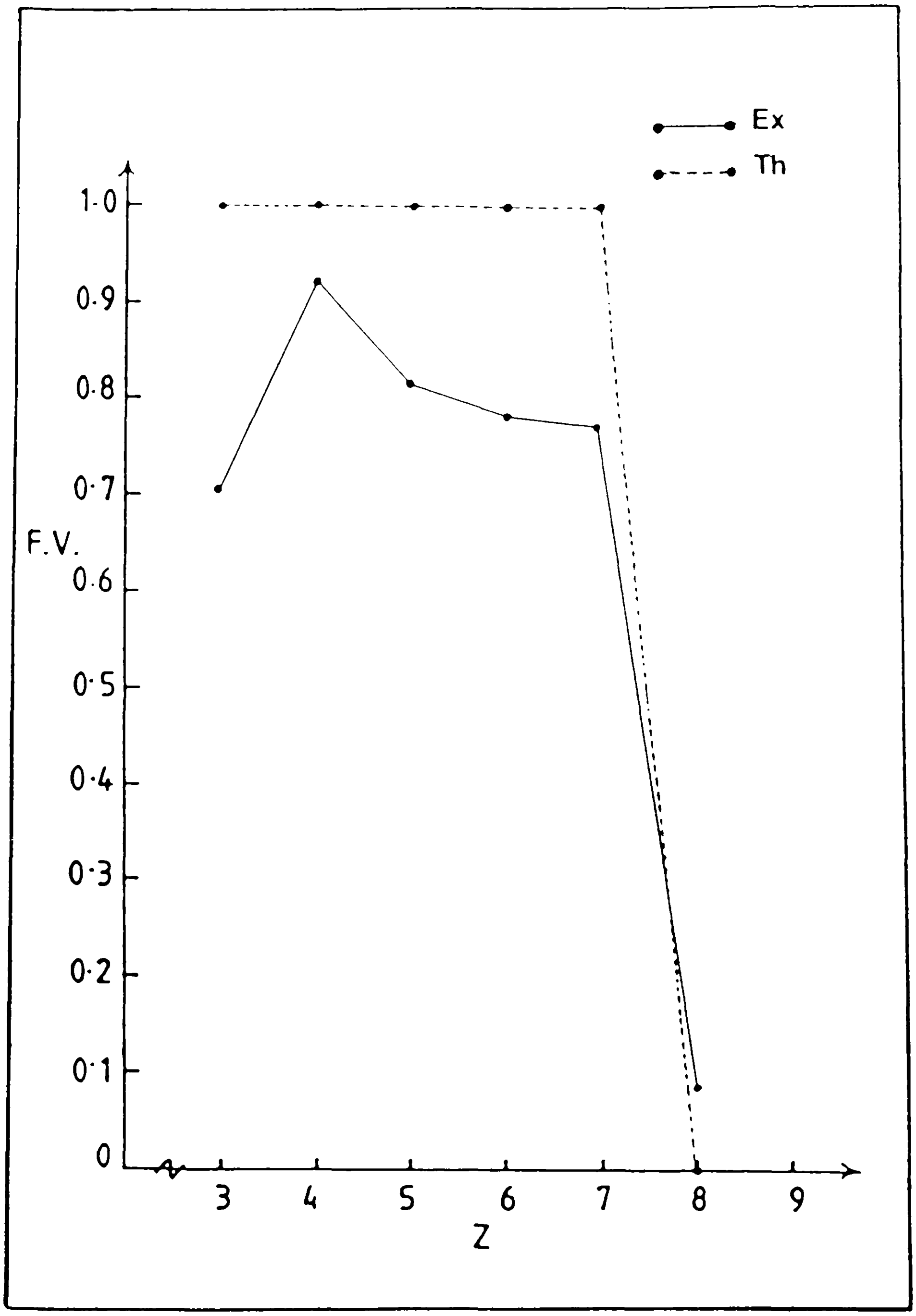


FIGURE 4. Results from students of X = 7 attempting the mole questions.
(1st year of testing)

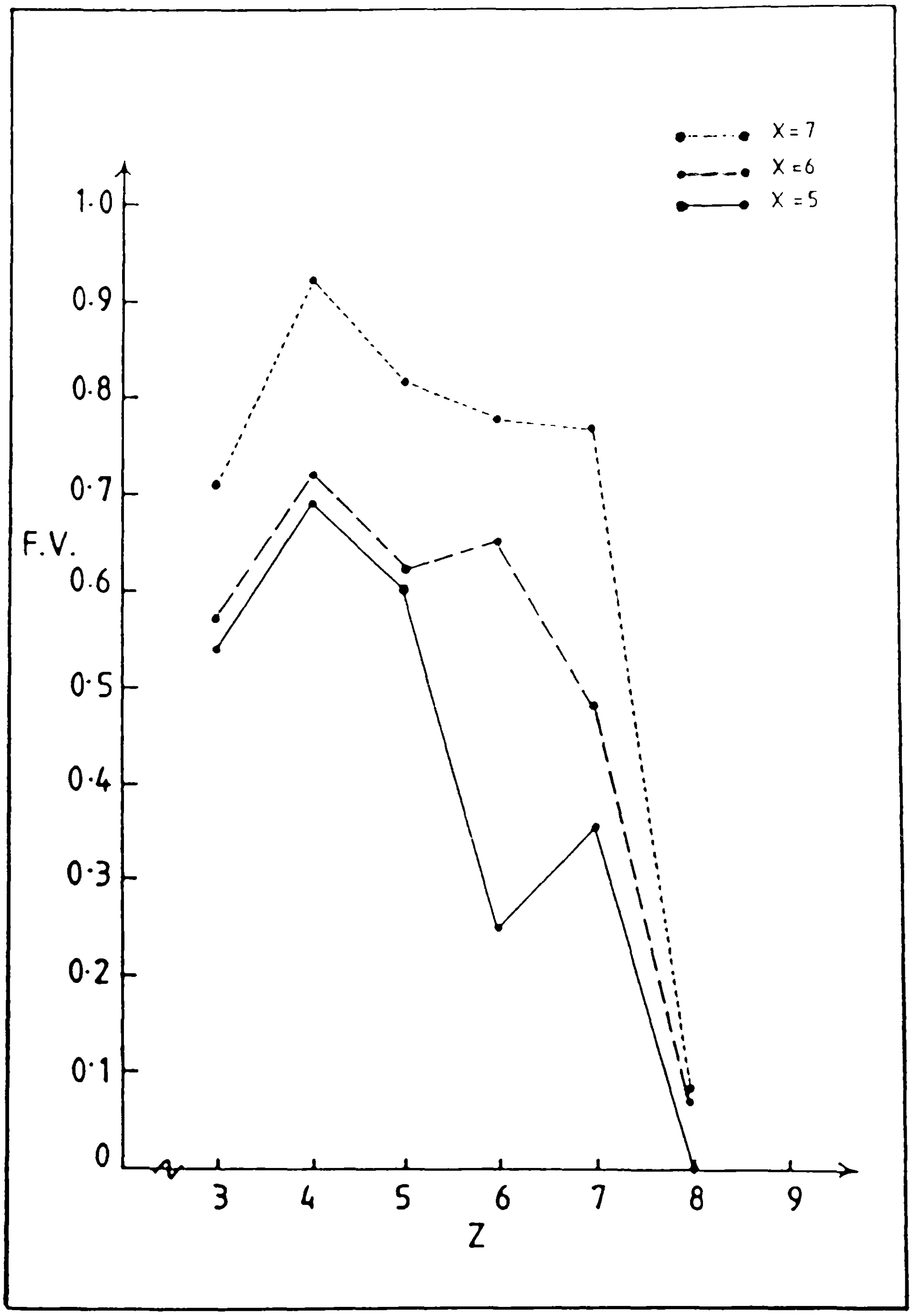


FIGURE 5. Comparison of results from students attempting the mole questions. (1st year of testing)

cent immediately.

At this stage, to find out whether the students' X-space significantly affected their ability to solve these questions of different complexity, a comparison was made for each question between students' groups of different X-space, using the method recommended by Kellett[42] (Appendix 6). Table 4 presents the results of this comparison.

TABLE 4

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENTS' GROUPS

Questions \ Groups' Diff.		X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	S.**	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.
Q.4	Z = 6	S.**	S.**	N.S.
Q.5	Z = 7	N.S.	S.**	S.*
Q.6	Z = 8	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

The results indicate that, in general, for questions of Z-demand equal to or less than the lowest X-space (in this case, the lowest X is that X = 5) all the groups' performance is similar since these questions were well within the capacity of all groups. In addition, for the question of Z-demand greater than the highest X-space (in this case, the highest X is that X = 7) the groups' performance is also similar since this question was well beyond the capacity of all groups.

As has been expected from Table 4, the significant differences lie in questions of Z = 6 and Z = 7. No significant differences can be claimed in performance between X = 6 and X = 7 students in a question of Z = 6, where the question's demand is within their X-space, but there should be significant differences between both and X = 5 in that question since its demand is greater than 5. The X = 7 group has the necessary condition for succeeding in question of Z = 7, but both X = 5 and X = 6 groups do not have access to that question since its demand is greater than their X-space. Therefore, the differences between X = 7 and both X = 5 and X = 6 are significant.

To find out whether there is an effect of Z-demand on the students' performance, another comparison was made for each X-space group between the questions of different Z-demand. The significance of all possible differences within each group of different X-space are given in Table 5.

As can be seen, the results from Table 5, in general, indicated that the questions' Z-demand has an affect on the students' performance when Z exceeds their measured X-space for all groups.

Data Using the Mean Scores

The second main aim of testing Hypothesis 1, was to find out whether there is a direct relationship between the students' X-space and their ability to solve individual chemistry questions of different Z-demand in terms of their mean scores (this is allowing for partially correct answers). Means and standard deviations for each question for all groups appear in Table 6. Figure 6 shows the mean scores for these three different X-space groups in each question. Once again, in all questions, the X = 7 curve represents better all-over performance than the X = 6 curve, and both are better than the X = 5 curve.

TABLE 5

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH STUDENTS' GROUP BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND

Groups	Z \ Z	3	4	5	6	7
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	S.*	S.**	S.*	-	-
	7	S.*	S.*	S.**	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**
X = 6	4	S.*	-	-	-	-
	5	N.S.	S.*	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	S.*	S.*	S.*	-
	8	S.**	S.**	S.**	S.**	S.**
X = 7	4	S.**	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	S.*	N.S.	-	-
	7	N.S.	S.**	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**

** at 0.01 level

* at 0.05 level

At this stage, it was necessary to see whether there is any significant difference between these means. This was done by using the same method as was employed in the case of the Facility Values.

TABLE 6

MEANS AND STANDARD DEVIATIONS FOR EACH QUESTION FOR ALL STUDENT GROUPS

(Possible Score for Each Question is 10)

Questions \ Groups		X = 5		X = 6		X = 7	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Q.1	Z = 3	6.8	2.0	7.4	2.4	8.0	3.5
Q.2	Z = 4	7.1	2.0	8.2	2.6	9.3	2.4
Q.3	Z = 5	7.0	2.0	7.2	2.4	9.1	2.4
Q.4	Z = 6	5.4	1.8	7.0	2.3	8.6	2.3
Q.5	Z = 7	4.8	1.8	6.6	2.2	8.0	2.3
Q.6	Z = 8	1.5	1.1	2.9	1.6	3.6	1.2

Two comparisons were made. The first was to find out the significance of the differences between the means of the X-space groups in each question (the effect of the students' X-space on their performance). The results of this comparison appear in Table 7 and indicate that there appear to have been no significant differences in means between X = 5 and X = 6, as well as X = 6 and X = 7 in all questions. The only significant differences were between X = 5 and X = 7 groups in questions of Z = 4, 6 and 7.

The second comparison was to find out the significance of the differences between the means of the questions in each X-space group (the effect of the question's demand on the students' performances). The results of this comparison appear in Table 8, which indicate that there appear to have been, in general, no significant differences in means between the questions in each group except the differences between question of Z = 8 and all the questions in other groups.

It should be noted that, students have had a chance to collect partial marks from the individual steps, and the results do not conform to the idealised pattern as in the case of the facility values. Nevertheless, the X = 7 group is better in over-all performance than the X = 6, and both are better than the X = 5.

The results, however, tend to support the hypothesis that there is a direct relationship between the students' holding-thinking space-X, and their ability to solve individual questions of different Z-demand in terms of the facility values and the means.

4.3.2 Testing Hypothesis 2

Students' results in the O-Grade chemistry examinations are given in Table 9, where the percentage of students of different X-space in each grade can be seen. Of X = 7 students, about 74% were in grade A, and only 6% failed. At the other extreme, only 40% of the X = 5 students attained grade A, and nearly a third of them failed. The X = 6 students were in between the X = 7 and the X = 5 students.

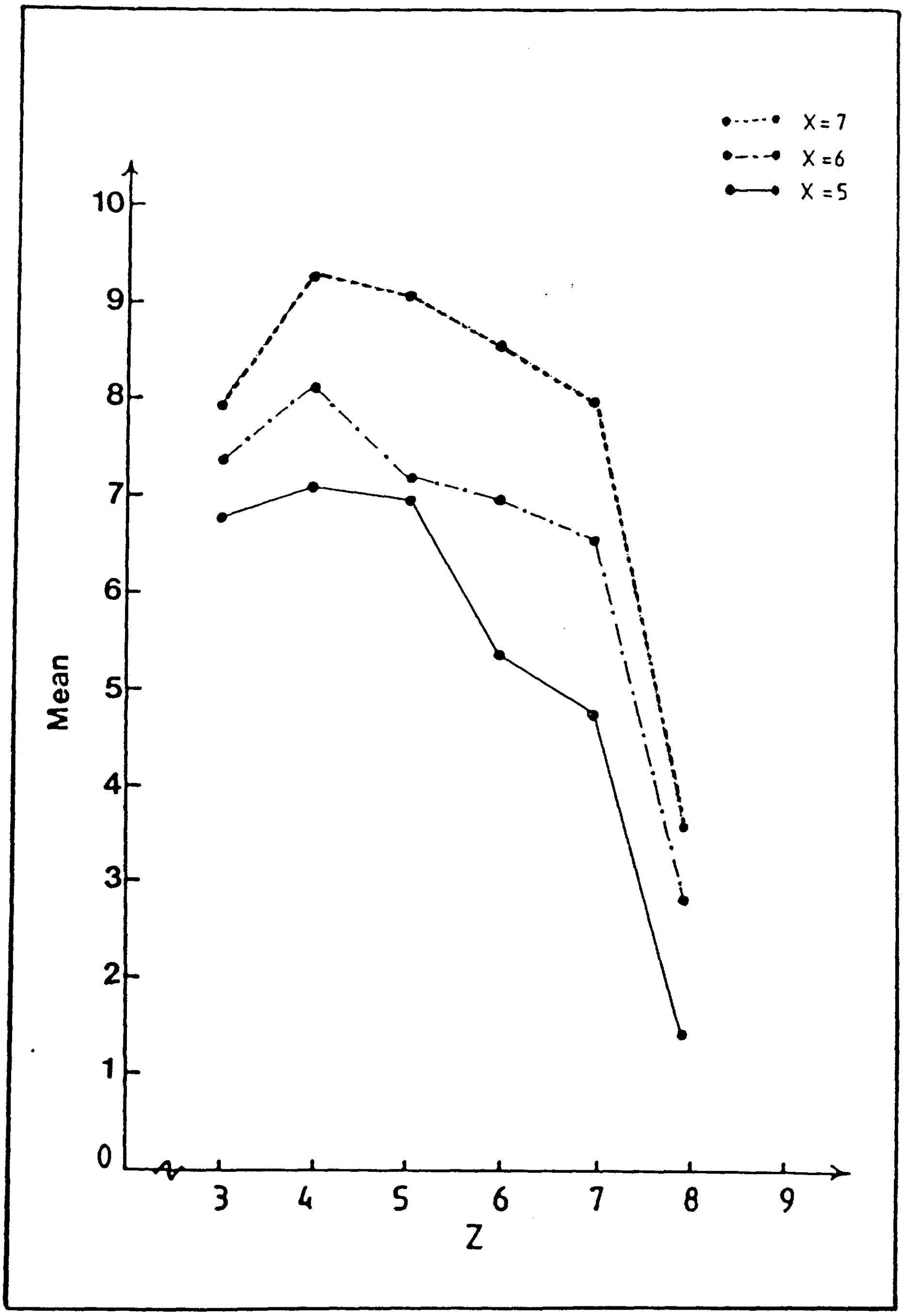


FIGURE 6. The Students' Mean Scores in the Mole Questions.

TABLE 7

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS IN EACH QUESTION BETWEEN THE STUDENT GROUPS

Questions	Groups Diff.	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	S.*	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.
Q.4	Z = 6	N.S.	S.**	N.S.
Q.5	Z = 7	N.S.	S.**	N.S.
Q.6	Z = 8	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

TABLE 8

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND FOR EACH STUDENT GROUP

Groups	Z \ Z	3	4	5	6	7
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	S.*	N.S.	S.*	N.S.	-
	8	S.**	S.**	S.**	S.*	S.*
X = 6	4	N.S.	-	-	-	-
	5	N.S.	S.*	-	-	-
	6	N.S.	S.*	N.S.	-	-
	7	N.S.	S.*	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**
X = 7	4	S.*	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.*	S.*

** at 0.01 level

* at 0.05 level

TABLE 9

PERCENTAGE OF STUDENTS IN EACH GRADE OF THE O-GRADE CHEMISTRY EXAMINATION

(June 1985)

Groups \ Grades	A	B	C	D + E*
X = 5	40%	20%	10%	30%
X = 6	58%	13%	10%	19%
X = 7	74%	14%	6%	6%

* Grades D and E represent fails

A comparison is made, using Kellett's method, to find out the significance of the differences in these percentages between the students' groups. The results are given in Table 10, and indicate that there is a significant difference in the students' percentages in grade A between the X = 5 group and both X = 6 and X = 7 groups and there is no significant difference in that grade between X = 6 and X = 7 groups. In addition, the percentage of the students who failed in the X = 5 group is significantly different from those in X = 7 group. No significant differences in these percentages appeared between the student groups in grade B and grade C.

The results, however, tend to support the hypothesis that there is a direct relationship between the students' holding-thinking space X, and their attainments grades in an O-Grade chemistry examination.

TABLE 10

THE SIGNIFICANCE OF THE DIFFERENCES IN STUDENTS' PERCENTAGE IN EACH GRADE

Grades / Groups Diff.	A	B	C	D + E
X = 5 and X = 6	S.*	N.S.	N.S.	N.S.
X = 5 and X = 7	S.**	N.S.	N.S.	S.**
X = 6 and X = 7	N.S.	N.S.	N.S.	N.S.

** at 0.01 level
* at 0.05 level

4.4 The Results: (Second Year of Testing)

4.4.1 Testing Hypothesis 1

Date Using the Facility Values

The methodology used in this replication study was the same as that in the original. It should be noted that the same questions on the mole have also been used. Table 11, shows the facility values of all questions for all groups of different X-space. It will be noted that the F.V. for the questions are lower than in the first year of testing.

TABLE 11

THE F.V. FOR THE MOLE QUESTIONS AGAINST STUDENTS' GROUPS (SECOND YEAR OF TESTING)

Groups \ Questions	Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 4 (N = 17)	0.18	0.24	0.18	0.18	0.06	0.00
X = 5 (N = 17)	0.47	0.53	0.53	0.24	0.06	0.00
X = 6 (N - 26)	0.48	0.58	0.54	0.54	0.24	0.08
X = 7 (N = 11)	0.60	0.73	0.55	0.73	0.73	0.00

Enquiries were made of the teachers. It was found that the pupils had not had any opportunity for revision before attempting the test, and so they were not as well prepared. Nevertheless, the results, illustrated in Figure 7, tend to support the results of first year of testing. It has been found that, when Z exceeds X, the students' performance falls away rapidly. In the case of X = 4 students, they were not able to deal even with the questions of complexity Z = 3 or Z = 4.

Table 12, shows the significance of the F.V. differences between the four groups of different X-space in each question. It was expected that the significance of the F.V. differences between the X = 4 and X = 5 groups would be in only the question of complexity Z = 5 since the performance of both groups should be the same in questions of /

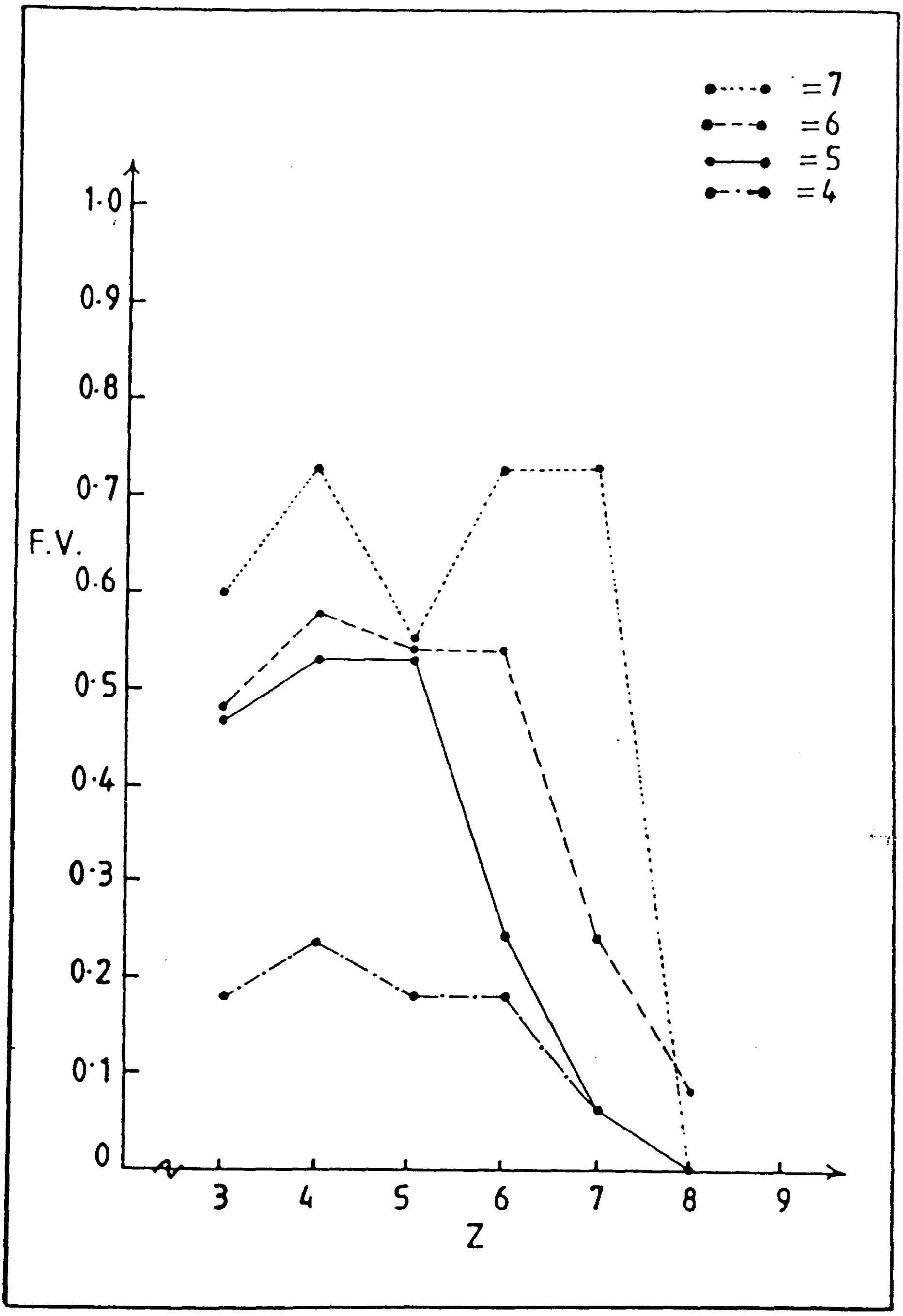


FIGURE 7. Comparison of results from students attempting the mole questions.
(2nd year of testing)

TABLE 12

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENT GROUPS (SECOND YEAR OF TESTING)

Questions \ Groups Diff.		X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	S.*	S.*	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	S.*	S.**	N.S.	N.S.	N.S.
Q.3	Z = 5	S.*	S.**	S.*	N.S.	N.S.	N.S.
Q.4	Z = 6	N.S.	S.**	S.**	S.*	S.**	N.S.
Q.5	Z = 7	N.S.	N.S.	S.**	N.S.	S.*	S.**
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

TABLE 13

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH STUDENTS' GROUP BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND (SECOND YEAR OF TESTING)

Groups	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	S.*	S.**	S.**	N.S.	-
	8	S.**	S.**	S.**	N.S.	N.S.
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	S.*	N.S.	N.S.	-
	8	S.*	S.**	S.**	S.**	N.S.
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**

** at 0.01 level

* at 0.05 level

complexity Z = 3 and Z = 4 (easy for both because $Z \leqslant X$), and questions of complexity Z = 6, Z = 7 and Z = 8 (difficult for both because $Z > X$). In addition, the significance of the F.V. differences between the X = 4 and X = 6 groups should be in the two questions of complexity Z = 5 and Z = 6. The differences between X = 4 and X = 7 groups should be in the questions of complexity Z = 5, Z = 6 and Z = 7. Similar trends were expected for other groups.

The results from Table 12, give these expected patterns except that the F.V. of the X = 4 group were exceptionally low in questions of complexity Z = 3 and Z = 4, even less than expected, and so, there are significant differences between the X = 4 group and both X = 6 and X = 7 groups in questions of complexity Z = 3 and Z = 4.

Table 13 shows the comparisons which have been made, within each X-space group, between the questions of different Z-demand to find out the effect of Z-demand on the students' performance. Once again, the results in general tend to support the first year's results in that there is a clear effect of the questions' Z-demand on the students' performance when Z exceeds their measured X-space except the Z = 4 group.

Data Using the Mean Scores

Means and standard deviations are given in Table 14. Figure 8, shows the mean scores for all X-space groups. It will be noted that, in general, the mean scores for the X = 5, X = 6 and X = 7 groups are lower than the mean scores in the first year of testing. This may be entirely due to the fact that the students were not as well prepared.

The means were compared as before and the results of this comparison are shown in Table 15. The purpose of this was to try to find out the effect of X-space on the students' performance in the questions of different Z-demand using their mean scores.

The significance of the mean scores between the questions of different Z-demand, within each X-space group, can be seen in Table 16.

TABLE 14

MEANS AND STANDARD DEVIATIONS FOR EACH QUESTION FOR ALL STUDENT GROUPS (SECOND YEAR OF TESTING)

(Possible Score for Each Question is 10)

Questions \ Groups		X = 4		X = 5		X = 6		X = 7	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Q.1	Z = 3	3.5	3.7	6.1	4.2	6.7	3.0	6.3	4.4
Q.2	Z = 4	3.9	4.0	5.8	4.6	7.3	3.1	8.2	3.2
Q.3	Z = 5	2.8	4.1	6.7	3.9	6.8	3.5	6.7	4.3
Q.4	Z = 6	2.9	3.8	3.1	4.3	6.0	4.3	7.8	3.9
Q.5	Z = 7	1.9	2.9	2.2	3.1	4.2	4.1	7.8	3.9
Q.6	Z = 8	1.0	1.9	1.3	2.2	2.2	3.5	3.3	2.6

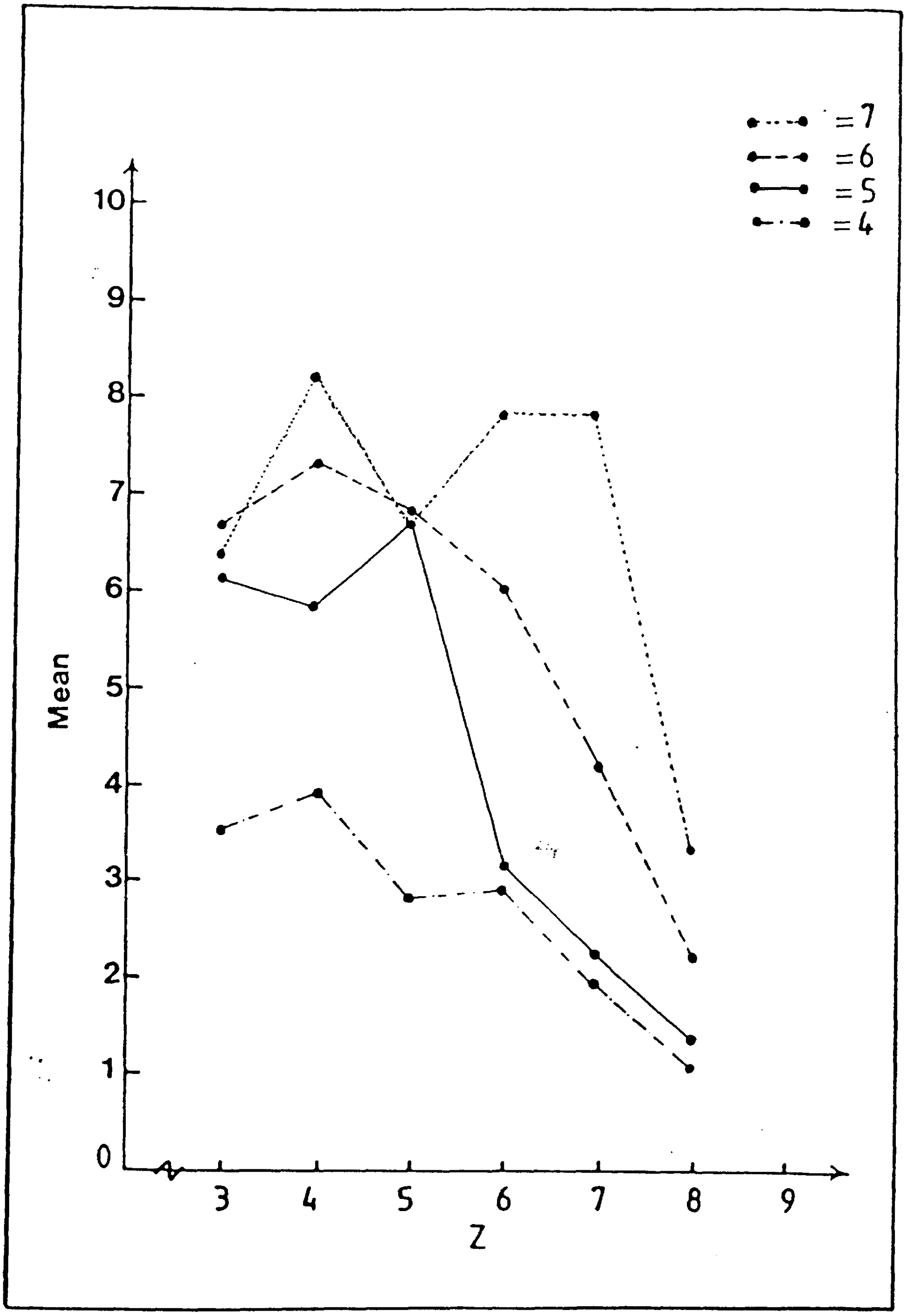


FIGURE 8. The Students' Mean Scores in the Mole Questions. (2nd year of testing)

TABLE 15

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS IN EACH QUESTION BETWEEN THE STUDENTS' GROUPS (SECOND YEAR OF TESTING)

Questions \ Groups Diff.		X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	S.*	S.*	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	N.S.	S.*	N.S.	N.S.	N.S.
Q.3	Z = 5	N.S.	S.*	S.*	N.S.	N.S.	N.S.
Q.4	Z = 6	N.S.	S.*	S.**	N.S.	S.**	N.S.
Q.5	Z = 7	N.S.	S.*	S.**	N.S.	S.**	S.**
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

TABLE 16

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND FOR EACH STUDENT GROUP (SECOND YEAR OF TESTING)

Group	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	S.*	-	-
	7	S.**	S.**	S.**	N.S.	-
	8	S.**	S.**	S.**	N.S.	N.S.
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.*	N.S.
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	S.**	S.**	S.**	S.**

** at 0.01 level

* at 0.05 level

16. There appear to have been no significant differences within the X = 4 group since all means are low. In addition to this the results do not confirm exactly the hypothesis that there is a significant difference in the students' performance in questions of complexity $Z \leqslant X$ and the questions of complexity $Z \geqslant X$. It could be argued that this is due to the small sample of X = 4 pupils and at the same time the students were not prepared for the test and, therefore, the results of the second year of testing are not exactly as in the first year of testing. There is an indication, however, particularly in X = 7 group, that there is a significant difference between the questions of lower and higher Z-demand.

In the the comparisons made in both the first and the second years of testing, the results confirm, in general, the hypothesis that there is a direct relationship between the students' holding-thinking space and their ability to solve questions of different Z-demand. The average of the F.V. from the two years of testing for each question are given in Table 17 and illustrated in Figure 9.

TABLE 17

OVERALL RESULTS FOR THE MOLE QUESTIONS FROM TWO YEARS OF TESTING (F.V.)

Questions / Groups	Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 4 (N = 17)	0.18	0.24	0.18	0.18	0.06	0.00
X = 5 (N = 65)	0.51	0.61	0.57	0.25	0.21	0.00
X = 6 (N =118)	0.53	0.65	0.58	0.6	0.36	0.08
X = 7 (N = 62)	0.66	0.83	0.67	0.76	0.75	0.04

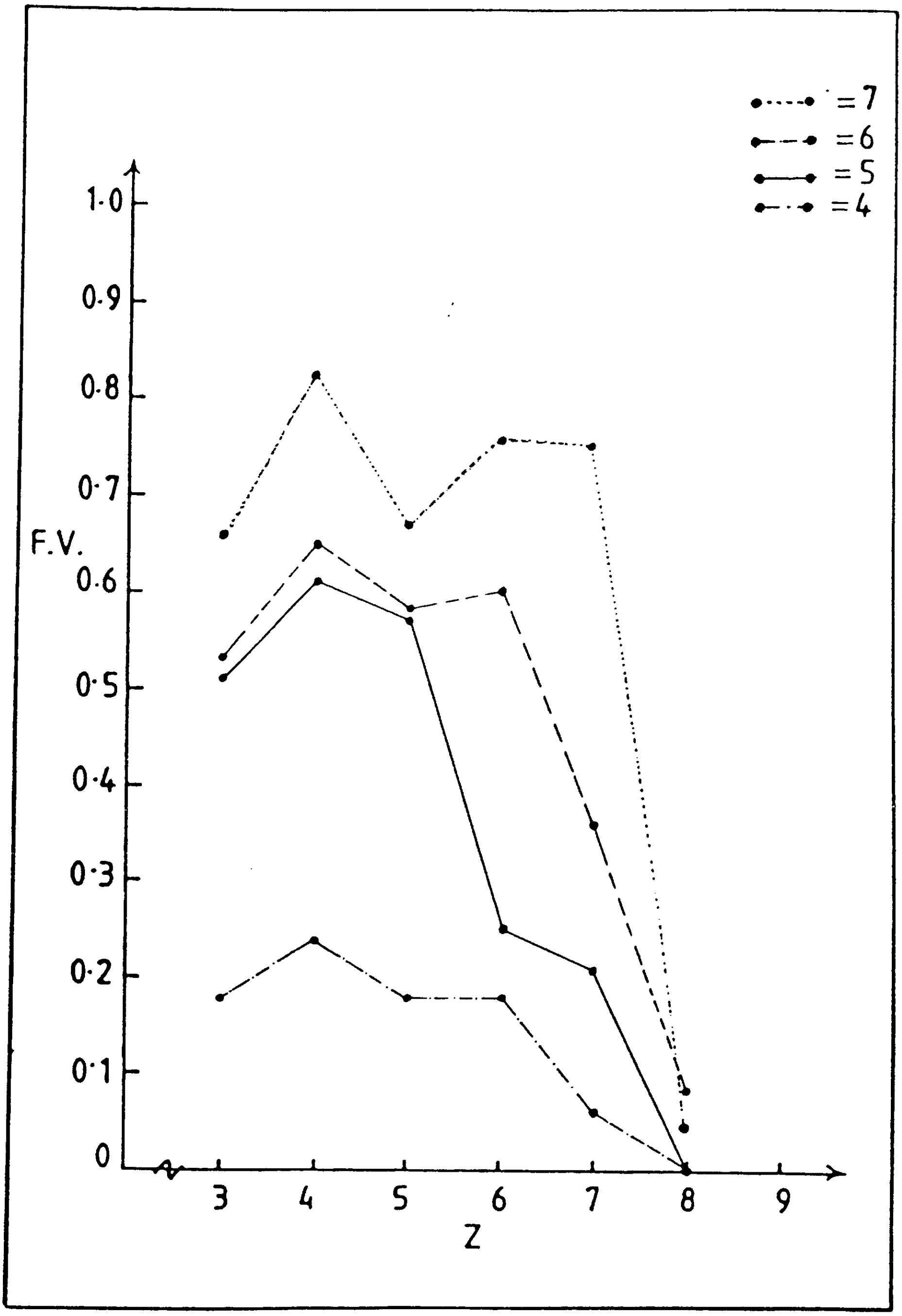


FIGURE 9. Overall Results for the Mole Questions from Two Years of Testing.

4.4.2 Testing Hypothesis 2

The O-Grade chemistry results in 1985-86 were in grades ranging from 1 to 6. The students' results in the O-Grade chemistry examination are given in Table 18, where the percentage of students with different X-space in each grade can be seen.

TABLE 18

STUDENTS' PERCENTAGE IN EACH GRADE OF THE O-GRADE CHEMISTRY EXAMINATION (SECOND YEAR OF TESTING)

Groups \ Grades	1	2	3	4+5+6*
X = 4 (N = 37)	14%	11%	24%	51%
X = 5 (N = 54)	20%	19%	26%	36%
X = 6 (N = 58)	36%	16%	24%	25%
X = 7 (N = 25)	72%	20%	8%	0%

* Grades 4, 5, 6 are fail grades

Of the X = 4 group, 14% were performing like the majority of the X = 7 group, but more than half of them failed. The composition, therefore, of H-Grade classes will be proportionally richer in students with X = 5, X = 6 and X = 7. The O-Grade examination has, in fact, "fractionated " /

TABLE 19

THE SIGNIFICANCE OF THE DIFFERENCES IN STUDENTS' PERCENTAGE IN EACH GRADE

Grades / Groups' Diff.	1	2	3	4+5+6
X = 4 and X = 5	N.S.	N.S.	N.S.	N.S.
X = 6	S.*	N.S.	N.S.	S.**
X = 7	S.**	N.S.	N.S.	S.**
X = 5 and X = 6	S.**	N.S.	N.S.	S.*
X = 7	S.**	N.S.	N.S.	S.**
X = 6 and X = 7	S.**	N.S.	N.S.	S.*

** at 0.01 level
* at 0.05 level

"fractionated out" those of X = 4.

At the other extreme, 72% of the X = 7 group were in grade 1 and none of them failed. Both X = 5 and X = 6 groups were in between the X = 4 and X = 7 groups. Table 19, shows the significance of the differences of the percentages between all groups in each grade.

The results of the second year of testing tend to confirm the results from the first year of testing. Both results tend to support the hypothesis that there is a direct relationship between the students' holding-thinking space X, and their attainment in the O-Grade chemistry examination.

4.5 Discussion

1. The following patterns emerge from the results of testing hypotheses stated earlier in this Chapter.

   (a) In all cases, the X = 7 curves represent better all-over performance than the X = 6, and both have better all-over performance than the X = 5 and X = 4.

   (b) There is, in general, a significant fall in students' performance, within all groups of different X-space, when Z exceeds their measured X-space, but not a fall to 0% immediately. In addition, there is a gradual fall off in the performance of X = 5 students, whereas the X = 6 students fall away more rapidly and X = 7 students show the sharpest fall of all.

   (c) When $Z \leqslant X$, there is a good performance, but not as good as 100%. Within this high performance area, there are fluctuations, but an easier question for one group is also easier for all, i.e. the graphs are usually parallel.

   (d) The X = 4 students have access to fewer questions in the examination. They have a lower potential maximum score than those for X = 5, X = 6 or X = 7 students and more /

more than half of them failed in the O-Grade chemistry examination.

(e) Despite the fact that the X = 4 students' performance is very low, some of them, as well as some of the X = 5 students, were performing as well as those of X = 7. Similarly, some of the X = 6 students were operating well beyond their X-space. This may have been achieved by using strategies and having practice to minimize the load on their holding-thinking space.

(f) There is strong evidence that the questions' Z-demand affects the students' performance as soon as Z exceeds their measured X-space. The students' holding-thinking space limits their ability to carry out the problem-solving tasks. This evidence indicated that the relationship between the tasks' complexity and the students' X-space is one of the most important factors influencing their ability to solve a problem, although the experimental curves do not conform exactly the theoretical curves.

2. It is worth emphasising that when $Z \leq X$, we have a <u>necessary</u> but not <u>sufficient</u> condition for success. The following are possible factors underlying the above patterns.

(a) Students' tendency, attitude or confidence to use their full measured X-space in solving problems in a particular area could control their ability to solve them regardless of their X-space.

(b) The degree of the students' perceptual field may affect their ability to deal with relevant data only and ignore the irrelevant. It could be argued that, if the students have too much information, they will have difficulty in selecting the relevant information from the irrelevant within their limited X-space and this could lead to over-load.

(c) /

(c) Failure to recall and apply the required information, or errors in arithmetic, are some of the reasons which cause the failure to solve chemical problems.[137] It seems possible that students' inability to retrieve items of information required for a particular question from their long term memory is a result of the way in which the information storage processes took place. According to Ausubel, if the learning materials are meaningfully acquired and stored alongside relevant existing concepts or propositions in the learner's cognitive structure, the learner will find it easy to retrieve or to remember.

(d) The failure to solve chemistry questions may also be due to the students' inability to simplify the question by breaking it into parts to reduce the load on their X-space, or by organizing the thinking before doing any calculation. The students may lack practice and experience which lead to familiarity with the kind of question and hence, more effort is needed to extract the strategy and solve the question.

It was, therefore, decided to concentrate further investigation on helping students to minimize the load on their X-space. This investigation is described in the next chapter.

CHAPTER 5

On the basis of the model, it should be possible to predict teaching and testing methods which would result in an improvement of students' performance.

The model suggests that anything which reduces the demand (Z) of a problem situation and brings it within the size of the capacity (X) is likely to bring about an improvement in performance.

Testing:

(i) If an opportunity was provided within the test system to make the students separate the planning stage from the calculation stage, there would be less chance of overloading X, and so improvement would be anticipated.

(ii) If the more complex questions (with demand $Z \geqslant 7$) were sub-divided so that each sub-problem had a demand less than X, improvement in performance should result.

Teaching:

If general problem solving strategies were to become an integral part of the teaching-learning process, improvement in performance would be expected.

1. There will be a significant improvement in performance in favour of students who are made to do their planning before doing any calculation, when compared with those who are left to do both simultaneously.

2. There will be a significant improvement in performance in favour of students who are given sub-divided questions when compared with those who are given the same questions undivided.

3. There will be significant improvement in performance in favour of students who have been taught problem solving strategies throughout and those who have not.

The methods adopted to provide the experimental conditions for testing these hypotheses are set out below.

5.1 /

5.1 Procedures

5.1.1 Method of Organisation Using Grids

The potential of using information grids for testing chemistry in a variety of ways has been explored.[138] What was required here were grids to help students to organize their thinking by weighing up the contents of each box in response to a question, deciding which box (boxes) constituted an answer and writing these steps, then working out the numerical answer according to the steps selected.

Johnstone[92] has pointed out that the general principle is to use the smallest grid size appropriate to the material being examined. The grid's size in this study was 9 boxes (3 x 3). In this method, what the student is being asked to do is to use the pieces of information offered in a random array in the grid to plan his answer to each question. He does this by selecting the boxes which, he thinks, are appropriate to his answer and writing them in sequence. The answer may be in one box or number of boxes. How the student selects the appropriate boxes and their order will depend upon his understanding and his ability to select relevant from irrelevant material.

For example, in a question which looks like this:

> How many moles of hydrogen ions are there in 200 mL of 2 M sulphuric acid (H_2SO_4)?

/

From the boxes below choose what you plan to do to answer the question. Arrange the box numbers in the order you plan to use them. Then, using this as a guide, do the calculation.

Find number of (H^+) in the formula. (1)	The G.F.M. of a compound is equal to 1 mole of the compound (2)	Work out number of (OH^-) in the formula (3)
The molarity is equal to number of the mole per litre (4)	Change mL into litres (5)	Write a correct balanced equation (6)
Convert moles of reactants into grams of reactants (7)	Relate moles of on reactant to moles of another reactant (8)	Number of moles of the ions is equal to M x $V_{(L)}$ x No. of ions in formula (9)

From the grid, a student would need:

BOX (1): Find number of (H^+) in the formula

BOX (5): Change mL into litres

BOX (9): Number of moles of ions is equal to M x $V_{(L)}$ x No. of ions in formula

Therefore, his order would be: 1, 5, 9. Having done this, his numerical answer would be:

From BOX (2): 2 H^+

From BOX (5): 200 mL = 0.2 L

From BOX (9): 2 x 0.2 x 2 = 0.8 moles of H^+

For another student, the answer would be one box only, box 9, since he can chunk the first two boxes (1 and 5).

On the basis of the teachers' strategies collected earlier for the mole concept questions (Chapter 4), all steps required to solve a question were offered in the grid's boxes. There was a grid for each of the six questions, but the boxes were quite similar (Appendix 7). In marking the questions, the researcher considered only the students who had matched between the number of boxes they selected and their numerical answers.

5.1.2 Reducing the Load by Sub-dividing the Question

The second suggested method for reducing the information load on the students' X-space is to help them to deal with only a small number of thought steps at a time. It has been shown(51) that some students are unable to solve a question of high information load although they have all the pre-requisite knowledge and skills to solve it. But they are able to solve all the thought steps (in terms of sub-questions) separately.

Within the context of the working model, the aim of this method is to identify whether the students could solve a question of Z-demand greater than their measured X-space by dividing the question into a series of questions, each of them having a complexity of $Z \leq X$. It should be noted that a question of high Z-demand is testing both X (the holding-thinking space) and Y (strategies).

To test this method, the researcher divided two of the mole questions of complexity $Z = 7$ and $Z = 8$ into three sub-questions. Each of these sub-questions has a complexity $Z < 5$ (Appendix 8).

5.1.3 Reducing the Load by Teaching the Students Strategies for Problem Solving

The implication of the working model explained in Chapter 3, in terms of writing textbooks and learning materials and also in the method of assessment, is clear: "any piece of learning must be given to the learner in such a form as to keep the demand of the task (Z) below /

below the holding-thinking space of the learner (X)". As has been stated above, the question of high Z-demand is testing both X and Y. If the Y (strategies) have not been taught to the students, the question of high demand may not be validly testing chemistry.

The researcher took into consideration the following points in the preparation of written strategies for solving stoichiometric and neutralization calculations.

1. Organized knowledge has to be provided for the students. The information should be presented in small portions and a summary should be provided to help students to grasp this information in smaller and meaningful "chunks" and to see meaningful patterns.

2. The information density per page should not exceed 3 or 4 ideas to keep the demand of the lesson (Z) below the lowest X-space. Therefore, the materials should be made suitable for the least able students. At the same time, simple language should be used to reduce the load on the students' X-space.

3. The total amount of the printed materials should be kept to a minimum for two reasons. The first is to reduce the burden on the students' X-space, and the second is to make it acceptable to teachers.

All the above points were considered, and three Teaching Units of 20 pages were prepared (Appendix 9).

5.1.4 The Experimental Design

In order to test the hypotheses stated earlier in this chapter, the researcher followed the experimental design set out in Table 20.

TABLE /

TABLE 20

THE EXPERIMENTAL DESIGN

Groups	Treatments		Group's Comparison	Hypothesis to be tested
	Teaching	Shape of the Test		
G1 N = 116	Normal	Test with grids	With G4	1
G2 N = 67	Normal	Test with sub-divided questions	With G4	2
G3 N = 79	New Materials	Raw test	With G4	3
G4 N = 262	Normal	Raw test	-	-

It was assumed that a fair comparison could be made between the three groups: G1, G2 and G3, against G4 as control group. That assumption was based on the fact that all the groups were drawn from the same schools, therefore, both the control group and the experimental group were affected by the same kinds of teaching from the same teachers in each school.

5.2 Data Analysis

The administration, marking and scoring the tests was done in exactly the same manner as described in Chapter 4. In addition to this, the hypotheses presented earlier in this chapter were also tested statistically by the same method employed in Chapter 4.

5.3 The Results

5.3.1 Data from Group 1

Tables Numbers 21 through 26, as well as Figures 10 and 11, show the results from Group 1. The students in this group were given the chemistry test (the same six questions on mole calculations as in Chapter 4) but with grids. Table 21 shows the F.V. of these questions attempted by the students of different holding-thinking space. The means and the standard deviations are given in Table 22. From Figures 10 and 11, where the F.V. and the mean scores of Group 1 can be seen, the $X = 7$ students are better in all over performance than $X = 6$ and both are better than $X = 5$. Once again, the $X = 4$ students' performance is still quite low. In addition to this, when Z exceeds X in all X-space groups, there is a sharp fall in performance. When $Z \leqslant X$, the students' performance still does not reach 100%

TABLE /

TABLE 21

THE F.V. FOR THE MOLE QUESTIONS ATTEMPTED BY THE STUDENTS IN GROUP 1

X-Space Groups \ Questions		Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 4	(N = 7)	0.57	0.43	0.30	0.14	0.14	0.00
X = 5	(N = 29)	0.66	0.76	0.76	0.52	0.31	0.03
X = 6	(N = 53)	0.72	0.76	0.70	0.68	0.38	0.06
X = 7	(N = 27)	0.78	0.82	0.82	0.85	0.70	0.11

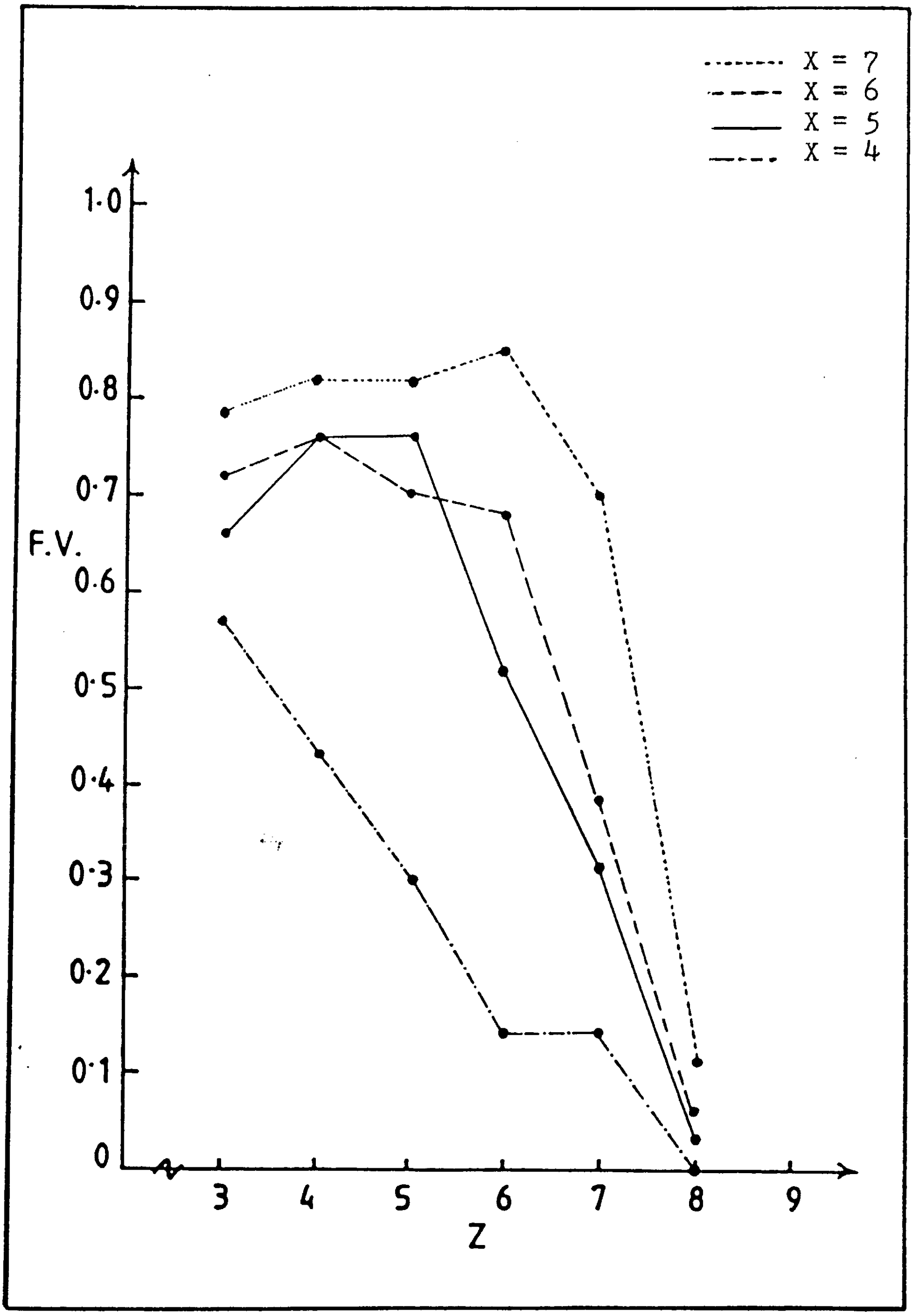


FIGURE 10. Results from Group 1 (F.V.)
(Test with Grids)

TABLE 22

MEANS AND STANDARD DEVIATIONS FOR THE STUDENTS IN GROUP 1

(Possible Score for each Question is 10)

X-space Groups \ Questions		Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 4 :	Means	5.4	4.9	4.7	3.6	3.8	1.1
	S.D.	4.8	4.7	4.3	4.1	4.6	2.2
X = 5 :	Means	7.0	8.3	8.0	5.7	4.1	2.2
	S.D.	4.3	3.6	3.9	4.8	4.4	2.4
X = 6 :	Means	7.4	8.7	8.0	7.7	5.5	2.5
	S.D.	4.3	2.6	3.3	3.7	4.0	3.1
X = 7 :	Means	7.8	8.5	8.8	8.6	8.2	3.8
	S.D.	4.1	4.5	2.8	3.4	4.0	3.2

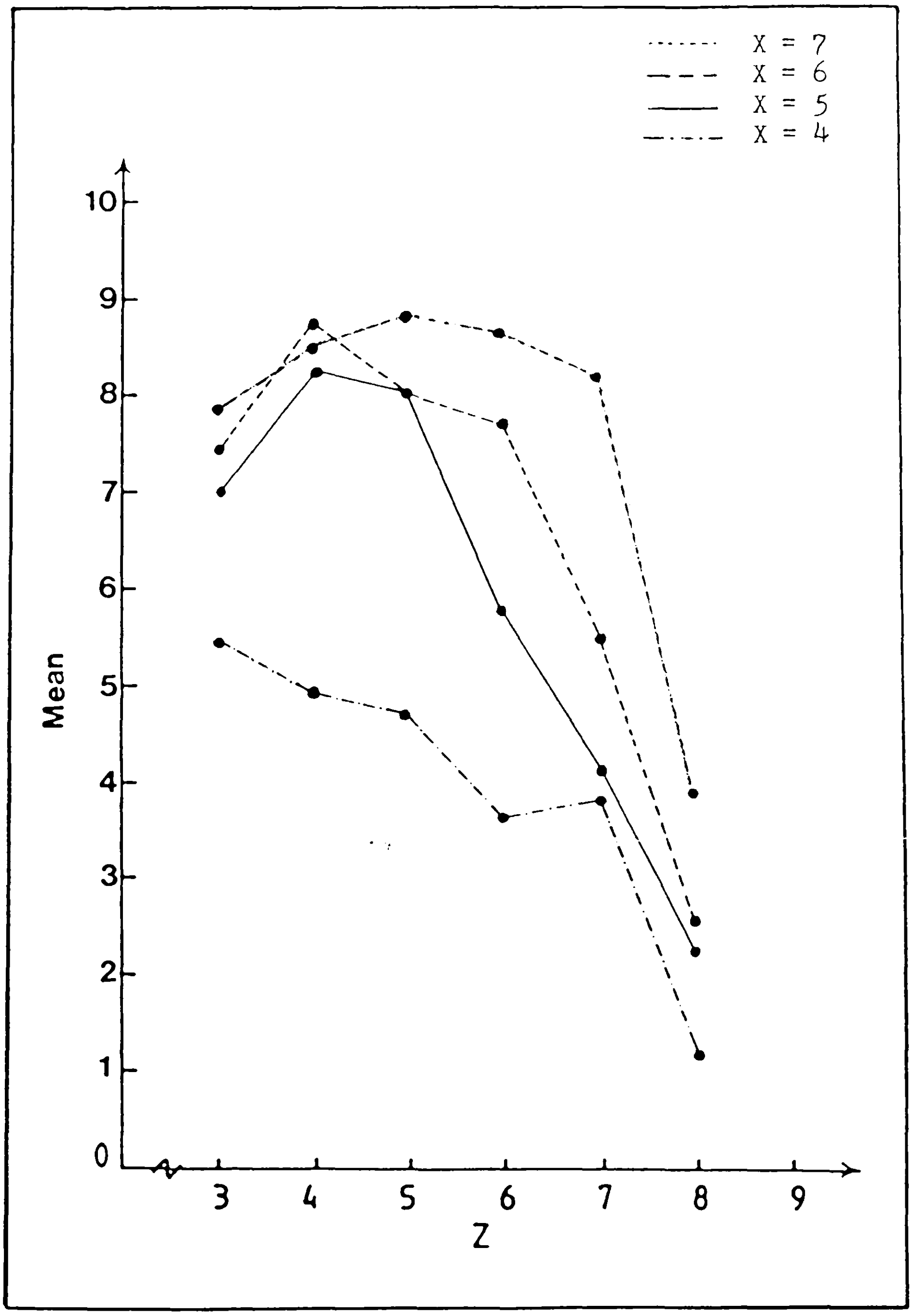


FIGURE 11. Results from Group 1 (Means)
(Test with Grids)

TABLE 23

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENT SUB-GROUPS

(Group 1)

Questions \ Sub-Groups Diff.		X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.2	Z = 4	S.*	S.*	S.*	N.S.	N.S.	N.S.
Q.3	Z = 5	S.*	S.*	S.**	N.S.	N.S.	N.S.
Q.4	Z = 6	S.*	S.**	S.**	N.S.	S.*	N.S.
Q.5	Z = 7	N.S.	N.S.	S.**	N.S.	S.**	S.**
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

TABLE 24

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS FOR EACH QUESTION BETWEEN THE STUDENT SUB-GROUPS

(Group 1)

Questions	Sub-Groups Diff.	X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	S.*	S.*	N.S.	N.S.	N.S.
Q.3	Z = 5	S.*	S.*	S.**	N.S.	N.S.	N.S.
Q.4	Z = 6	S.*	S.**	S.**	N.S.	S.*	N.S.
Q.5	Z = 7	N.S.	N.S.	S.**	N.S.	S.**	S.**
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

The relationship between the questions' Z-demand and the students' holding-thinking space in the light of using grids was examined. To find the significance of the differences between and within the four sub-groups of different X-space in each question, four comparisons were made in exactly the same manner as in Chapter 4. Tables Numbers 23 through 26 show the results of these comparisons.

Tables 23 and 24 show the significance of the differences in the F.V. and the means between the four sub-groups of different X-space in all questions. These comparisons have been made to find out whether there is an effect of the X-space on students' performance in the questions with grids.

The results indicated that there was no significant difference between the four sub-groups in the questions of Z equal to the lowest X (Question 1) or greater than the highest X (Question 8). In addition to this, there is no significant difference between the two sub-groups of X = 5 and X = 6 in all the questions. On the other hand, there is a significant difference between each pair of sub-groups when Z exceeds the lowest X except in the case of X = 4 and X = 5 sub-groups.

Tables 25 and 26 show the significance of the differences in the students' performance within each sub-group in all questions. These two comparisons, in terms of the F.V. and the means, have been made to find out whether there is an effect of the questions' complexity (Z-demand) on the students' performance in the questions with grids. Once again, the results indicate that in all sub-groups of different X-space, there are significant differences, in general, between the questions of demand lower or higher than the relevant X, except in the case of X = 4 sub-group since the only differences between Z = 8 and Z = 3, 4 and 5 were significant.

Conclusion

Taking into account the sample size and the employment of the grids as a method of helping students to reduce the information load on their X-space, the relationship between the students' holding-thinking space and their ability to solve questions of different complexity /

TABLE 25

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH OF THE STUDENT SUB-GROUPS BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND

(Group 1)

Sub-Groups	Z / Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	S.*	N.S.	N.S.	-	-
	7	S.*	N.S.	N.S.	N.S.	-
	8	S.**	S.*	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	S.*	S.*	-	-
	7	S.**	S.**	S.**	N.S.	-
	8	S.**	S.**	S.**	S.**	S.*
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	S.**	S.**	S.**	S.**	-
	8	S.**	S.**	S.**	S.**	S.**
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**

** at 0.01 level

* at 0.05 level

TABLE 26

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS, FOR EACH STUDENT SUB-GROUPS, BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND

(Group 1)

Sub-Groups	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	S.*	S.*	-	-
	7	S.*	S.**	S.**	N.S.	-
	8	S.**	S.**	S.**	S.*	N.S.
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	S.**	S.**	S.**	-
	8	S.*	S.**	S.**	S.**	S.**
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**

** at 0.01 level

* at 0.05 level

complexity still persisted. To find out whether there was an improvement in the students' performance, further comparisons were made between the performance of the students in this group and the performance of the students in Group 4 (the control group).

5.3.2 Testing Hypothesis 1

Comparison Between Group 1 (Test with Grids) and Group 4 (Raw Test)

The hypothesis: "There will be a significant improvement in performance in favour of students who are made to do their planning before doing the calculation, when compared with students who do both simultaneously", was tested in all sub-groups of different X-space by comparing each sub-group in Group 1 and Group 4 together.

Tables 27 and 28, as well as Figures 12 through 19, show the results of the comparisons of the F.V. differences and the students' mean scores differences in all questions for all sub-groups of different X-space.

In general, the F.V. and the mean scores in Group 1 are higher than Group 4 but the results from Tables 8 and 9 indicate that there is no significant difference in the students' performance between Group 1 and Group 4 in individual question for sub-groups of different X-space. All the trends, however, are in favour of the grid students and this itself is significant. It could be argued that the students were dealing with this type of questions for the first time and they, therefore, were unfamiliar with using the grids. In addition to this, the students may prefer their own way of solving a question, and when they have been forced to use the grid, they found this harder.

It /

TABLE 27

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN GROUP 1 AND GROUP 4

Questions \ Sub-Groups		X = 4	X = 5	X = 6	X = 7
Q.1	Z = 3	N.S.	N.S.	S.*	N.S.
Q.2	Z = 4	N.S.	N.S.	N.S.	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.	N.S.
Q.4	Z = 6	N.S.	S.*	N.S.	N.S.
Q.5	Z = 7	N.S.	N.S.	N.S.	N.S.
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.

* at 0.05 level

TABLE 28

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS FOR EACH QUESTION BETWEEN GROUP 1 AND GROUP 4

Questions \ Sub-Groups		X = 4	X = 5	X = 6	X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	N.S.	N.S.	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.	N.S.
Q.4	Z = 6	N.S.	N.S.	N.S.	N.S.
Q.5	Z = 7	N.S.	N.S.	N.S.	N.S.
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.

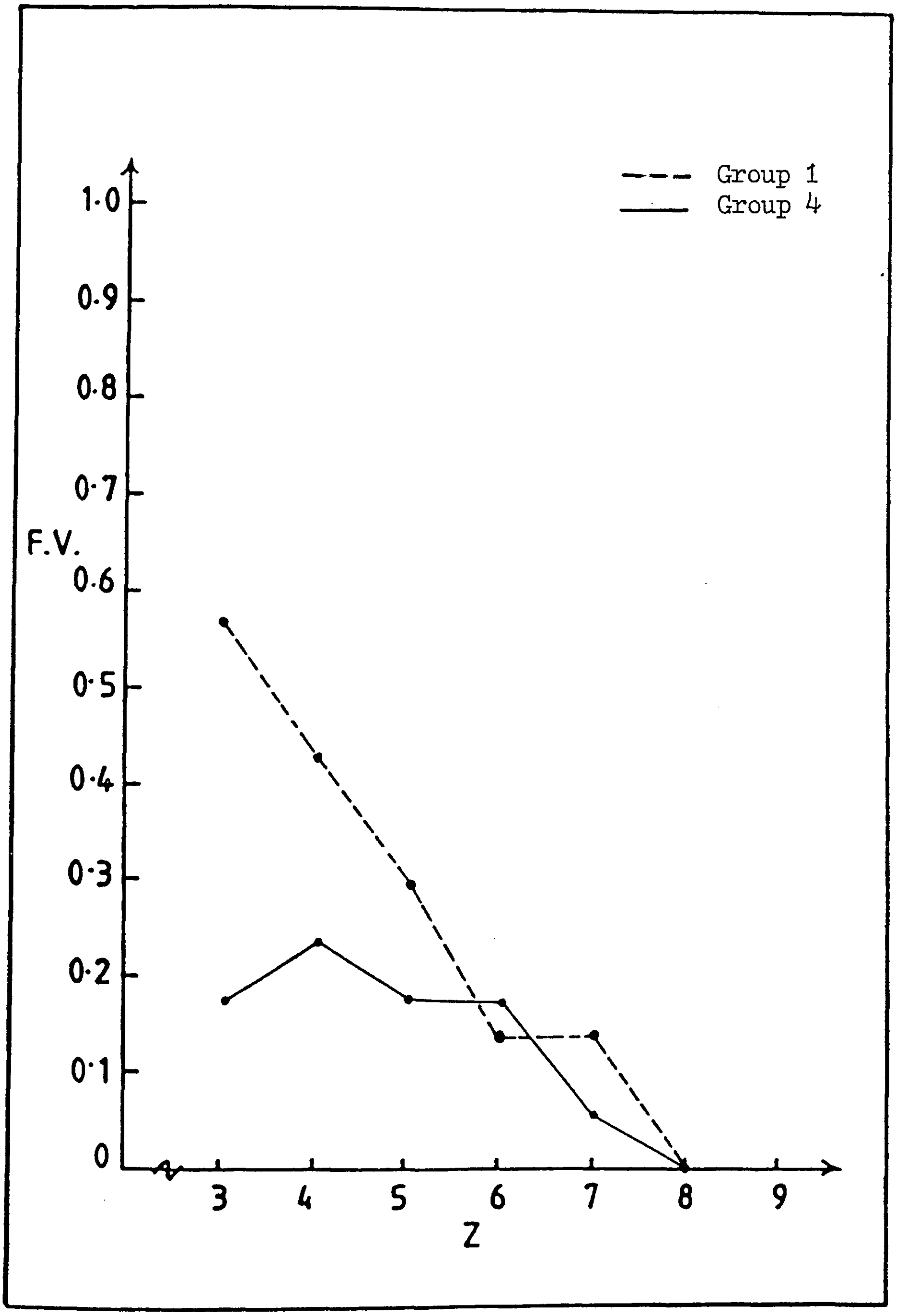


FIGURE 12. Comparison of the F.V. between Group 1 and Group 4.
(Sub-group X = 4)

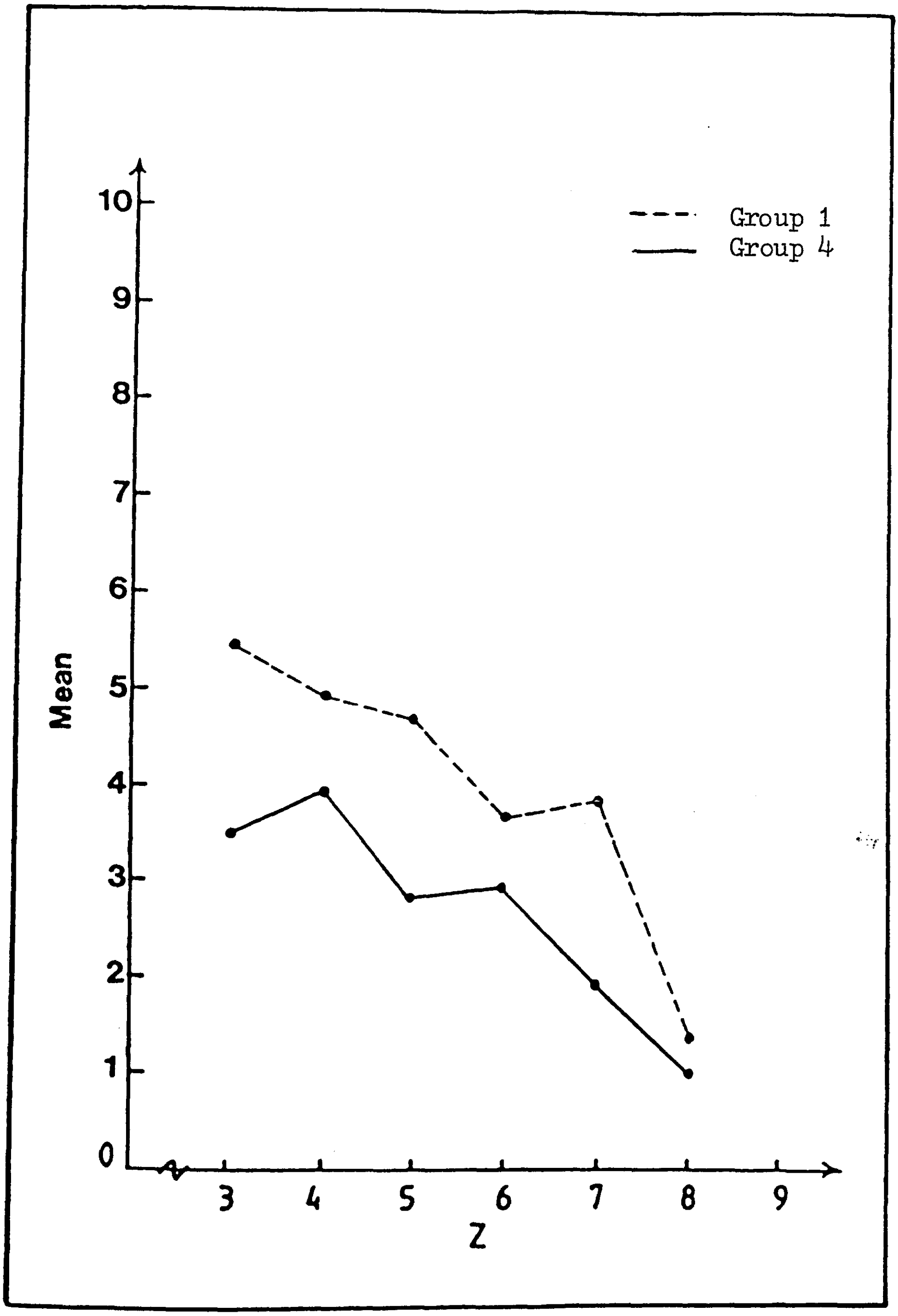


FIGURE 13. Comparison of the Means between Group 1 and Group 4.
(Sub-group X = 4)

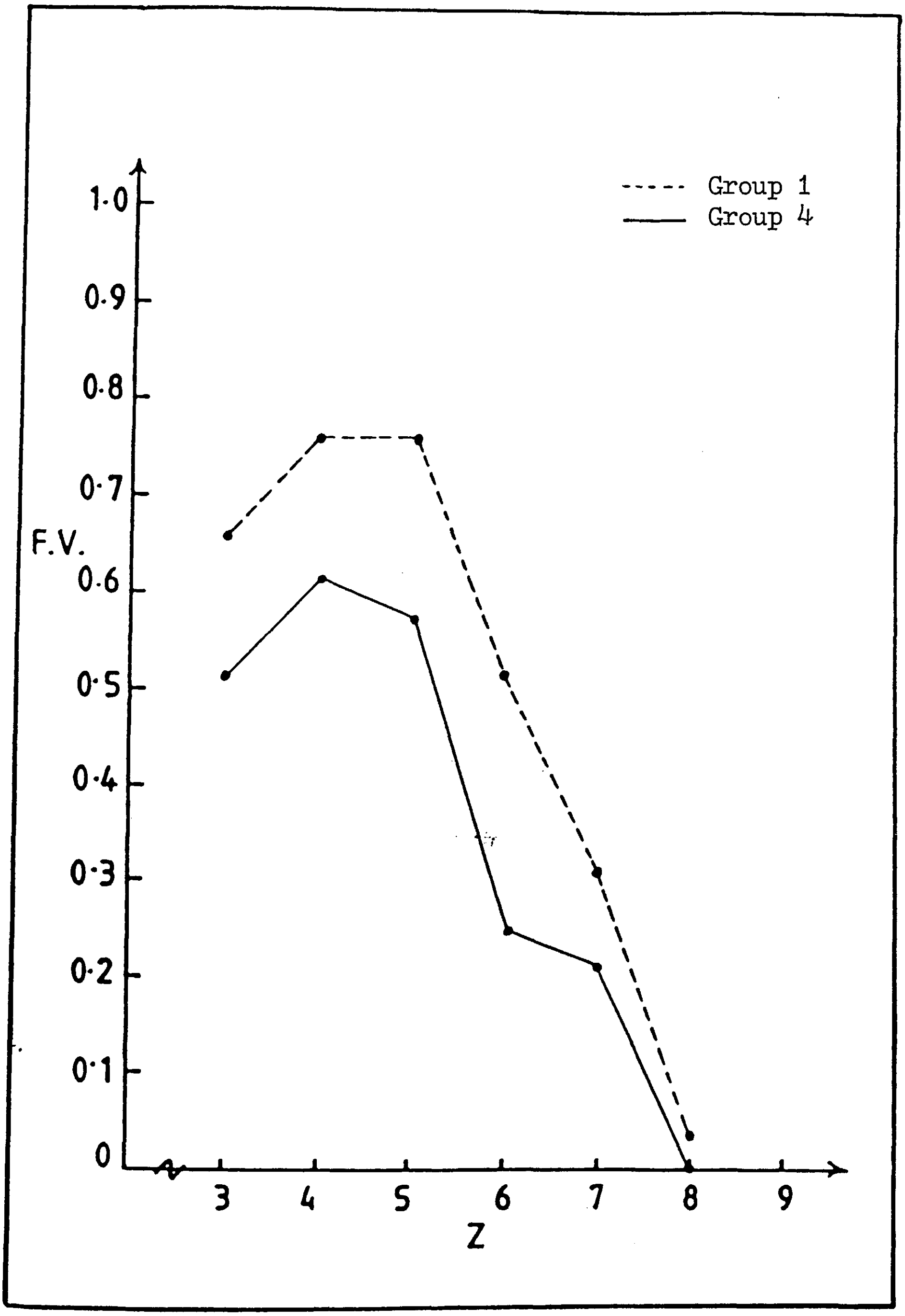


FIGURE 14. Comparison in the F.V. between Group 1 and Group 4.
(Sub-group X = 5)

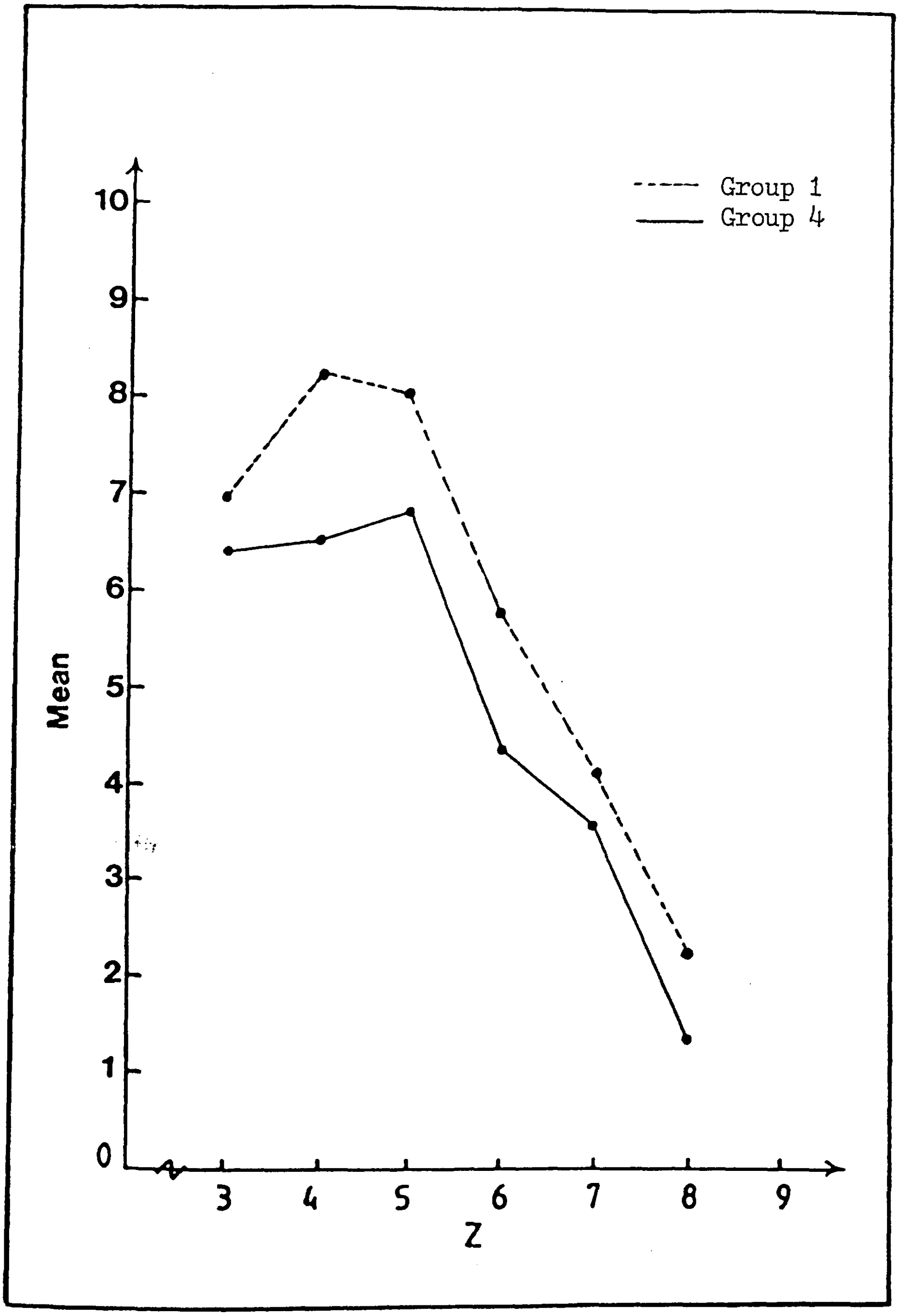


FIGURE 15. Comparison of the Means between Group 1 and Group 4.

(Sub-group X = 5)

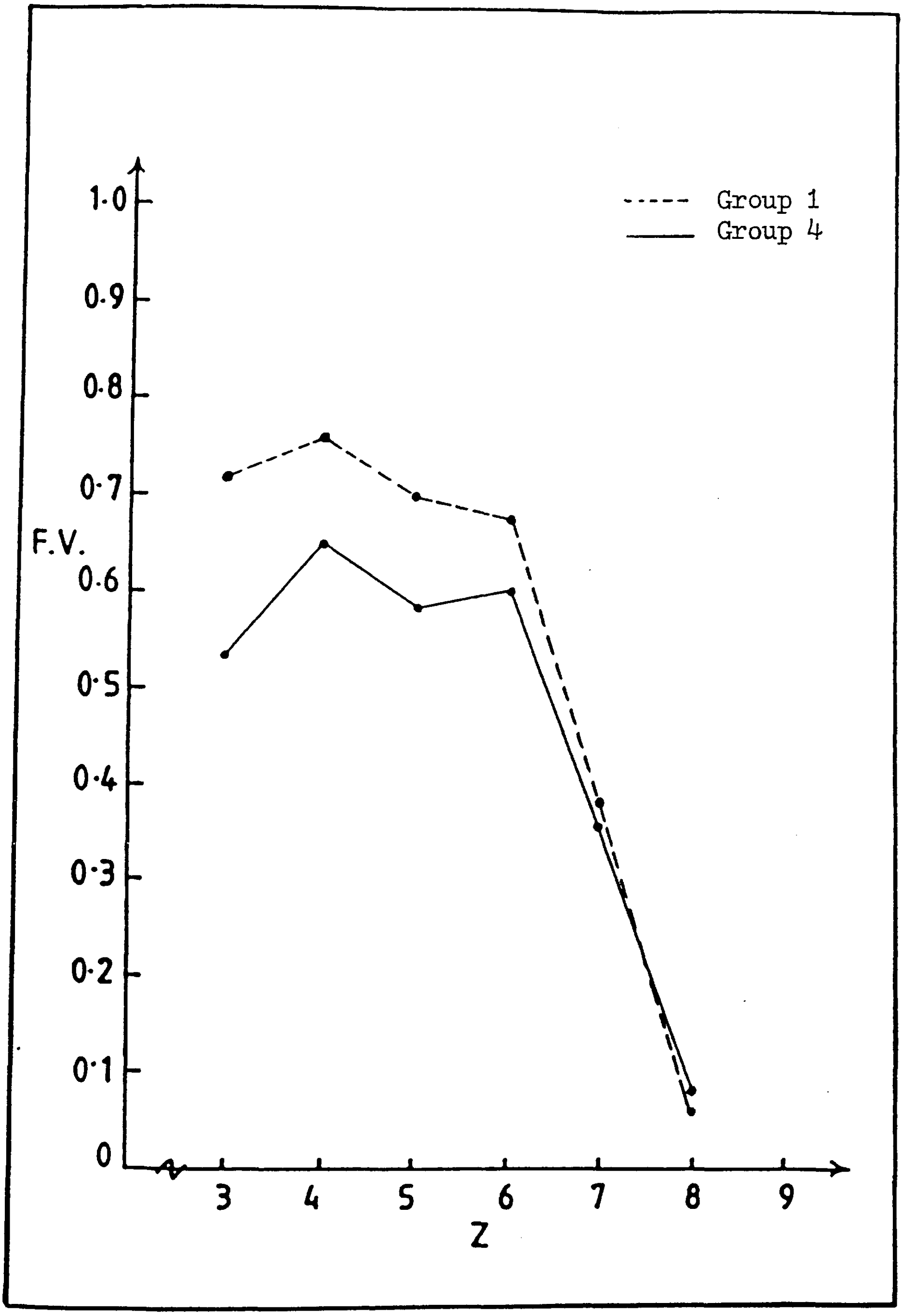


FIGURE 16. Comparison of the F.V. between Group 1 and Group 2.
(Sub-group X = 6)

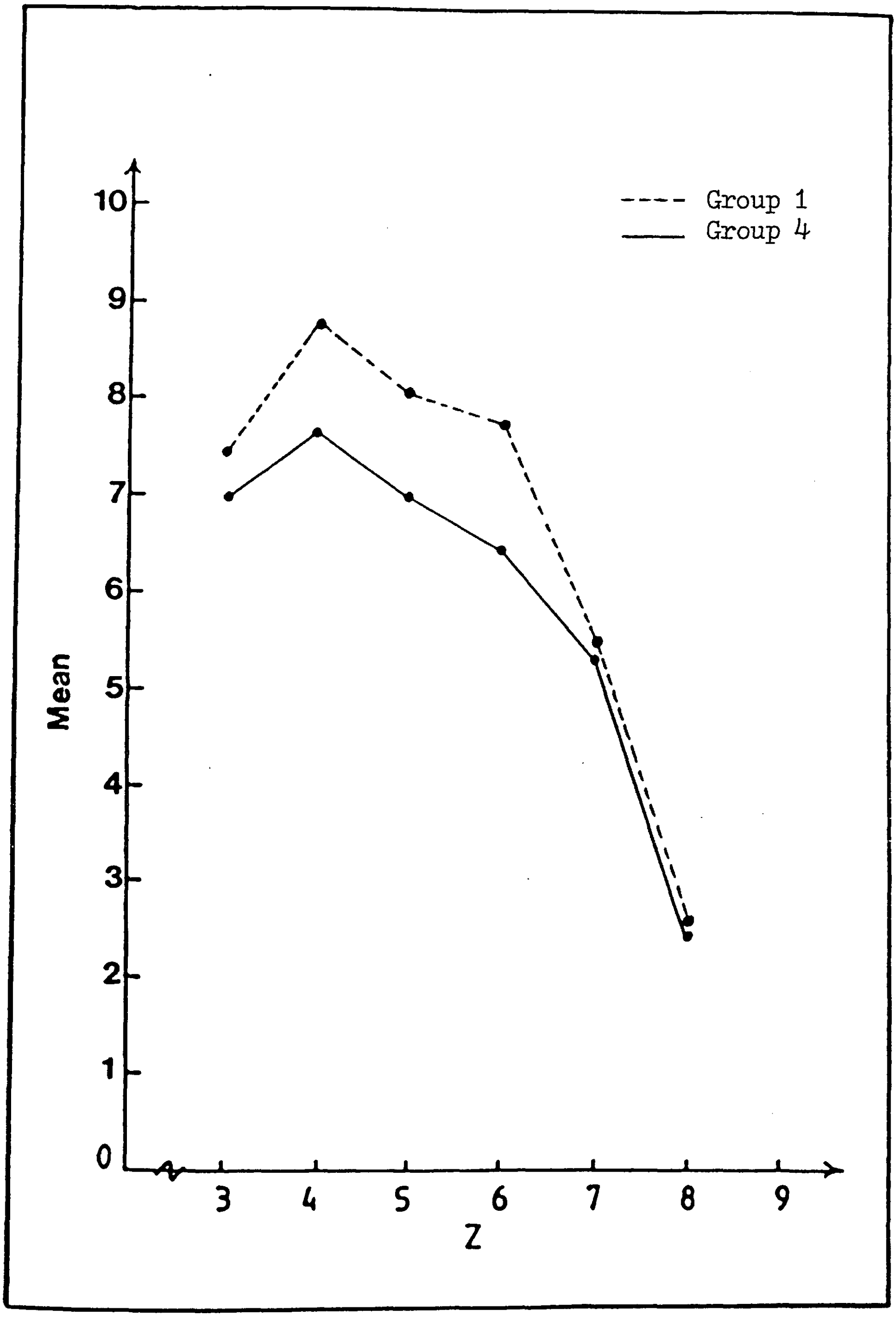


FIGURE 17. Comparison of the Means between Group 1 and Group 4.
(Sub-group X = 6)

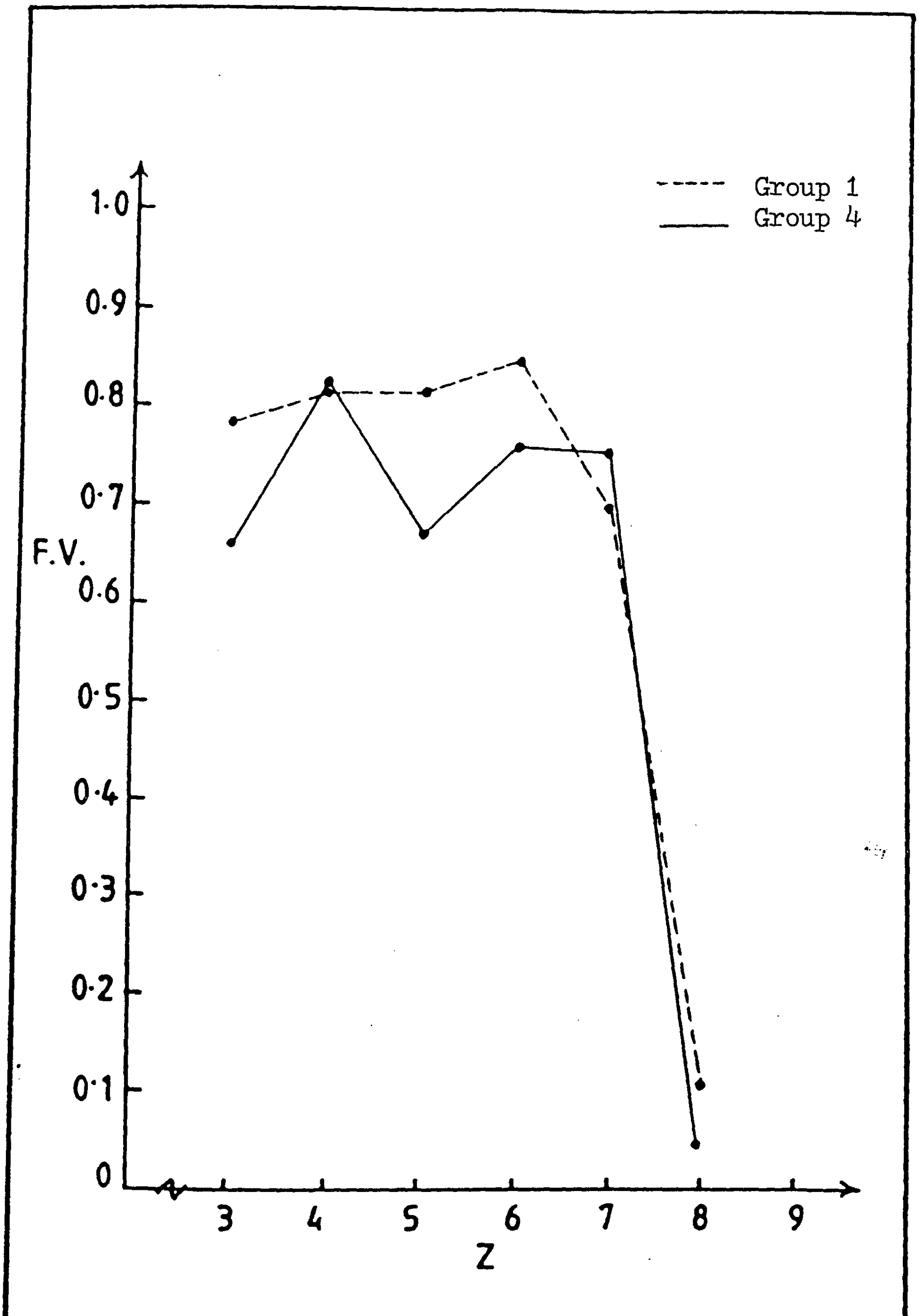


FIGURE 18. Comparison of the F.V. between Group 1 and Group 4.

(Sub-group X = 7)

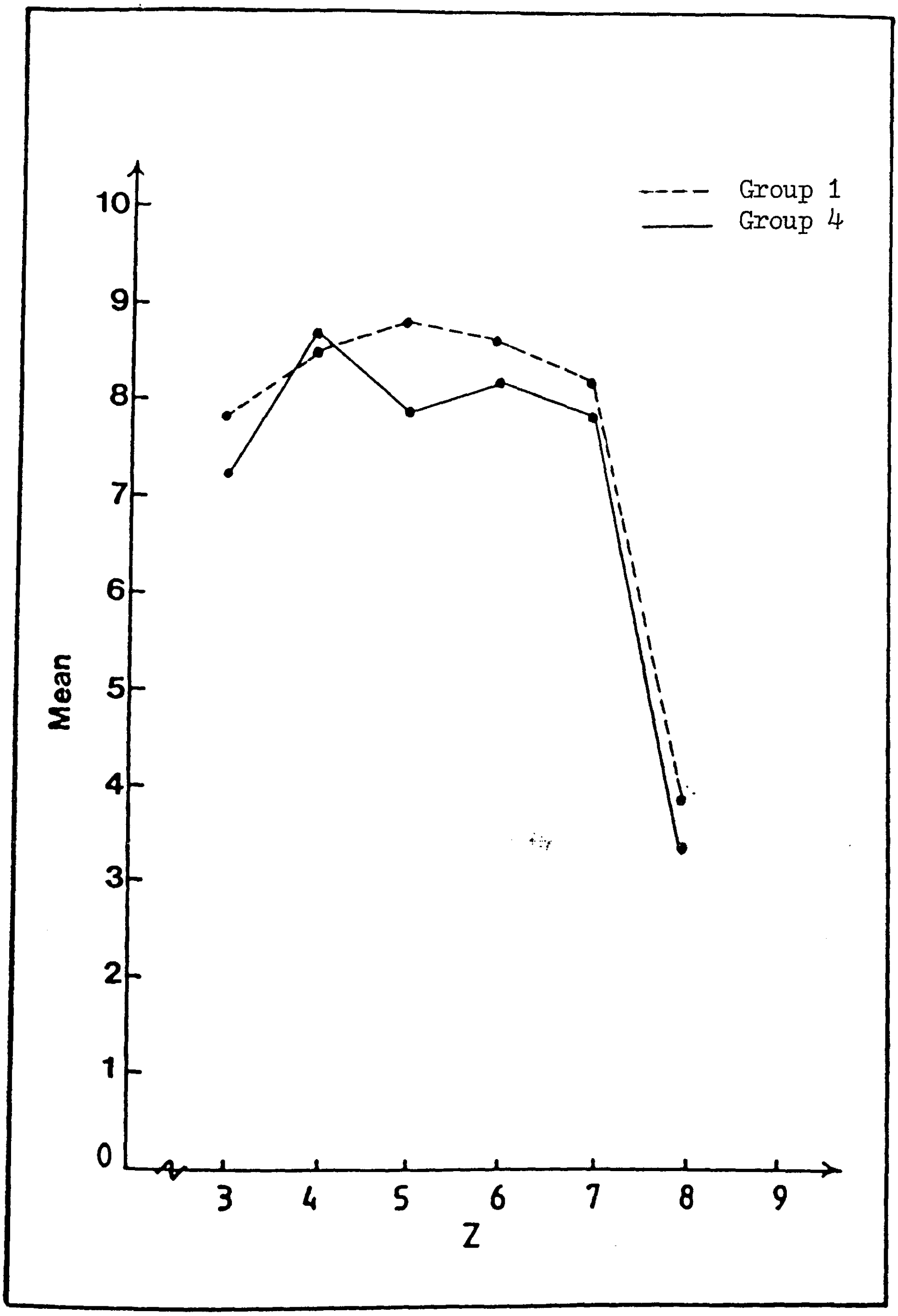


FIGURE 19. Comparison of the Means between Group 1 and Group 4.
(Sub-group X = 7)

It could be argued also that a high degree of independence of perception of the information is needed in this type of question. They will not be easy for students who have difficulty in picking out relevant from irrelevant information. It was found that some students selected only one box to solve a question (Question 1), others selected three boxes in the same question. Figures 20(A) through 20(D) show actual examples of pupils' answers. Nevertheless, since the means and the F.V. for the students in Group 1 (test with grids) are consistently higher than those in the control group (raw test) and all are in the same direction, it has to be accepted that the differences cannot be by chance. It would seem to be useful, therefore, to encourage students to organize their thinking before doing the calculation as a routine method.

Conclusion

In individual questions there appears to have been no significant difference between Group 1 and Group 4, but taking all the questions together, these results show evidence consistent with hypothesis 1.

5.3.3 Data from Group 2

Tables Numbers 29 through 34, as well as Figures 21 and 22, show the results from Group 2. The students in this group were given the chemistry test on the mole calculations as in Chapter 4, but two questions, of $Z = 7$ and $Z = 8$, were broken down into three sub-questions. Each of these sub-questions has a demand of $Z < 5$. It should be noted that these three sub-questions have been taken together and scored as one question. Table 10 shows the F.V. of these six questions attempted by the students of different X-space. The means and the standard deviations can be seen in Table 29.

How many moles of hydrogen ions (H^+) are there in 200 ml. of 2M sulphuric acid (H_2SO_4)?

find number of (H^+) in the formula. (1)	The G.F.M. of a compound is equal to 1 mole of the compound. (2)	work out number of (OH^-) in the formula. (3)
the molarity is equal to number of moles per litre. (4)	change ml. ⟶ litre. (5)	write a correct balanced equation. (6)
convert moles of reactant ⟶ grams of reactant. (7)	relate moles of one reactant ⟶ moles of another reactant. (8)	Number of moles of the ion is equal to MxVx No. of ion in formula. (9)

* The order

1	5	9					

* Numerical Answer:-

step (1) No. of $H^+ = 2$

" (5) 200ml ⟹ 0·2l

" (9) No. of moles = MxVx No. of ion in formula.

= 2 x 0·2 x 2

= 0·8 moles

FIGURE 20 (A). Actual Example of Pupils' Answers

What weight of potassium hydroxide is contained in 0.2L. of 4M potassium hydroxide solution?
(At. masses: K = 39, O = 16, H = 1)

write the formula of potassium hydroxide. (1)	find number of $(oH)^-$ in the formula. (2)	convert moles of potassium hydroxide → grams. (3)
find number of moles in solution. (4)	The molarity is equal to number of moles per litre. (5)	find G.F.M. of potassium hydroxide. (6)
convert grams of potassium hydroxide → moles. (7)	Change unit: Litre → ml. (8)	find number of (H^+) in the solution. (9)

* The order

1	5	3					

* Numerical Answer:-

Step (1) KOH

(5) molarity = no. of moles per litre.

∴ no of moles = molarity × volume

= 4 × 0·2

= 0·8 moles

(3) 1 mole ↔ 56g

0·8 moles ↔ 44·8g

FIGURE 20 (B). Actual Example of Pupils' Answers

How many grams of magnesium would react exactly with 0.4L. of 1M sulphuric acid solution?
(At. mass of Mg = 24).

write the formula of reactant(s) (1)	find number of moles of sulphuric acid actually reacting. (2)	relate moles of one reactant → moles of another reactant. (3)
write a correct balanced equation. (4)	the molarity is equal to number of moles per litre. (5)	write the formula of product(s). (6)
convert moles of magnesium grams of magnesium. (7)	from balanced equation write down number of moles involved. (8)	find number of (H^+) in the solution. (9)

* The order

1	6	4	8	2	3	7	

* Numerical Answer:-

Step (1) Mg and H_2SO_4

" (6) $MgSO_4$ and H_2

" (4) $Mg + H_2SO_4 \Rightarrow MgSO_4 + H_2$

" (8) 1mole 1mole 1mole 1mole

" (2) Moles = molarity x volume

= 1 x 0.4

= 0.4moles

" (3) 0.4moles H_2SO_4 ↔ 0.4 moles Mg.

" (7) 1 mole ↔ 24g

0.4moles ↔ 24 x 0.4 = 9.6g

FIGURE 20 (C). Actual Example of Pupils' Answers

What is the molarity of lithium hydroxide solution if 2L. of 0.4M nitric acid will neutralise 0.3L. of it?

write the formula of reactant(s). (1)	find volume in litres (2)	find number of moles of nitric acid actually reacting. (3)
write a correct balanced equation. (4)	number of moles is equal to molarity X volume (L). (5)	write the formula of product(s). (6)
relate moles of one reactant into moles of another reactant. (7)	from balanced equation write down number of moles involved. (8)	convert moles of reactant → grams of reactant (9)

* The order

1	6	4	8	5	7	5	

* Numerical Answer:-

Step (1) LiOH and HNO_3

" (6) $LiNO_3$ and H_2O.

" (4) $LiOH + HNO_3 \Rightarrow LiNO_3 + H_2O$

" (8) 1mole 1mole 1mole 1mole

" (5) moles = molarity x volume

$= 0.4 \times 2$

$= 0.8$ moles HNO_3.

" (7) 0.8 moles $HNO_3 \leftrightarrow$ 0.8 moles LiOH

" (5) moles = molarity x volume.

$\therefore$ Molarity $= \frac{\text{moles}}{\text{volume}} = \frac{0.8}{0.3} = \underline{\underline{2.67\,M}}$

FIGURE 20 (D). Actual Example of Pupils' Answers

TABLE 29

THE F.V. FOR THE MOLE QUESTION ATTEMPTED BY THE STUDENTS IN GROUP 2

Students \ Questions		Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 4	(N = 15)	0.47	0.53	0.40	0.33	0.27	0.20
X = 5	(N = 22)	0.55	0.59	0.68	0.50	0.64	0.41
X = 6	(N = 21)	0.62	0.71	0.67	0.62	0.67	0.43
X = 7	(N = 9)	0.67	0.67	0.78	0.89	0.89	0.78

TABLE 30

MEANS AND STANDARD DEVIATIONS FOR THE STUDENTS IN GROUP 2

(Possible Score is 10)

Students \ Questions		Q.1	Q.2	Q.3	Q.4	Q.5	Q.6
X = 4	Mean	6.3	6.5	5.1	4.1	3.5	3.0
	S.D.	3.8	3.9	4.6	4.4	4.2	3.9
X = 5	Mean	6.7	6.5	6.7	6.1	6.6	4.5
	S.D.	4.3	4.2	4.1	3.2	3.9	4.0
X = 6	Mean	6.8	7.3	6.8	7.1	6.9	5.3
	S.D.	4.3	4.4	4.6	3.9	4.5	4.6
X = 7	Mean	7.7	7.8	9.0	9.6	9.0	8.0
	S.D.	3.5	3.1	1.6	0.7	2.8	3.9

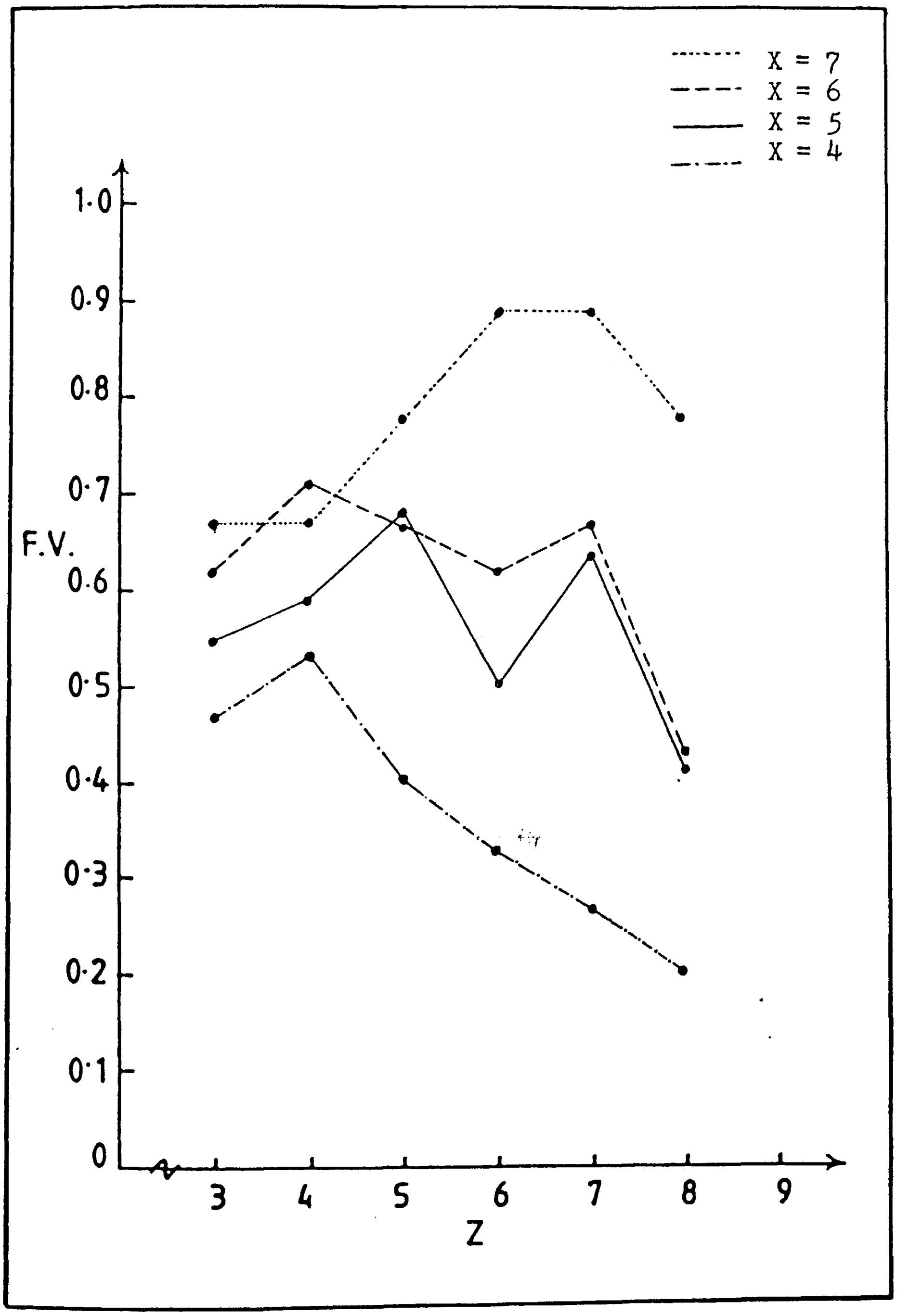


FIGURE 21. Results from Group 2 (F.V.)

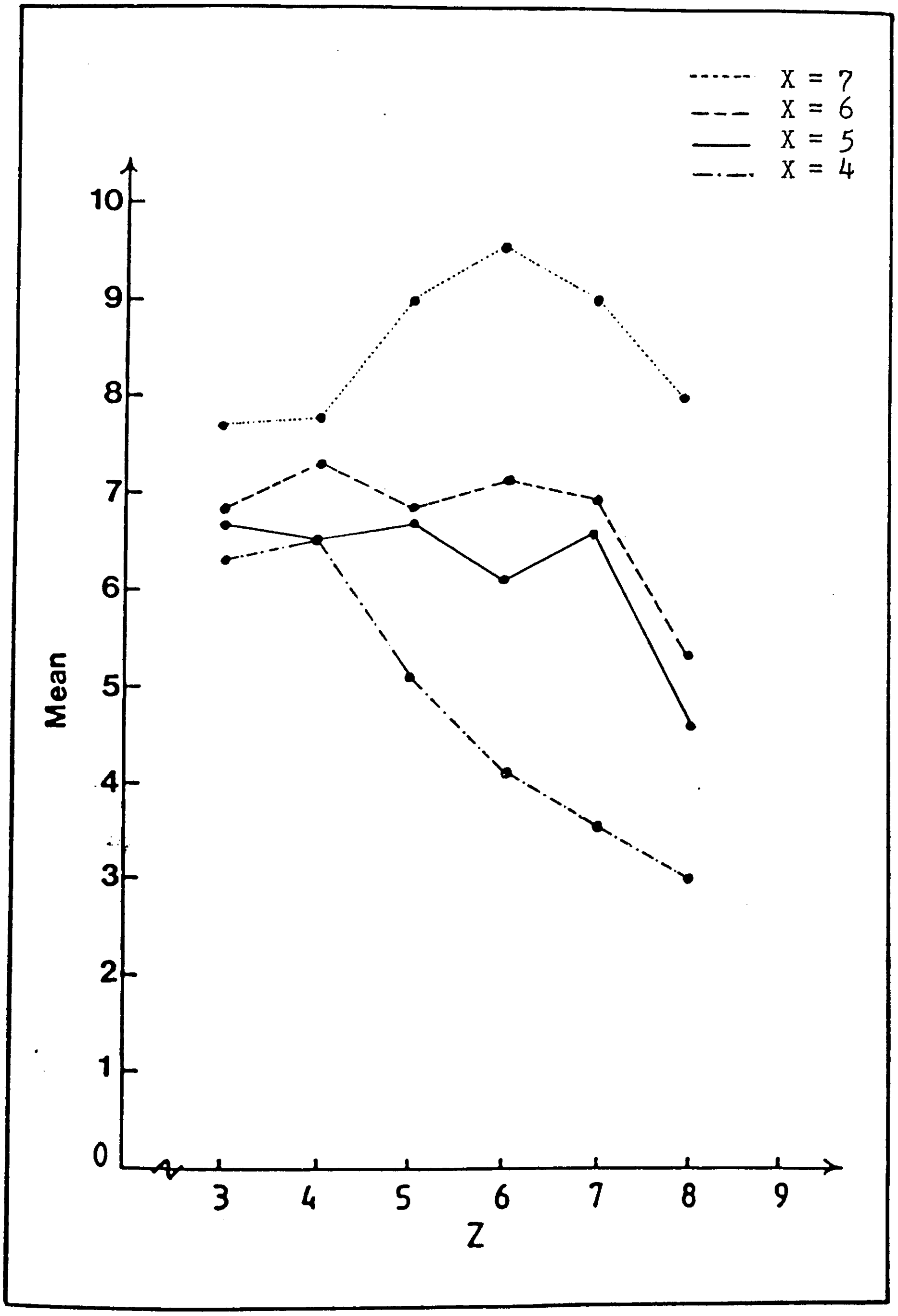


FIGURE 22. Results from Group 2 (Means)

Figures 21 and 22 show the F.V. and the means for all sub-groups of different X-space. Once again, the X = 7 students, in general, have a better all-over performance than X = 6 and X = 5, and the X = 4 students' performance, is still the lowest in all the questions. The gap between the X = 6 students and the X = 5 students is, in general, quite small in all the questions. The remarkable result is that as soon as Z exceeds X, there is a variety of performance across the sub-groups of different X-space. The X = 4 students' performance falls after the question of Z = 4. The same trend is seen for the X = 5 group, in the question of Z = 6, where about half of them succeeded. They also make a temporary recovery at Z = 7 and then, about 41% succeeded in the question of Z = 8. In the case of both X = 6 and X = 7, there is a good performance in the question of $Z > X$, as if the demand has come within their X-space, except for the question of Z = 8 in the case of X = 6 students.

The same four comparisons were made as in Chapter 4, to find out the relationship between the students' holding-thinking space and their ability to solve questions of different complexity. Tables Numbers 12 through 15 show the results of these comparisons.

The significance of the F.V. differences and the differences in mean scores between the four sub-groups of different X-space in all the questions are given in Tables 31 and 32. The results indicate that there is no significant difference in the students' performance between X = 5, X = 6 and X = 7 in all the questions. On the other hand, there is a significant difference between the students' performance in these three sub-groups and the students' performance of X = 4 in questions of Z = 6 and Z = 7, and in questions of Z = 8 in the case of X = 6 and X = 7.

It can be argued that the similarity in the performance of the X = 5 and X = 7, is due to breaking down the questions of Z = 7 and Z = 8 into sub-questions of $Z < 5$. Taking into account that some of the X = 5 students may have used a strategy to reduce the load of the question of Z = 6 as has been found in Chapter 4, and there was no question of $Z > 5$, the students of capacity X = 6 and X = 7 would not /

TABLE 31

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENT SUB-GROUPS

(Group 2)

Questions	Sub-groups Diff.	X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.4	Z = 6	S.*	S.*	S.**	N.S.	N.S.	N.S.
Q.5	Z = 7	S.*	S.**	S.**	N.S.	N.S.	N.S.
Q.6	Z = 8	N.S.	S.*	S.**	N.S.	N.S.	N.S.

** at 0.01 level
* at 0.05 level

TABLE 32

THE SIGNIFICANCE OF THE MEANS DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENT SUB-GROUPS

(Group 2)

Questions	Sub-groups Diff.	X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.4	Z = 6	S.*	S.*	S.**	N.S.	N.S.	N.S.
Q.5	Z = 7	S.*	S.*	S.**	N.S.	N.S.	N.S.
Q.6	Z = 8	N.S.	S.*	S.*	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

not be able to exhibit a superior performance over those of X = 5. In this case, the students' holding-thinking space X does not distinguish between the students' performance except in the case of X = 4.

The other two comparisons were made to find out the effect of the questions' complexity on the students' performance. The significance of the differences in F.V. and means between the questions for each sub-groups, can be seen in Tables 33 and 34.

The results indicate that there is no significant difference between the students' performance, in terms of both the F.V. and the means, between the questions of low and high Z-demand. Once again, it can be argued that this is due to the similarity in the performance, within each sub-groups, in the questions after breaking down the questions of high Z-demand (there is, in effect, no questions of Z = 7 or Z = 8).

Conclusion

In the comparisons made, and taking into account the sample size, no difference can be claimed to exist between the students' performance for all sub-groups of different X-space in all the questions. The results, therefore, tend to support the prediction that there is not a relationship between the students' X-space and the questions' complexity when questions of high Z-demand are divided into a series of sub-questions having a Z value within the X-space of the students

5.3.4 Testing Hypothesis 2

Comparison Between Group 2 (Test with divided questions) and Group 4 (Raw test)

The hypothesis, "there will be a significant improvement in performance in favour of students who are given sub-divided questions and those who are given the same questions undivided", was tested in all sub-groups of different X-space by comparing the results of each sub-group /

TABLE 33

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH STUDENT SUB-GROUP BETWEEN QUESTIONS OF DIFFERENT Z-DEMAND

(Group 2)

Sub-Groups	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.

TABLE 34

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS FOR EACH STUDENT SUB-GROUP BETWEEN QUESTIONS OF DIFFERENT Z-DEMAND

(Group 2)

Sub-Groups	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	-	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.

sub-group in Group 2 (using the test with divided questions) and Group 4 (using the raw test).

Tables 35 and 36, as well as Figures 23 through 30, show the results of these comparisons. Table 35 shows the comparison of the F.V. between Group 2 and Group 4 in all the questions in each sub-group. The results indicate that, within the X = 5 sub-group, there is a significant difference in the students' performance between both groups in the questions of complexity Z = 7 and Z = 8 in the favour of Group 2. It should be noted that, in Group 2, these questions were broken down into three sub-questions each of them has Z 5. The X = 6 students' performance was also significantly different in the same questions. Another remarkable result appeared in the X = 7 sub-group where the Z = 8 question gave a F.V. of about 0.8. There is a big difference (74%) between both groups in the question of complexity Z = 8. No difference can be claimed to exist in the X = 4 sub-group since the students' performance in Group 2 and Group 4 are so low.

Table 36 shows similar trends, in the case of the mean scores, except in the question of Z = 7 within the sub-group X = 6, since there is no significant difference between Group 1 and Group 4 in that question.

Conclusion

The results tend to support the hypothesis that "there will be a significant difference in the performance between the students who solve the question in the form of sub-questions, and those who solve the complete question undivided in all sub-groups of different X-space" except in the case of X = 4.

TABLE 35

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN GROUP 2 AND GROUP 4

Questions \ Sub-groups	X = 4	X = 5	X = 6	X = 7
Q.1	N.S.	N.S.	N.S.	N.S.
Q.2	N.S.	N.S.	N.S.	N.S.
Q.3.	N.S.	N.S.	N.S.	N.S.
Q.4	N.S.	N.S.	N.S.	N.S.
Q.5	N.S.	S.**	S.**	N.S.
Q.6	N.S.	S.**	S.**	S.**

** at 0.01 level

* at 0.05 level

TABLE 36

THE SIGNIFICANCE OF THE MEANS DIFFERENCES FOR EACH QUESTION BETWEEN GROUP 2 AND GROUP 4

Questions \ Sub-groups	X = 4	X = 5	X = 6	X = 7
Q.1	N.S.	N.S.	N.S.	N.S.
Q.2	N.S.	N.S.	N.S.	N.S.
Q.3	N.S.	N.S.	N.S.	N.S.
Q.4	N.S.	N.S.	N.S.	N.S.
Q.5	N.S.	S.*	N.S.	N.S.
Q.6	N.S.	S.*	S.*	S.*

* at 0.05 level

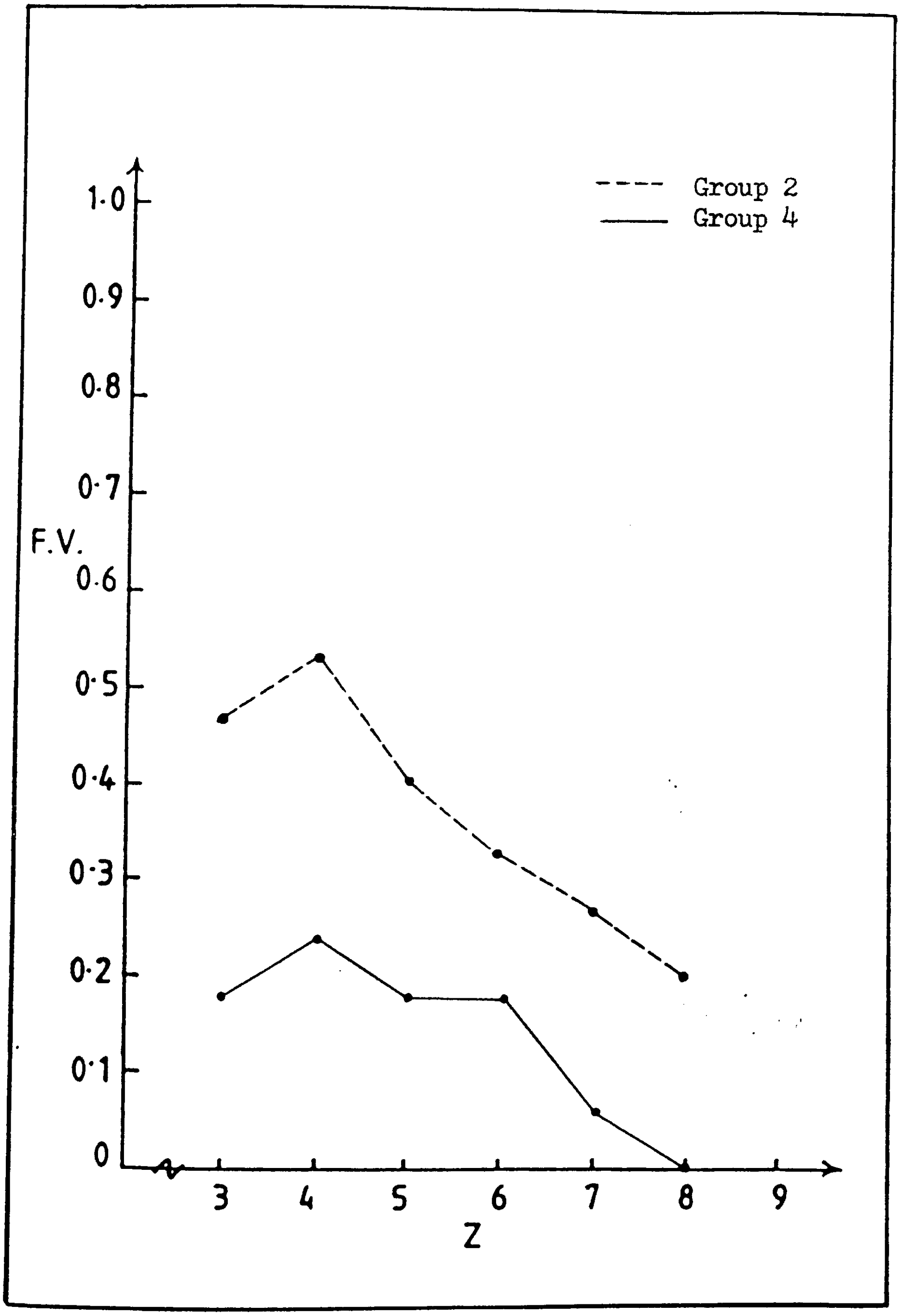


FIGURE 23. Comparison of the F.V. between Group 2 and Group 4.

(Sub-group X = 4)

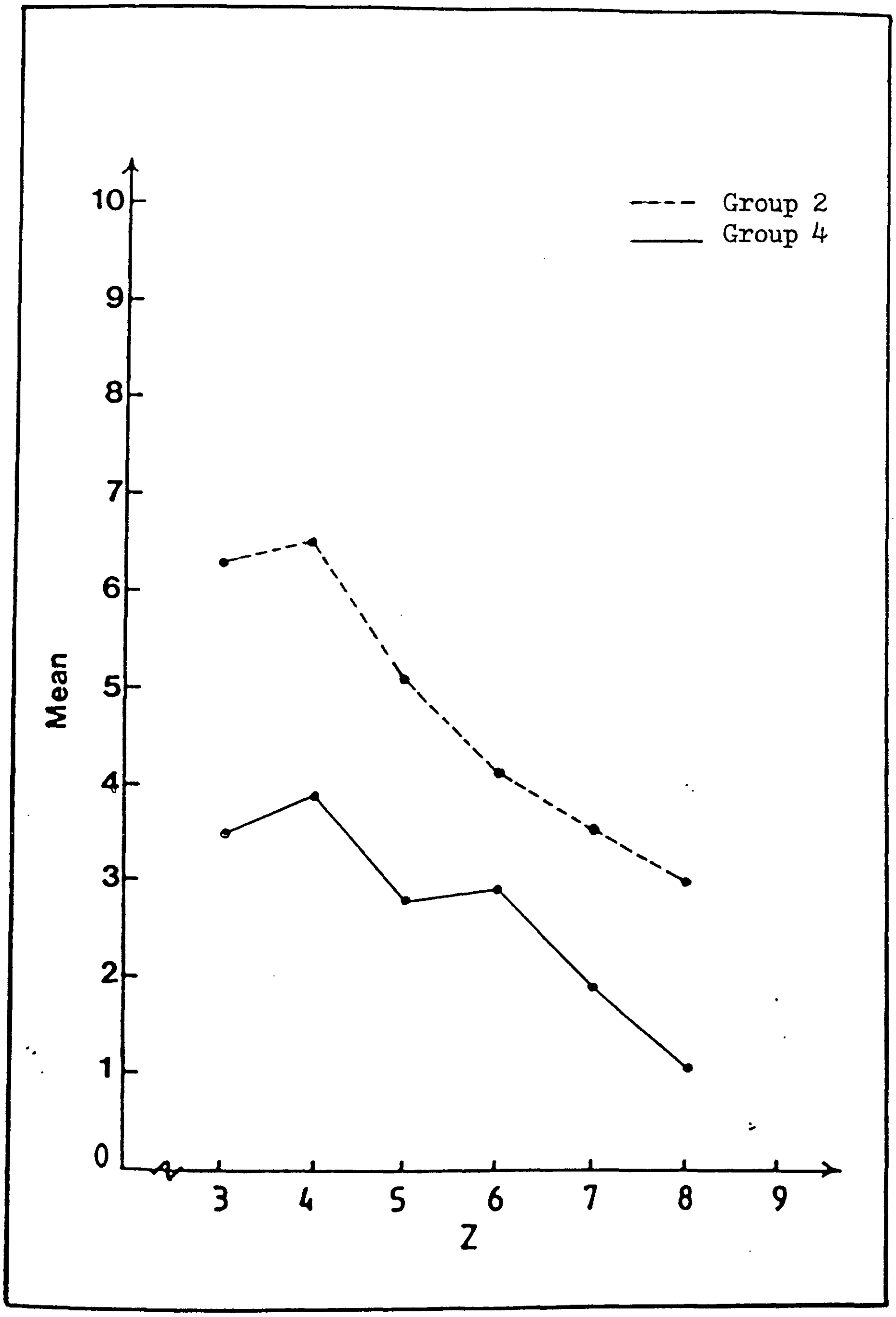


FIGURE 24. Comparison of the Means between Group 2 and Group 4.
(Sub-group X = 4)

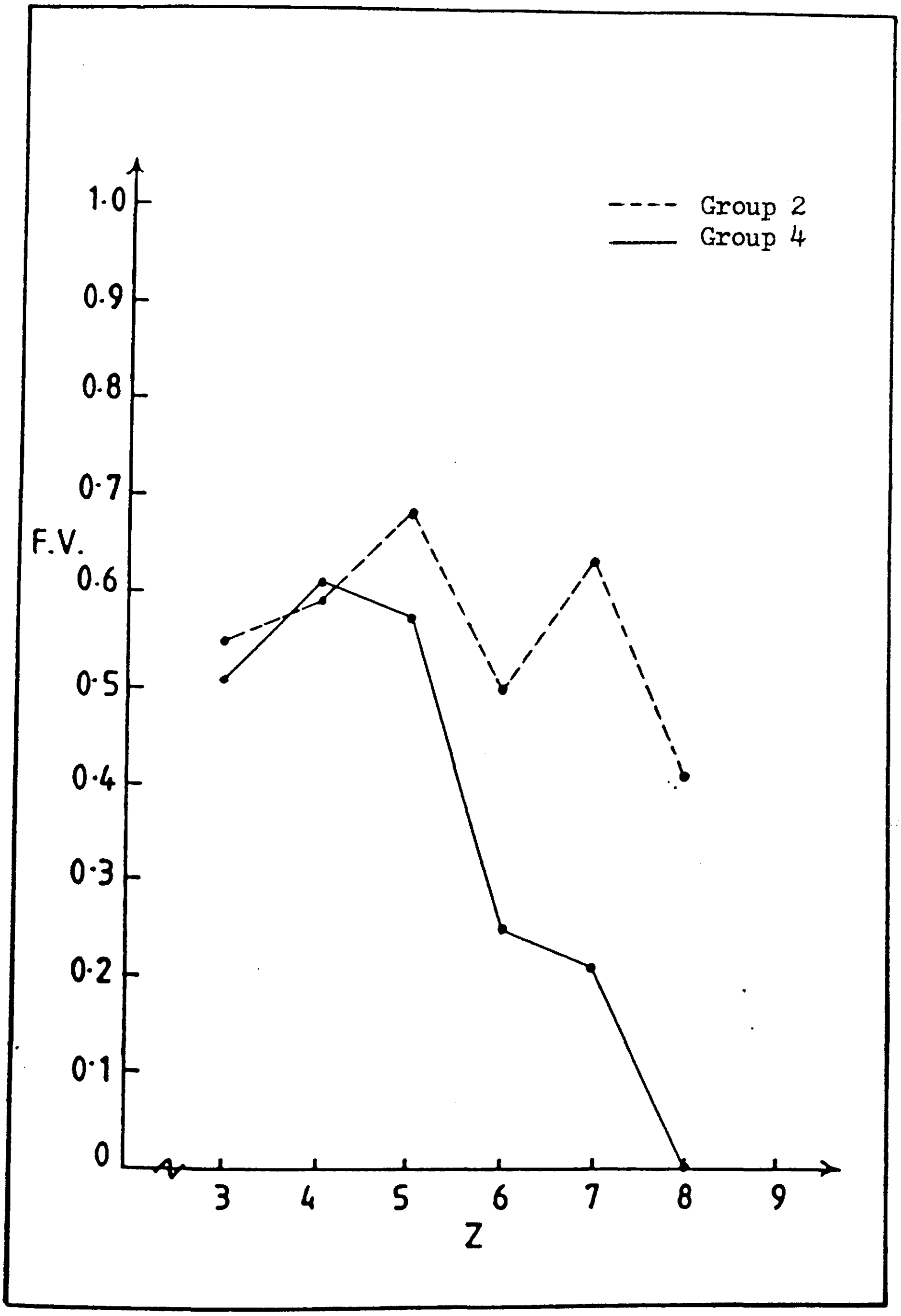


FIGURE 25. Comparison of the F.V. between Group 2 and Group 4.
(Sub-group X = 5)

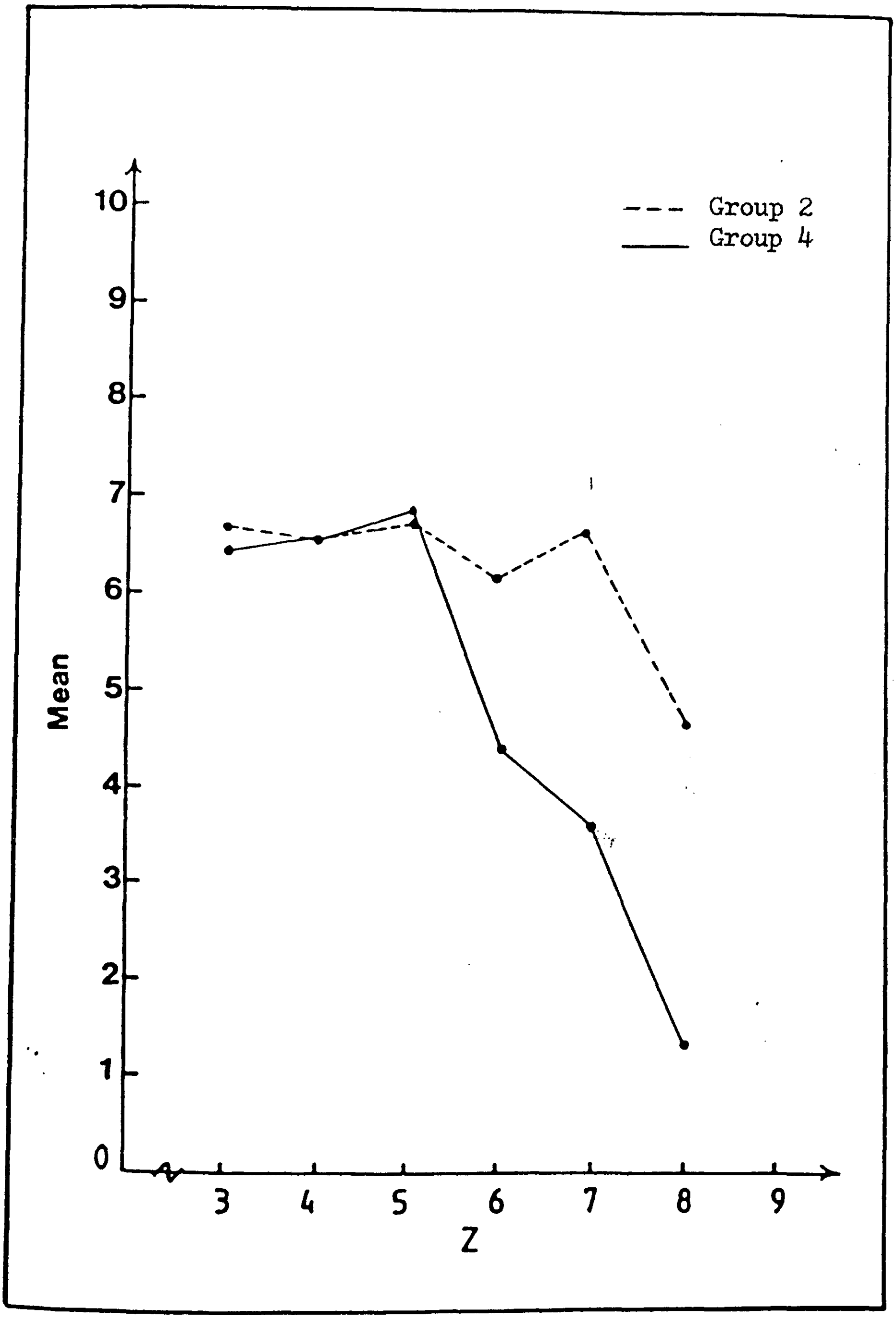


FIGURE 26. Comparison of the Means between Group 2 and Group 4.
(Sub-group X = 5)

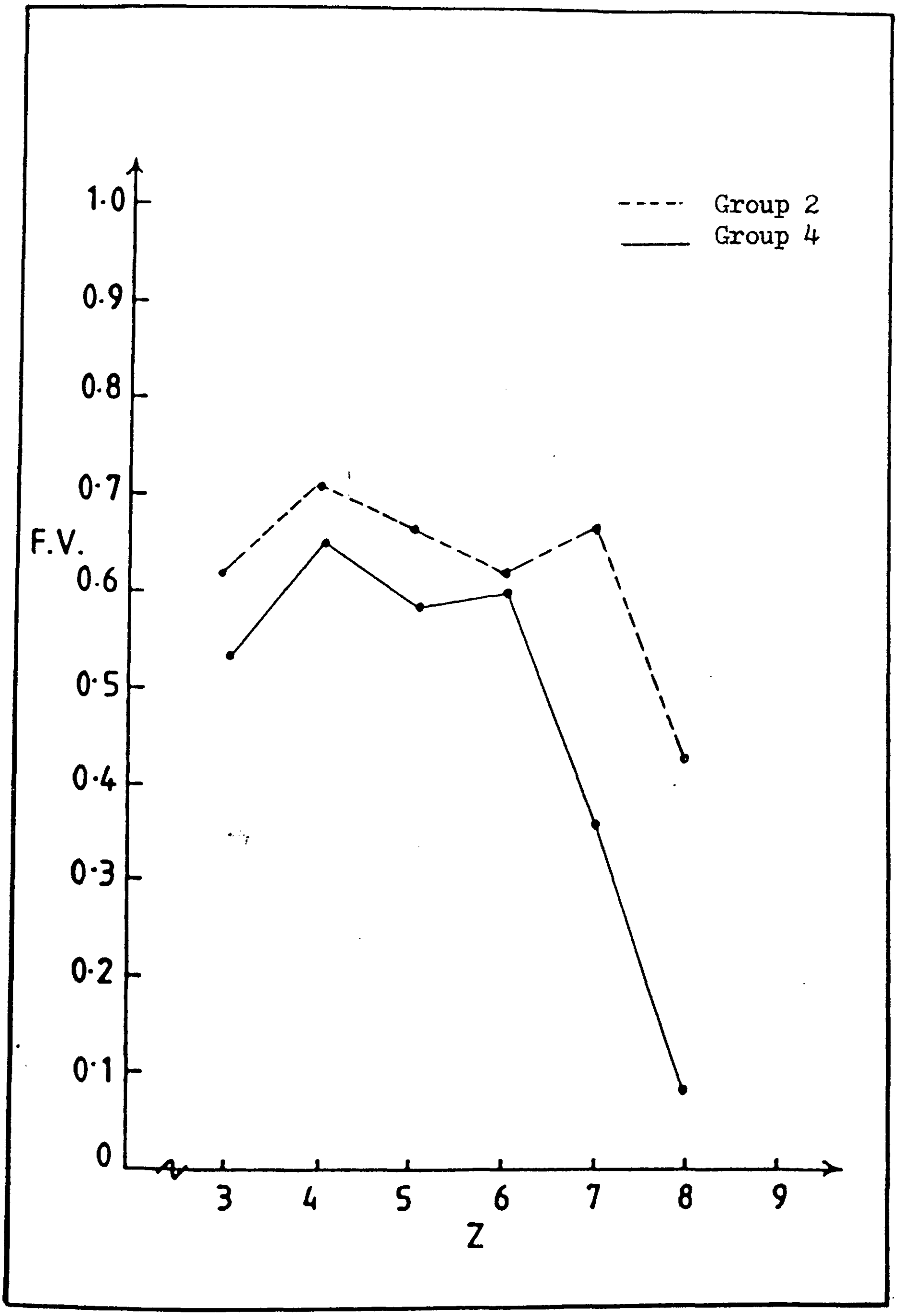


FIGURE 27. Comparison of the F.V. between Group 2 and Group 4.
(Sub-group X = 6)

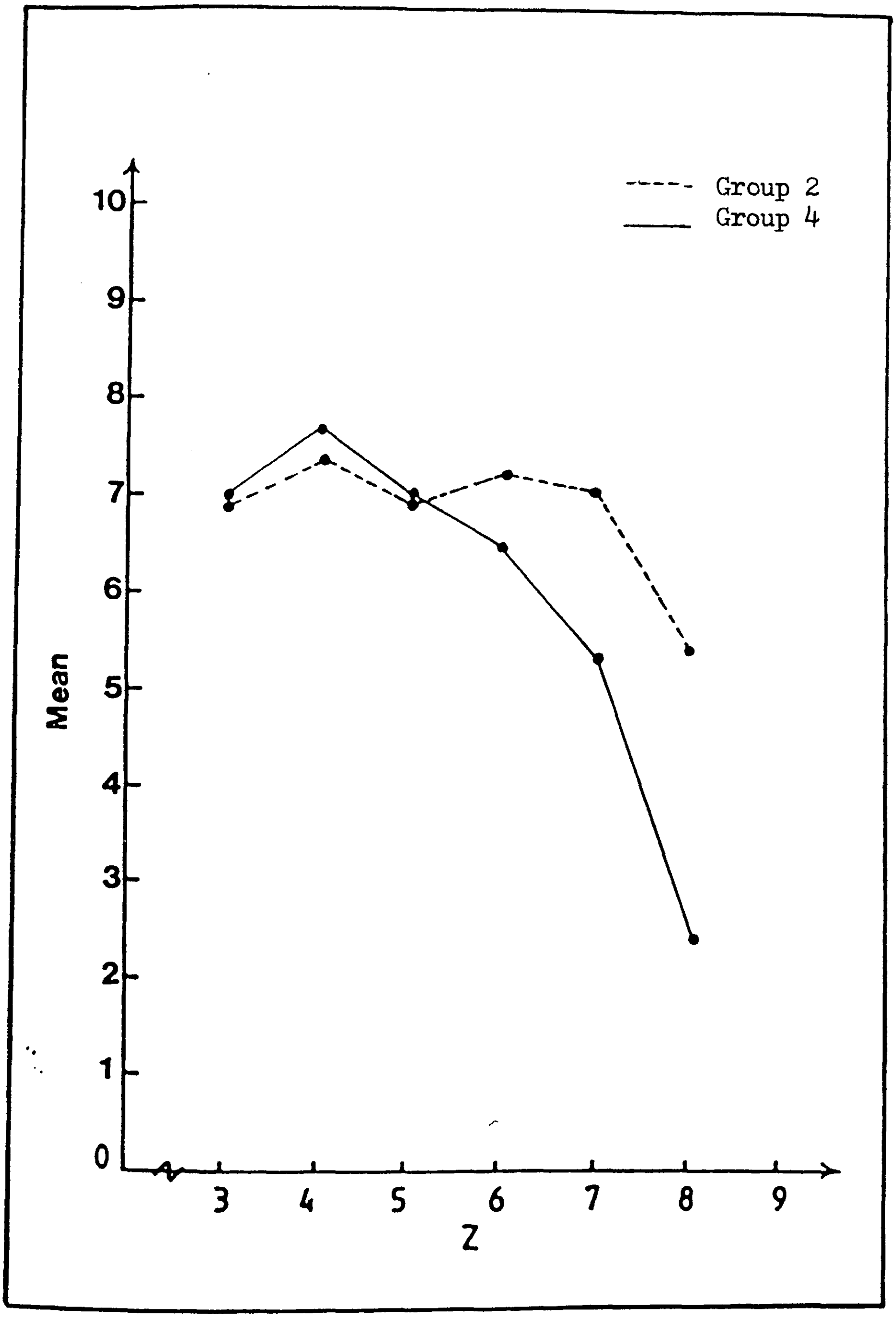


FIGURE 28. Comparison of the Means between Group 2 and Group 4.
(Sub-group X = 6)

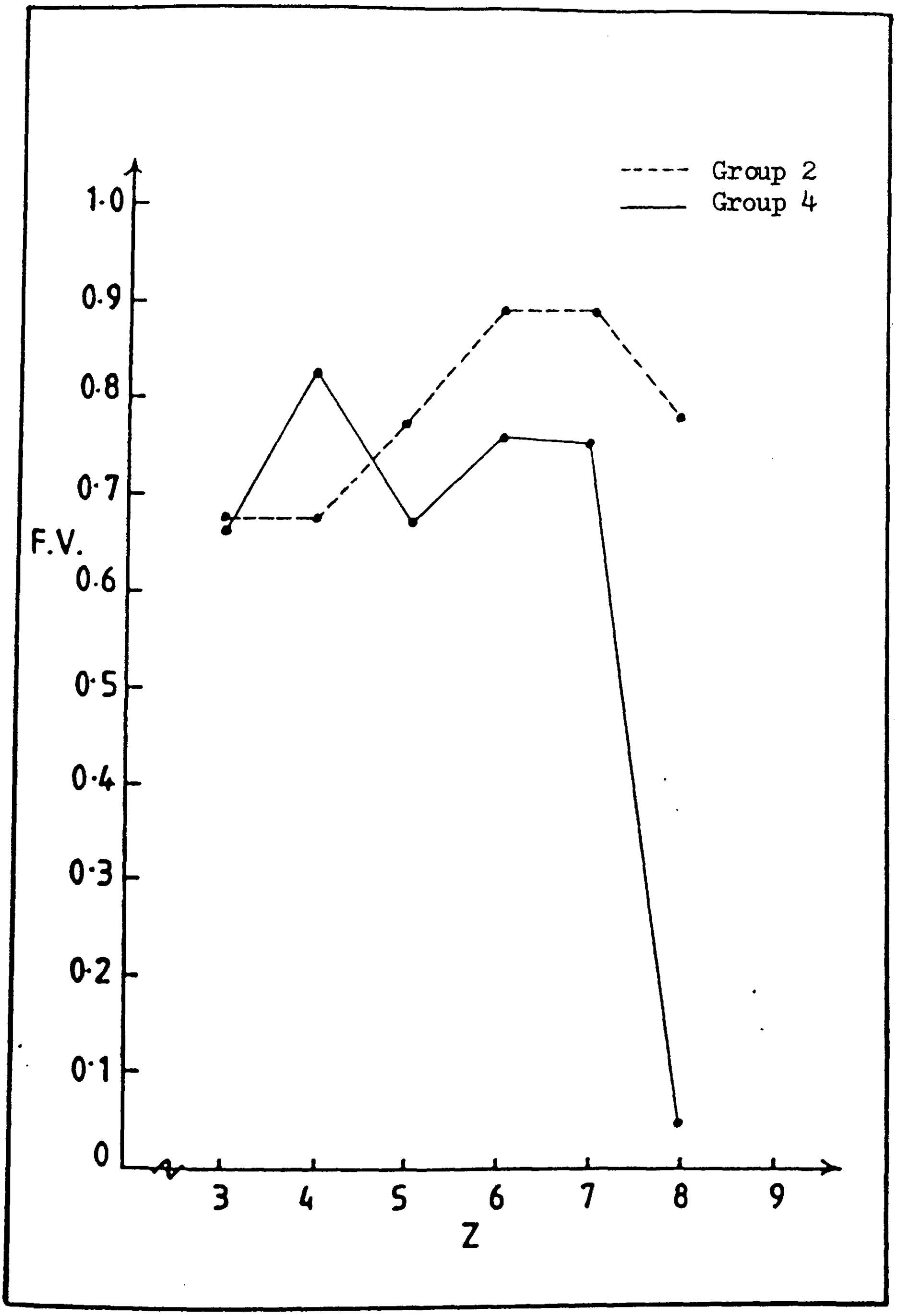


FIGURE 29. Comparison of the F.V. between Group 2 and Group 4.
(Sub-group X = 7)

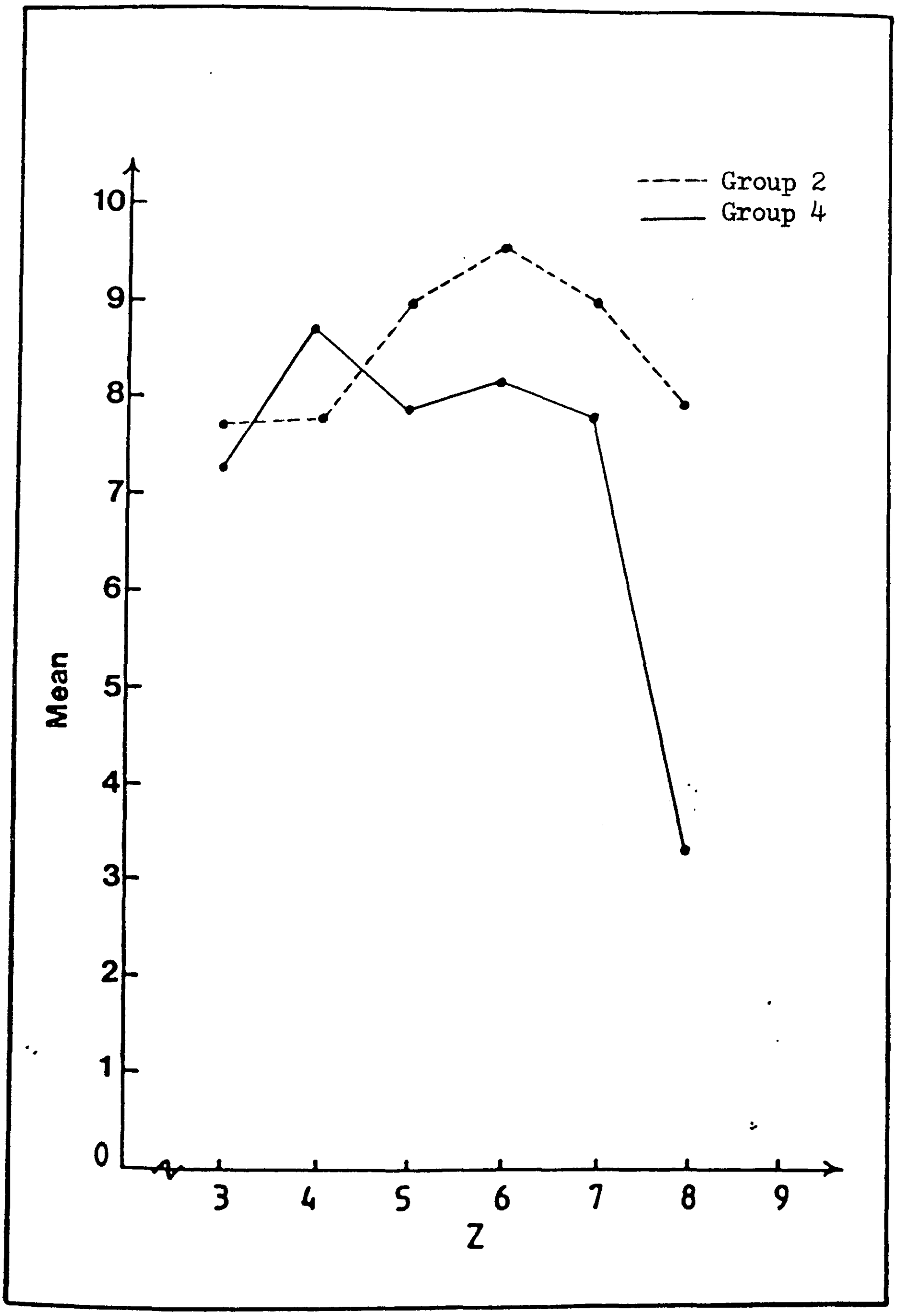


FIGURE 30. Comparison of the Means between Group 2 and Group 4.
(Sub-group X = 7)

5.3.5 Data from Group 3

Tables Numbers 37 through 42, as well as Figures 31 and 32, show the results from the students in Group 3. The students in this group had been given the teaching material giving strategies for handling stoichiometric calculations and neutralization reactions for the O-Grade examination. It should be noted that this material was used either instead of the original material used by the teacher, or as a revision after the teacher had finished his teaching from his original material.

Table 37 shows the F.V. of the mole questions (the raw test similar to the Group 4) attempted by the students of different holding-thinking space. The means and the standard deviations are given in Table 38.

In Figure 31, where the F.V. of the mole questions can be seen, the X = 7 students are better, once again, in their all-over performance than the X = 6 and both have better all-over performance than the X = 5 except in questions 2 and 3. The X = 4 students have the lowest performance. However, three patterns emerge from this figure. The first is that, in the neutralization questions (Question 4 and Question 5) there is a high performance for the X = 5 and X = 6 students regardless of the fact that $Z \not> X$. The second is that the students' performance in Questions 1, 2 and 3 is quite similar within the X = 5, X = 6 and X = 7 sub-groups. The third is that, when Z exceeds X, for X = 5 and X = 6, there is no falling down so that their performance is quite similar. Similar trends are given in Figure 32, in the case of means.

At this stage, four comparisons were made exactly in the same way as in Chapter 4, to find out whether there is a relationship between the students' holding-thinking space X and their ability to solve the questions of different complexity after they have been given the new material. Tables Numbers 39 through 42 show the results of these comparisons.

Table 39, shows the effect of the students X-space on their ability to solve mole questions of different Z-demand. The results indicate /

TABLE 37

THE F.V. FOR THE MOLE QUESTIONS ATTEMPTED BY THE STUDENTS IN GROUP 3

Sub-groups \ Questions		Q.1 Z = 3	Q.2 Z = 4	Q.3 Z = 5	Q.4 Z = 6	Q.5 Z = 7	Q.6 Z = 8
X = 4	N = 16	0.44	0.38	0.38	0.13	0.00	0.00
X = 5	N = 24	0.63	0.67	0.71	0.67	0.58	0.08
X = 6	N = 26	0.73	0.65	0.77	0.69	0.62	0.12
X = 7	N = 13	0.77	0.69	0.69	0.85	0.77	0.31

TABLE 38

MEANS AND STANDARD DEVIATIONS FOR THE STUDENTS IN GROUP 3

(Possible Score for Each Question is 10)

Questions	Sub-groups	X = 4	X = 5	X = 6	X = 7
Q.1	Mean	4.9	7.1	8.2	8.4
	S.D.	4.6	4.1	3.3	3.1
Q.2	Mean	5.8	7.7	7.5	7.9
	S.D.	3.7	3.6	3.9	3.4
Q.3	Mean	4.2	7.8	8.5	8.1
	S.D.	3.1	3.7	3.2	3.1
Q.4	Mean	1.8	7.2	7.4	9.1
	S.D.	3.2	3.4	4.0	2.6
Q.5	Mean	1.6	6.7	6.8	8.6
	S.D.	3.0	4.1	4.3	3.0
Q.6	Mean	1.0	2.8	2.7	5.7
	S.D.	1.4	3.0	3.2	3.9

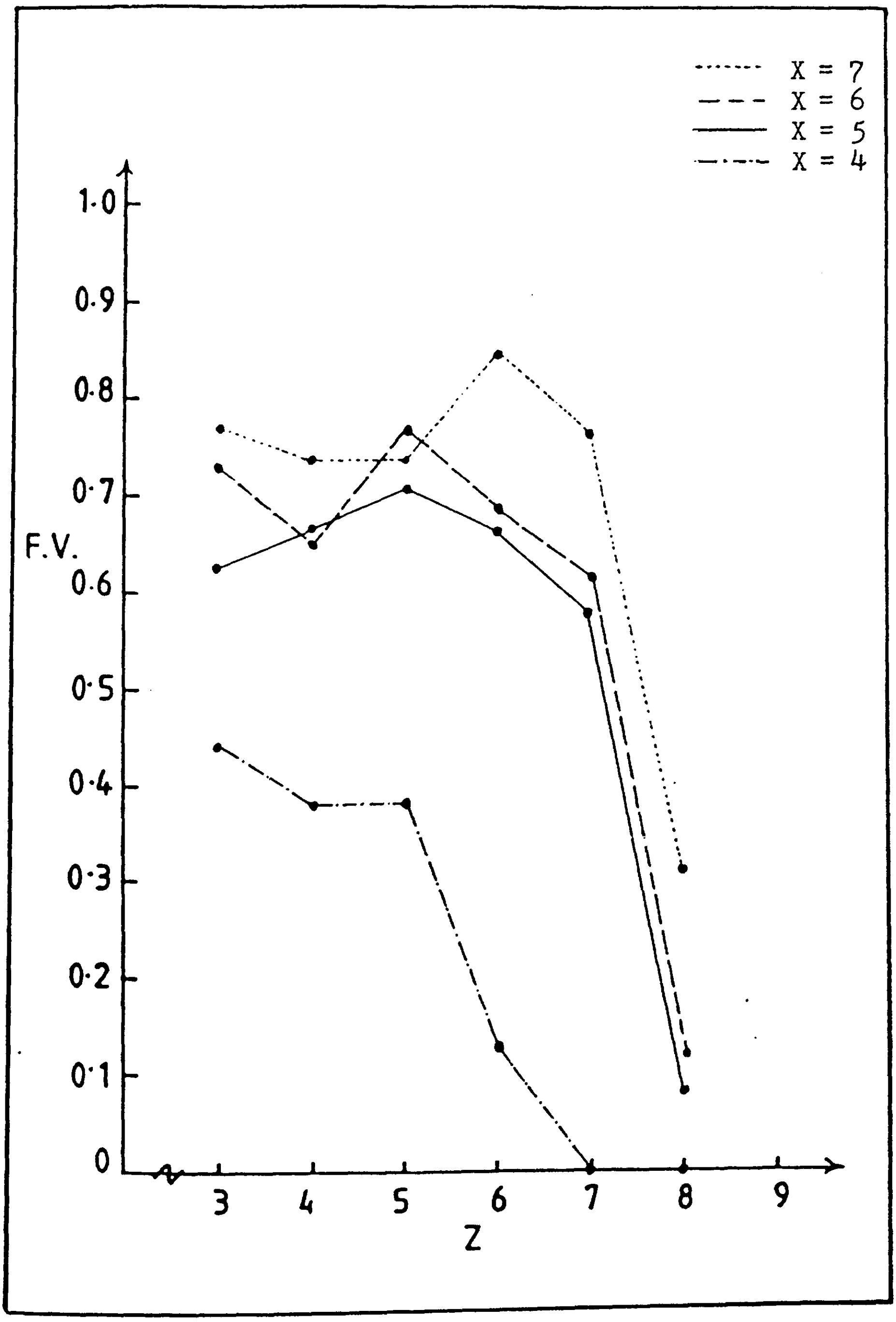


FIGURE 31. Results from Group 3 (F.V.)

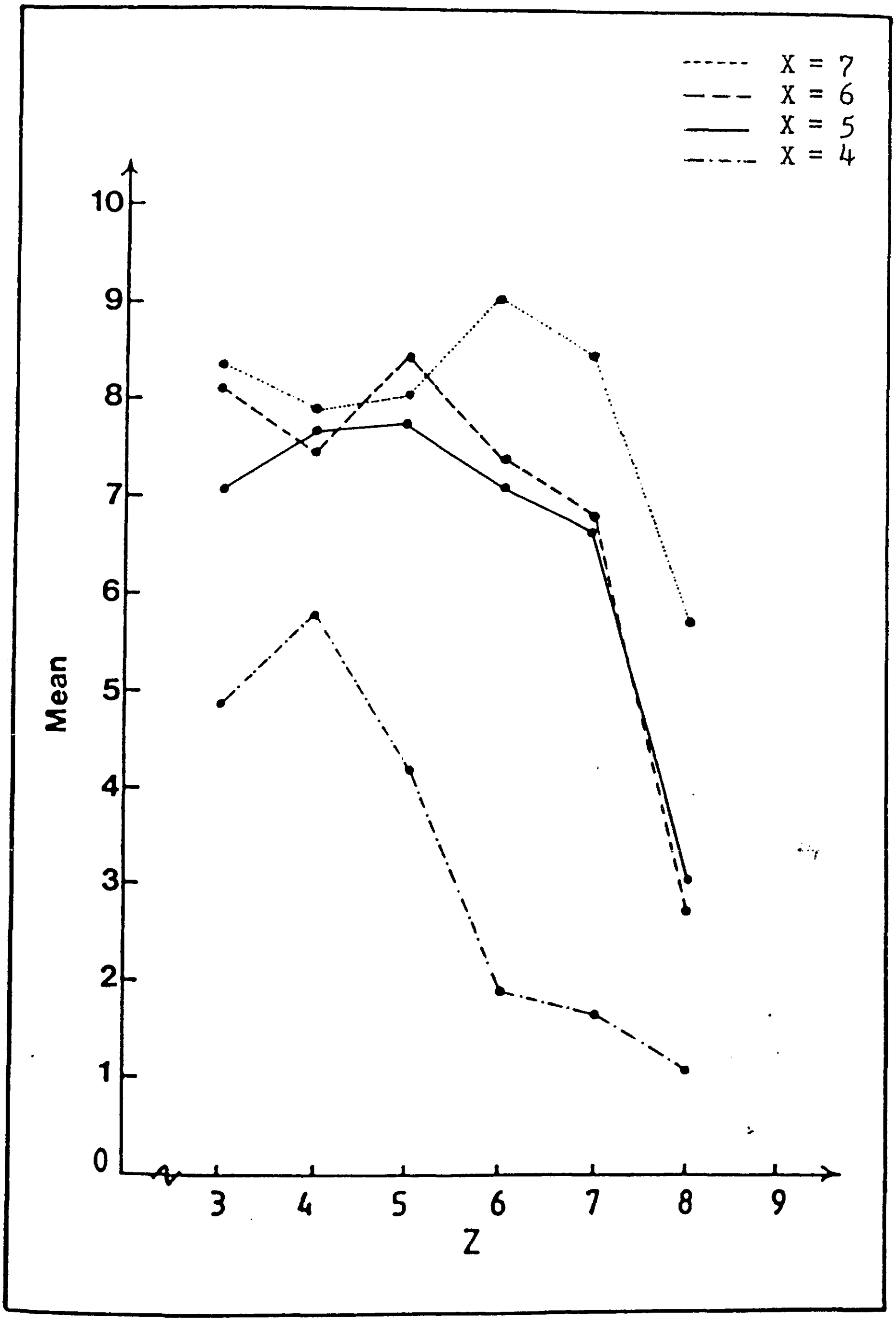


FIGURE 32. Results from Group 3 (Means)

TABLE 39

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENTS' SUB-GROUPS

(Group 3)

Questions	Sub-groups / Diff.	X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	N.S.	S.*	N.S.	N.S.	N.S.
Q.2	Z = 4	S.*	N.S.	S.*	N.S.	N.S.	N.S.
Q.3	Z = 5	S.*	S.*	S.*	N.S.	N.S.	N.S.
Q.4	Z = 6	S.**	S.**	S.*	N.S.	N.S.	N.S.
Q.5	Z = 7	S.**	S.**	S.**	N.S.	N.S.	N.S.
Q.6	Z = 8	N.S.	N.S.	S.*	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

indicate that the X = 4 students' performance is significantly different from the X = 7 in all the questions, and from the X = 6 and X = 5 in questions of complexity Z = 5, 6 and 7. On the other hand, there is no significant difference in the performance between the X = 5, 6 and 7. It could be argued that the teaching strategy enabled the X = 5 and X = 6 students to reduce the information load in these questions. Similar results were found in the case of the students' means scores, except in Questions 1 and 2, as can be seen in Table 40.

Table 41 shows the significance of the differences in the students' performance within each sub-group of different X-space in all the questions in terms of the F.V. This comparison has been made to find out whether there is an effect of the questions' complexity on the students' performance. The results indicate that in the sub-group of X = 4, there is a significant difference between the question of Z = 7 and all the questions of $Z < 7$, also between the question of Z = 8 and all the questions of $Z < 7$. In the sub-groups X = 5 and X = 6 significant differences occurred between the question of Z = 8 and all the questions of $Z < 8$. In the sub-group X = 7, the differences between questions of Z = 3 and Z = 8, between questions of Z = 6 and Z = 7, and between questions of Z = 7 and Z = 8 are significant.

Table 42 gives similar results in the case of the students' mean scores except that of the sub-group X = 7, since there is no significant difference in the students' performance in all the questions.

Conclusion

In the comparison made, based upon the use of the new teaching material, there is in general, no relationship between the students' holding-thinking space X and their ability to solve questions of different complexity, within the sub-groups of X = 5 to X = 7. The sub-group of X = 4 performance is still low despite the fact that they were exposed to the new teaching method.

TABLE 40

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS FOR EACH QUESTION BETWEEN THE STUDENT SUB-GROUPS

(Group 3)

Questions	Sub-groups Diff.	X = 4 and X = 5	X = 4 and X = 6	X = 4 and X = 7	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 3	N.S.	S.*	N.S.	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q.3	Z = 5	S.*	S.**	S.**	N.S.	N.S.	N.S.
Q.4	Z = 6	S.**	S.**	S.**	N.S.	N.S.	N.S.
Q.5	Z = 7	S.**	S.**	S.**	N.S.	N.S.	N.S.
Q.6	Z = 8	N.S.	N.S.	S.**	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

TABLE 41

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH STUDENT SUB-GROUP BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND

(Group 3)

Sub-groups	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	S.*	S.*	S.*	N.S.	-
	8	S.*	S.*	S.*	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**
X = 6	4	N.S.	-	-	-	-
	6	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.*	N.S.	N.S.	S.**	S.**

** at 0.01 level
* at 0.05 level

TABLE 42

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS FOR EACH STUDENT SUB-GROUP BETWEEN THE QUESTIONS OF DIFFERENT Z-DEMAND

(Group 3)

Sub groups	Z \ Z	3	4	5	6	7
X = 4	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	S.*	N.S.	-	-
	7	N.S.	S.*	N.S.	N.S.	-
	8	S.*	S.*	N.S.	N.S.	N.S.
X = 5	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**
X = 6	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	S.**	S.**	S.**	S.**	S.**
X = 7	4	N.S.	-	-	-	-
	5	N.S.	N.S.	-	-	-
	6	N.S.	N.S.	N.S.	-	-
	7	N.S.	N.S.	N.S.	N.S.	-
	8	N.S.	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

5.3.6 Testing Hypothesis 3

Comparison Between Group 3 (new teaching materials and raw test) and Group 4 (Raw Test)

The hypothesis that, "there will be a significant improvement in performance in favour of students who have been taught problem solving strategies throughout and those who have not", was tested by comparing each sub-group in Group 3 (new teaching materials and raw test) and each in Group 4 (raw test). Tables Numbers 43 and 44, as well as Figures 33 through 40, show the results of these comparisons.

The results from Tables 43 and 44, indicate that the performance of the students in Group 3 and Questions 4 and 5 (neutralization reactions) is significantly better than the students' performance in Group 4 in the case of the sub-group of X = 5. Similar results were found in the case of the X = 6 in Question 5. There is no significant difference in the performance of the X = 4 and the X = 7 between Group 3 and Group 4 in these questions (neutralization reactions), although the performance in Group 3 is better than Group 4. On the other hand, there is no significant difference in the students' performance in the stoichiometric calculations (Questions 2, 3 and 6) between Group 1 and Group 4 for all the sub-groups of different X-space. Nevertheless, the students' performance in Group 3 in these questions is better than those in Group 4.

Conclusion

Although the results of comparing the performance question by question between Group 3 and Group 4 do not yield significant differences in some questions, the trends are in the direction which favours the experimental group (Group 3).

TABLE 43

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN GROUP 3 AND GROUP 4

Questions \ Sub-Groups	X = 4	X = 5	X = 6	X = 7
Q.1	S.*	N.S.	N.S.	N.S.
Q.1	N.S.	N.S.	N.S.	N.S.
Q.3	N.S.	N.S.	N.S.	N.S.
Q.4	N.S.	S.**	N.S.	N.S.
Q.5	N.S.	S.*	S.*	N.S.
Q.6	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

TABLE 44

THE SIGNIFICANCE OF THE MEANS DIFFERENCES FOR EACH QUESTION BETWEEN GROUP 3 AND GROUP 4

Questions \ Sub-groups		X = 4	X = 5	X = 6	X = 7
Q.1	Z = 3	S.*	N.S.	N.S.	N.S.
Q.2	Z = 4	N.S.	N.S.	N.S.	N.S.
Q.3	Z = 5	N.S.	N.S.	N.S.	N.S.
Q.4	Z = 6	N.S.	S.*	N.S.	N.S.
Q.5	Z = 7	N.S.	S.*	N.S.	N.S.
Q.6	Z = 8	N.S.	N.S.	N.S.	N.S.

** at 0.01 level

* at 0.05 level

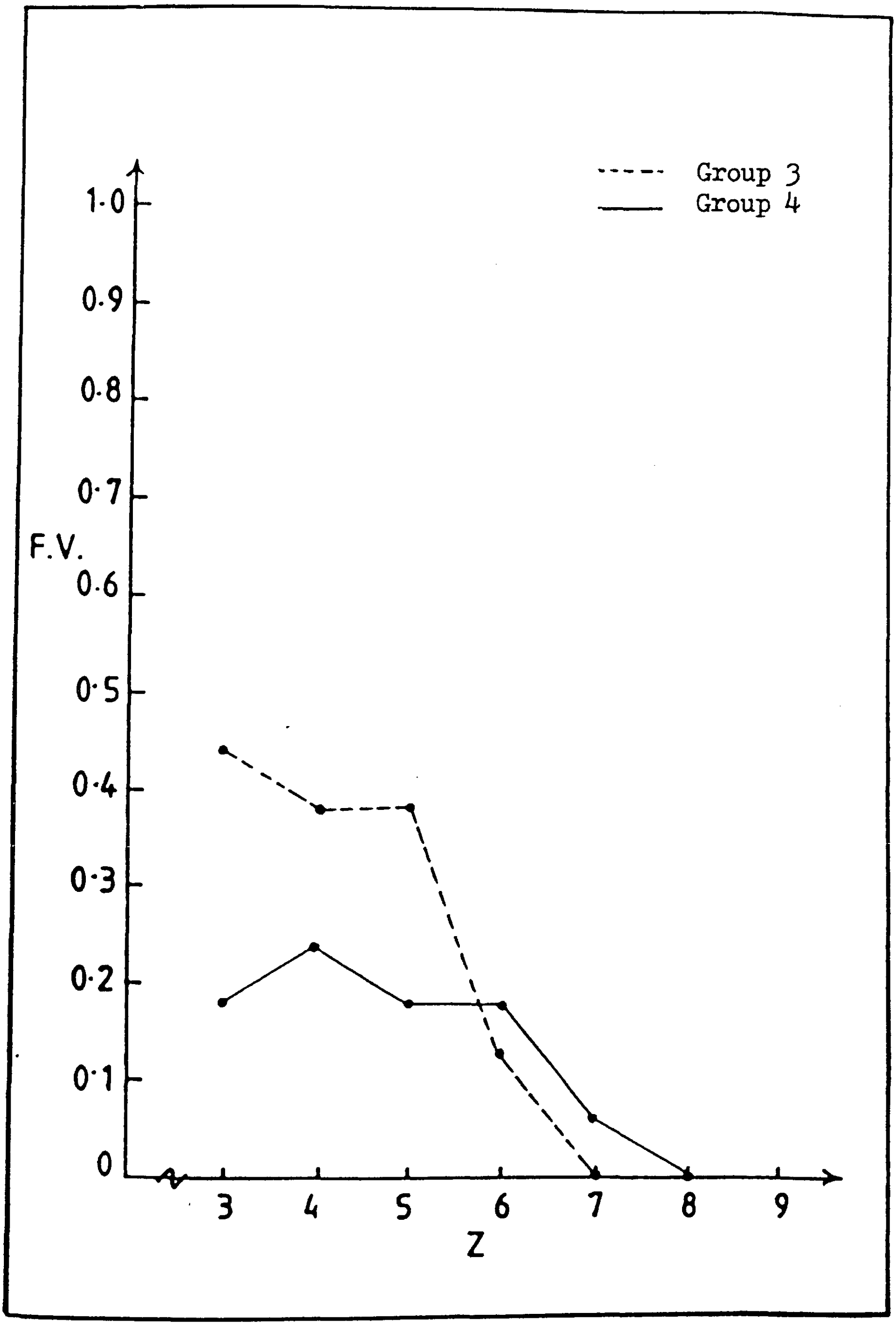


FIGURE 33. Comparison of the F.V. between Group 3 and Group 4.
(Sub-group X = 4)

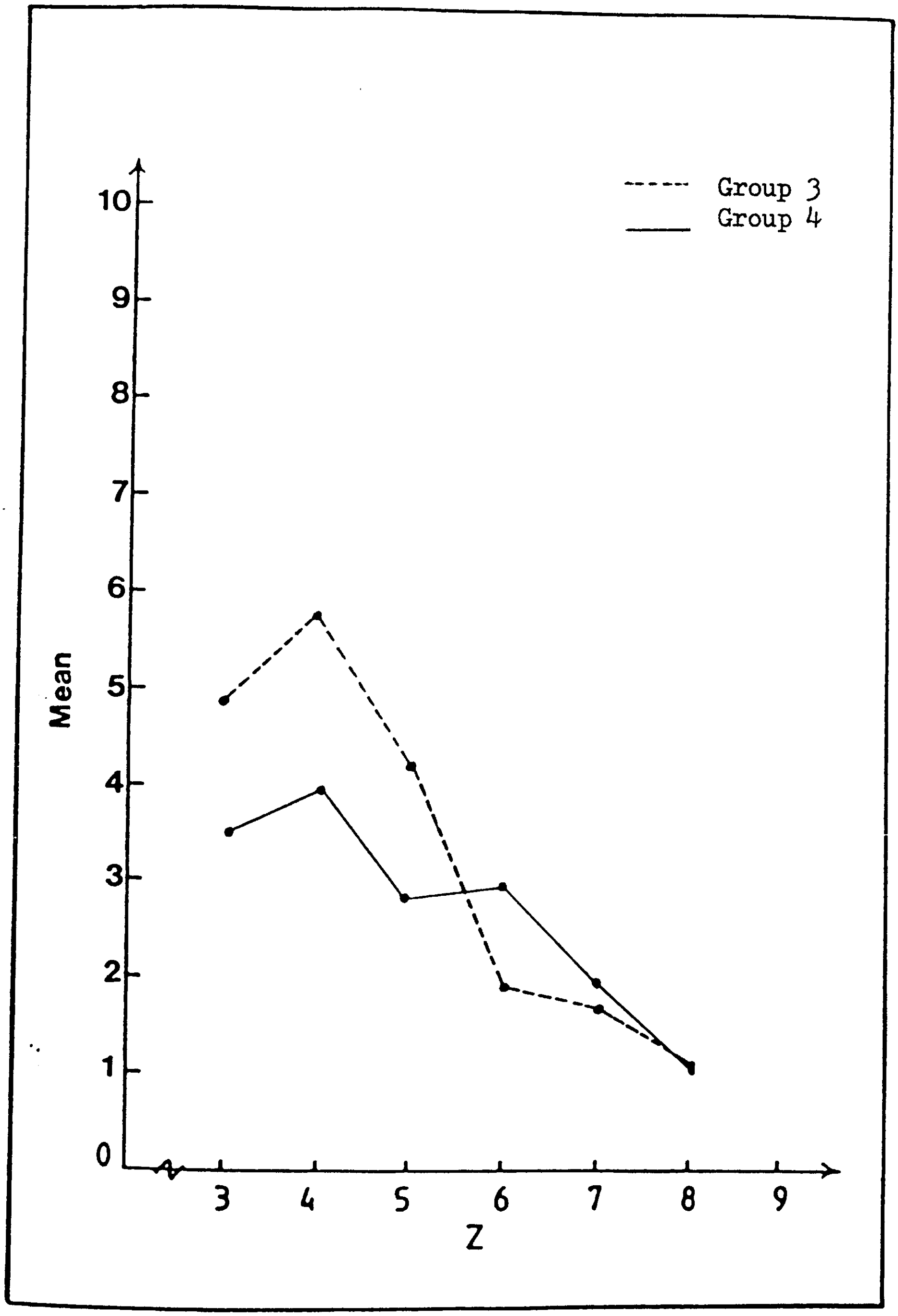


FIGURE 34. Comparison in the Means between Group 3 and Group 4.
(Sub-group X = 4)

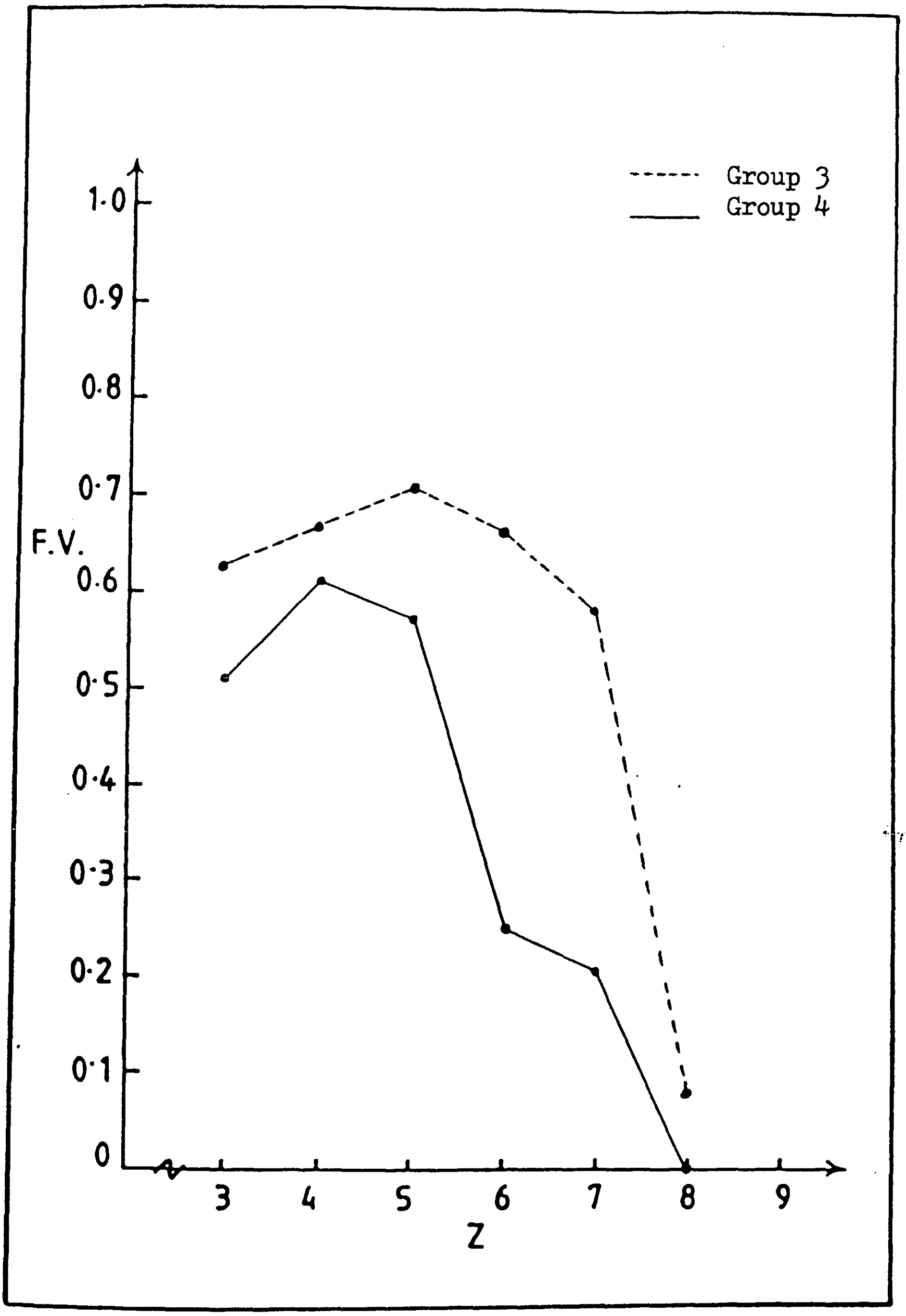


FIGURE 35. Comparison of the F.V. between Group 3 and Group 4.
(Sub-group X = 5)

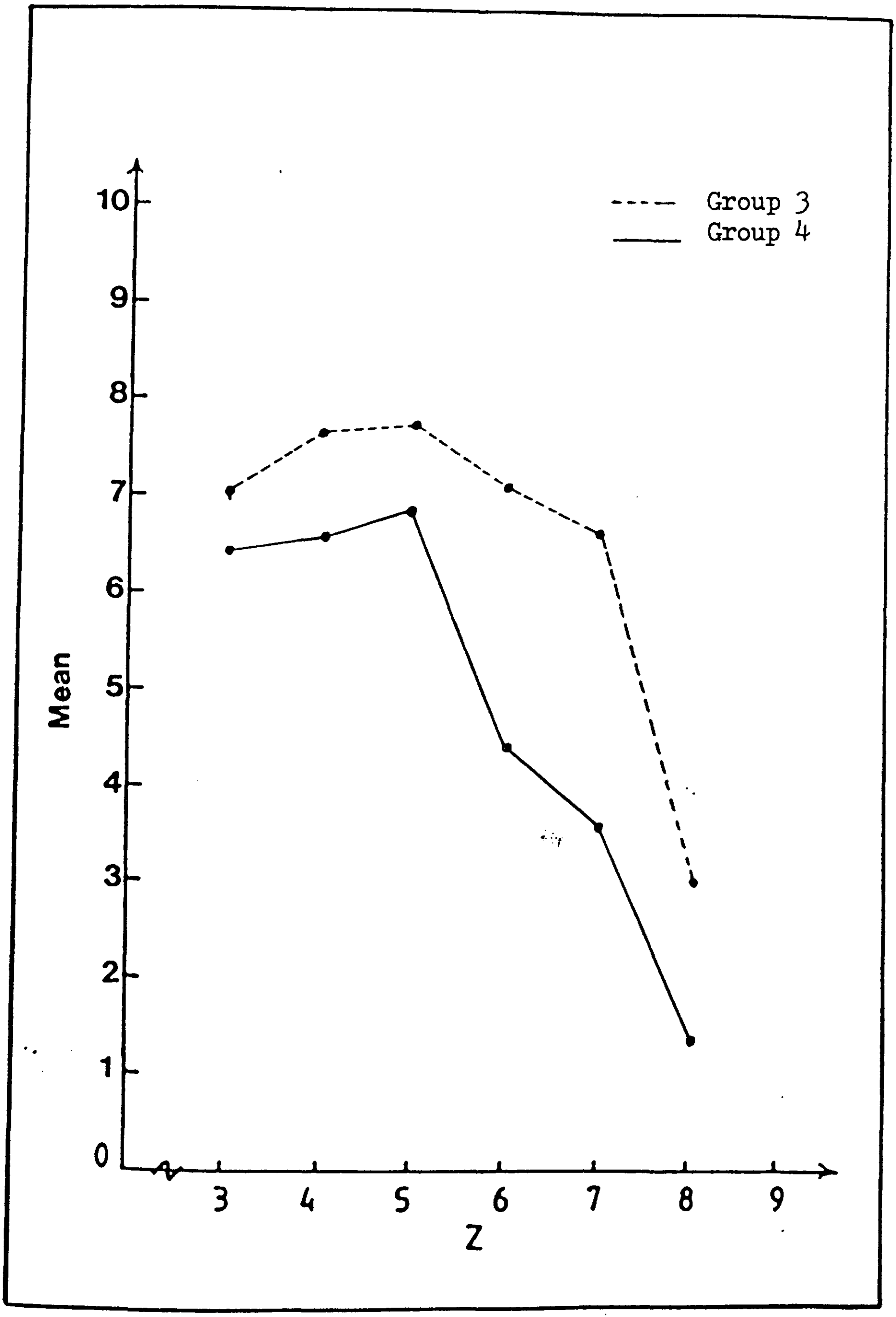


FIGURE 36. Comparison of the Means between Group 3 and Group 4.
(Sub-group X = 5)

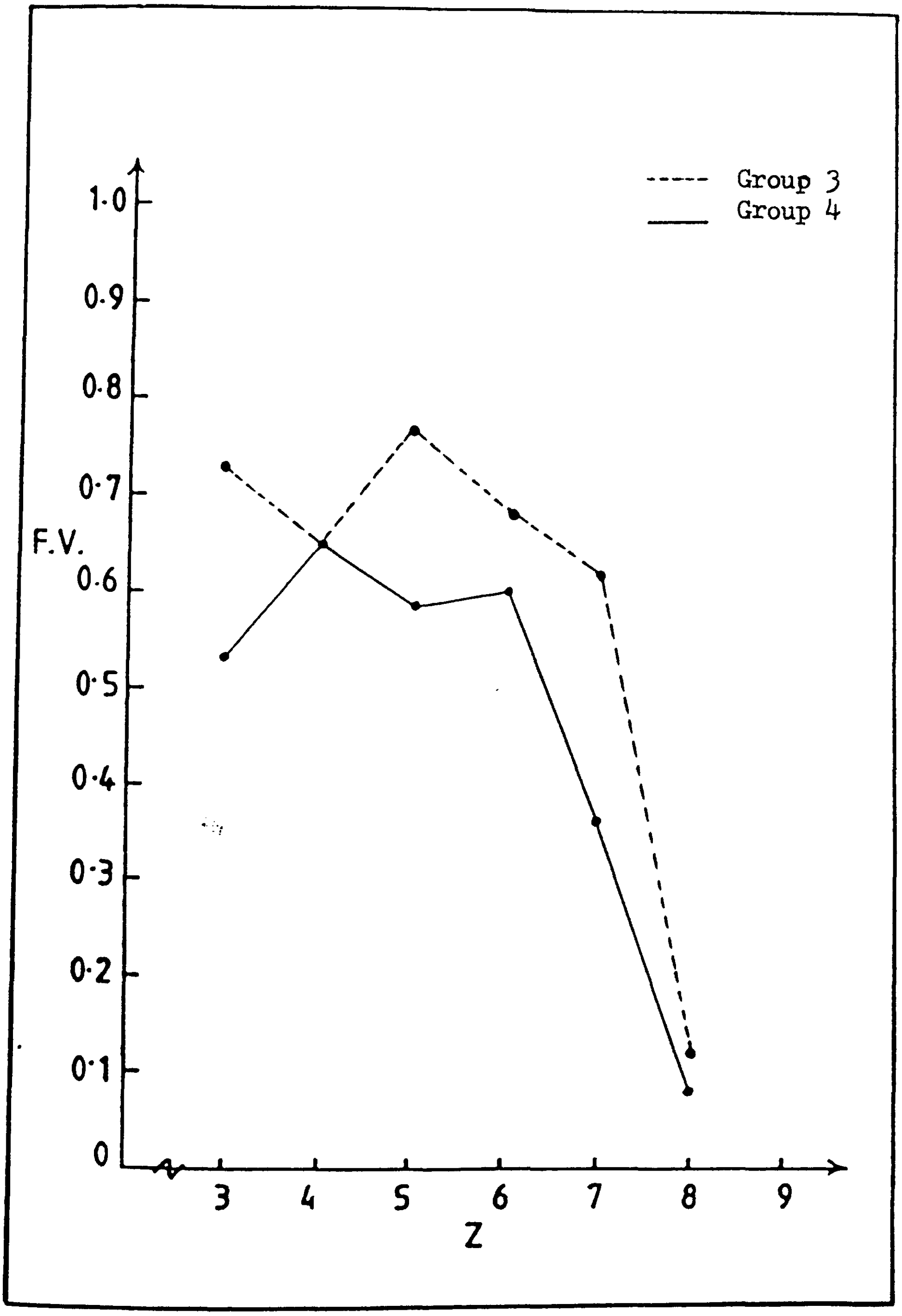


FIGURE 37. Comparison of the F.V. between Group 3 and Group 4.
(Sub-group X = 6)

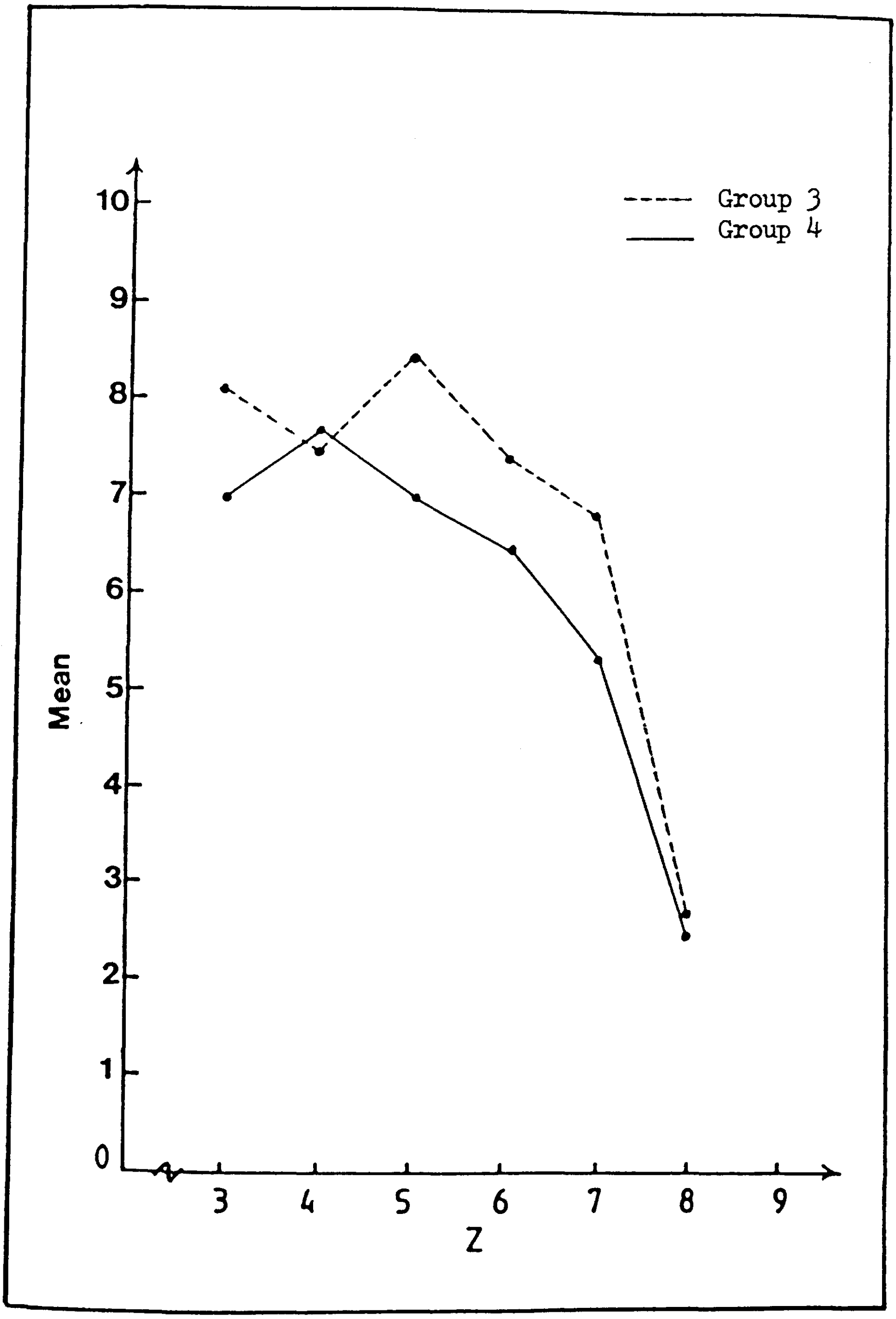


FIGURE 38. Comparison of the Means between Group 3 and Group 4.
(Sub-group X = 6)

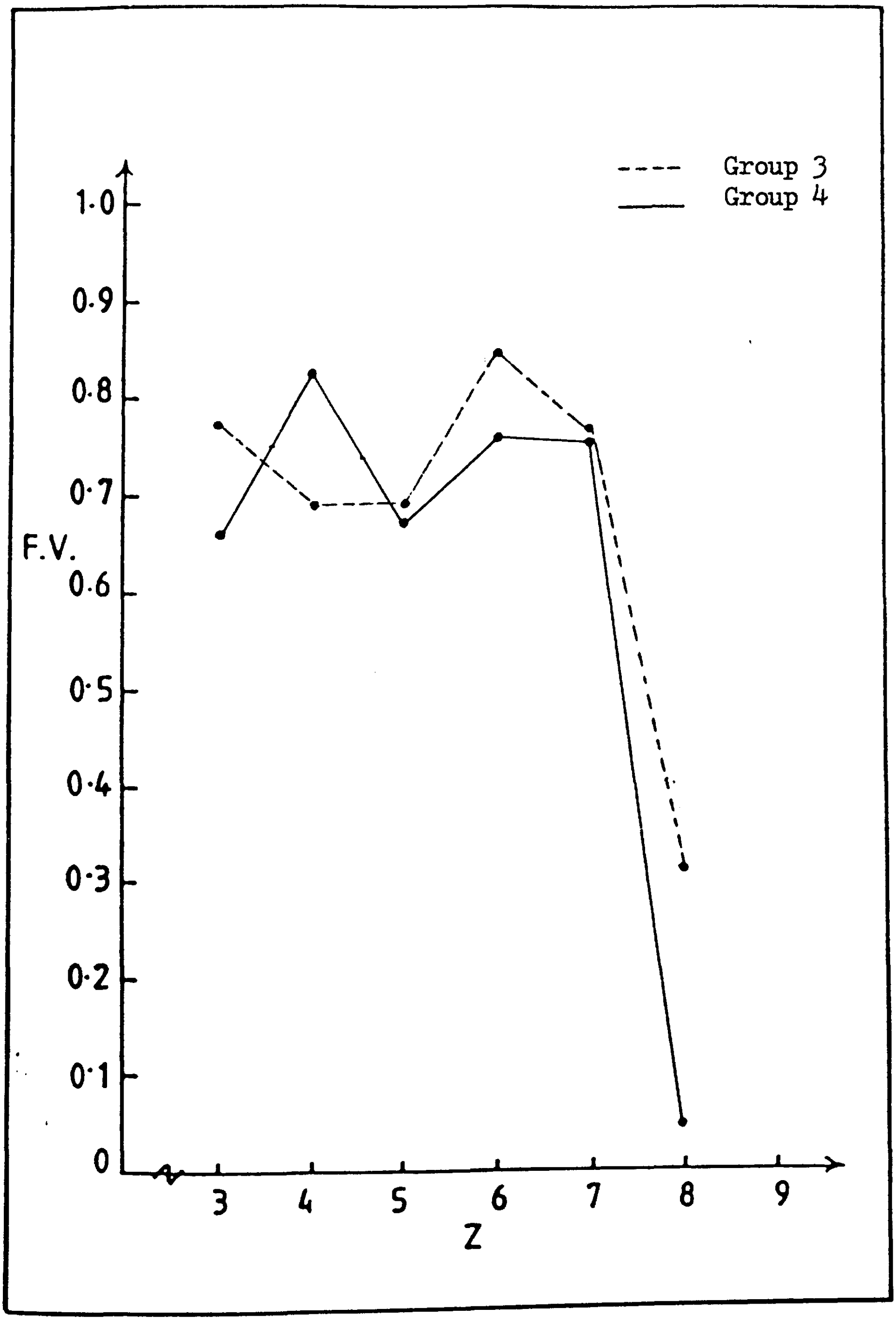


FIGURE 39. Comparison of the F.V. between Group 3 and Group 4.
(Sub-group X = 7)

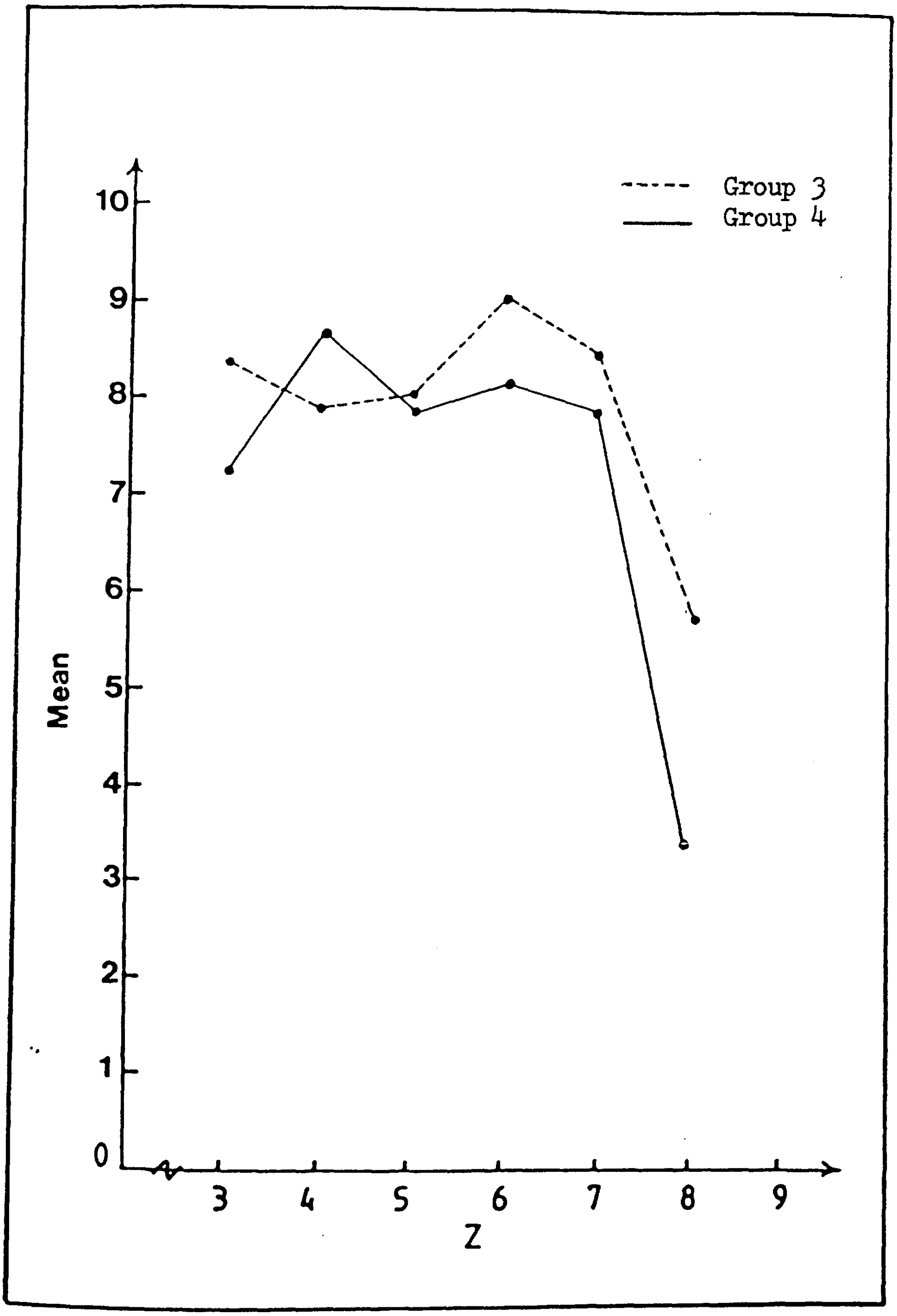


FIGURE 40. Comparison of the Means between Group 3 and Group 4.
(Sub-group X = 7)

5.4 Over-all Discussion

Let us return to the hypotheses raised at the beginning of this chapter to see how well they have fared.

1. "There will be a significant improvement in performance between students who are made to do their planning before doing any calculation and those who are left to do both simultaneously."

Although a question by question analysis between groups does not yield a large proportion of statistically significant differences, the trends are in the direction which favours the experimental group over the control group. This in itself is significant (unlikely to be by chance) and so the hypothesis is substantially upheld.

It is interesting to observe that the sharp drops in performance still take place at the value of $Z = X + 1$, but that the high performance plateau is, in general, higher for the experimental group.

2. "There will be a significant improvement in performance between students who are given sub-divided questions and those who are given the same question undivided."

Question by question analysis indicates larger improvements than those noted between the two groups above. Rather more of the differences are statistically significant and in favour of the experimental group. The over-all effects are, as predicted, to postpone the sharp drops in performance to $Z = X + 2$ or more. The higher demand questions have, in effect, become low in demand and so performance has remained high. The hypothesis has been amply supported.

3. "There will be a significant improvement in performance in favour of students who have been taught problem solving strategies throughout and those who have not."

Here /

Here again question by question analysis indicates that there are substantial improvements (not all statistically significant) between Group 3 (experimental group) and Group 4 (control group), and that the trends are almost all in favour of the experimental group. It is also noteworthy that the sharp falls in performance are postponed beyond $Z = X + 1$. Pupils seem to have incorporated the problem solving strategies to the extent that their over-all performance was improved and also their ability to tackle problems of $Z > X$ improved. This hypothesis has been well supported.

In this chapter the theory has been seen to have predictive power. A further study of this should open up many possibilities for the improvement of teaching and learning. Comparisons between the three experimental groups and the control group are given in Figures 41 through 44 for each group of X-space.

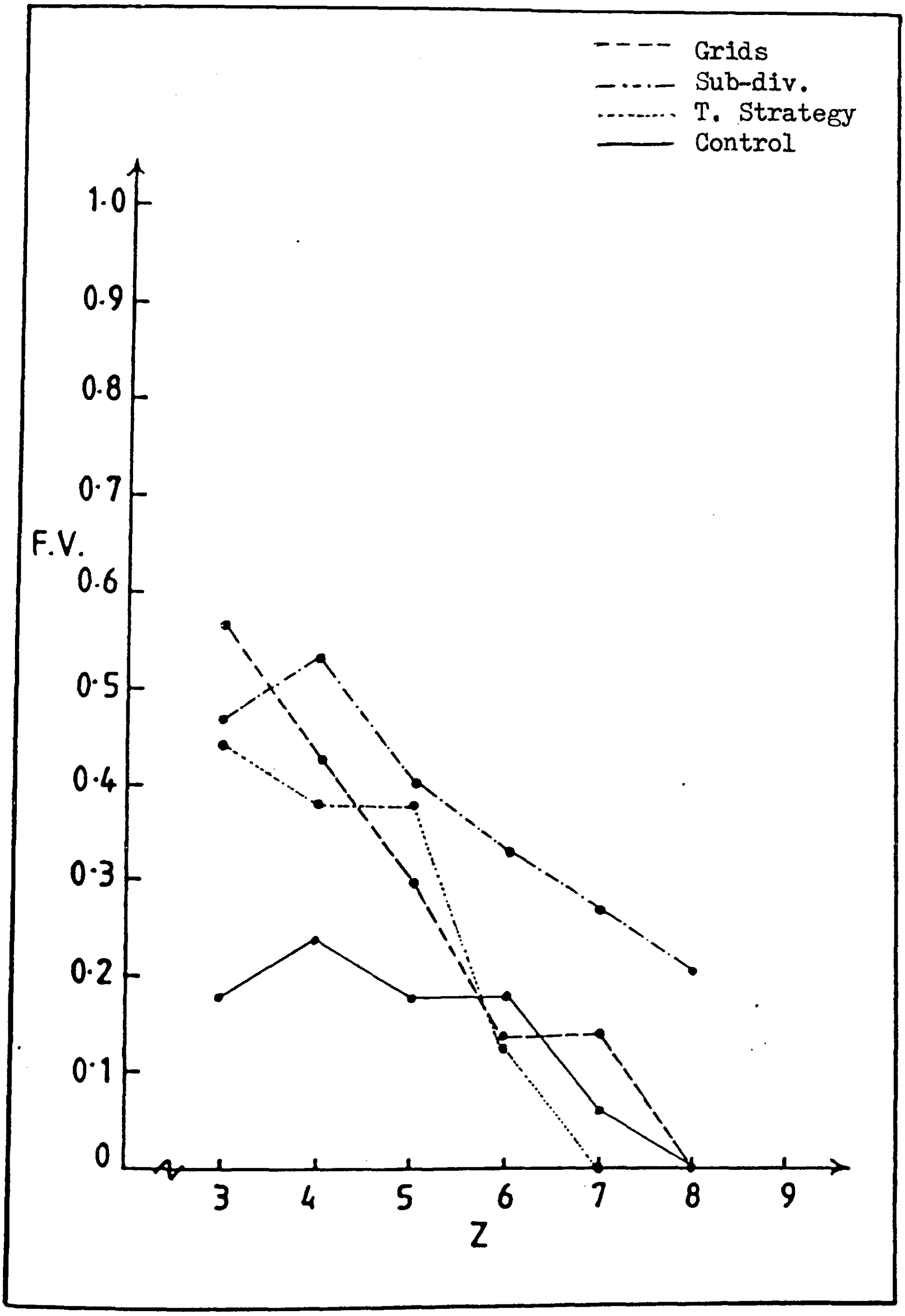


FIGURE 41. Overall Results for Sub-group X = 4 (F.V.)

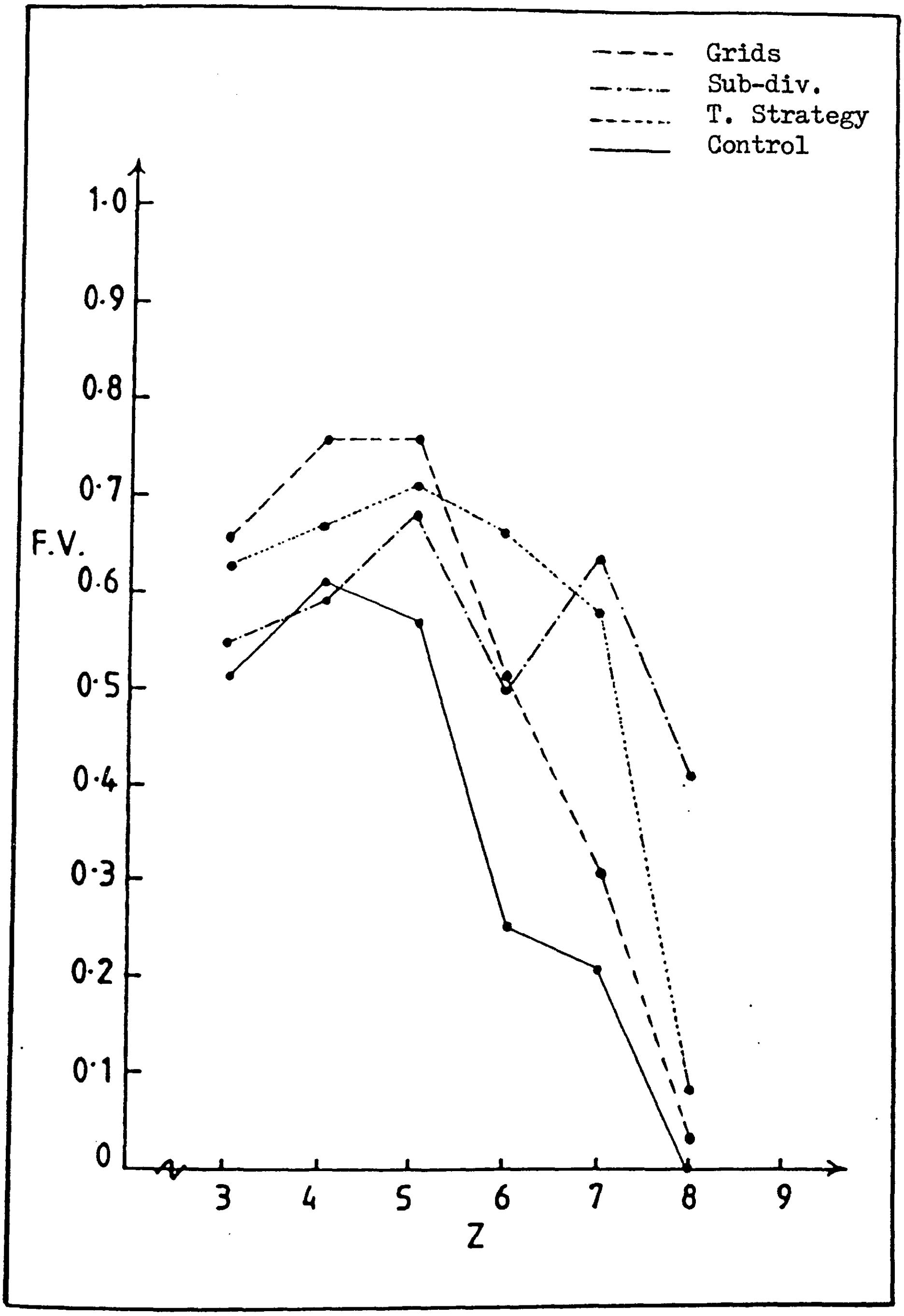


FIGURE 42. Overall Results for Sub-group X = 5 (F.V.)

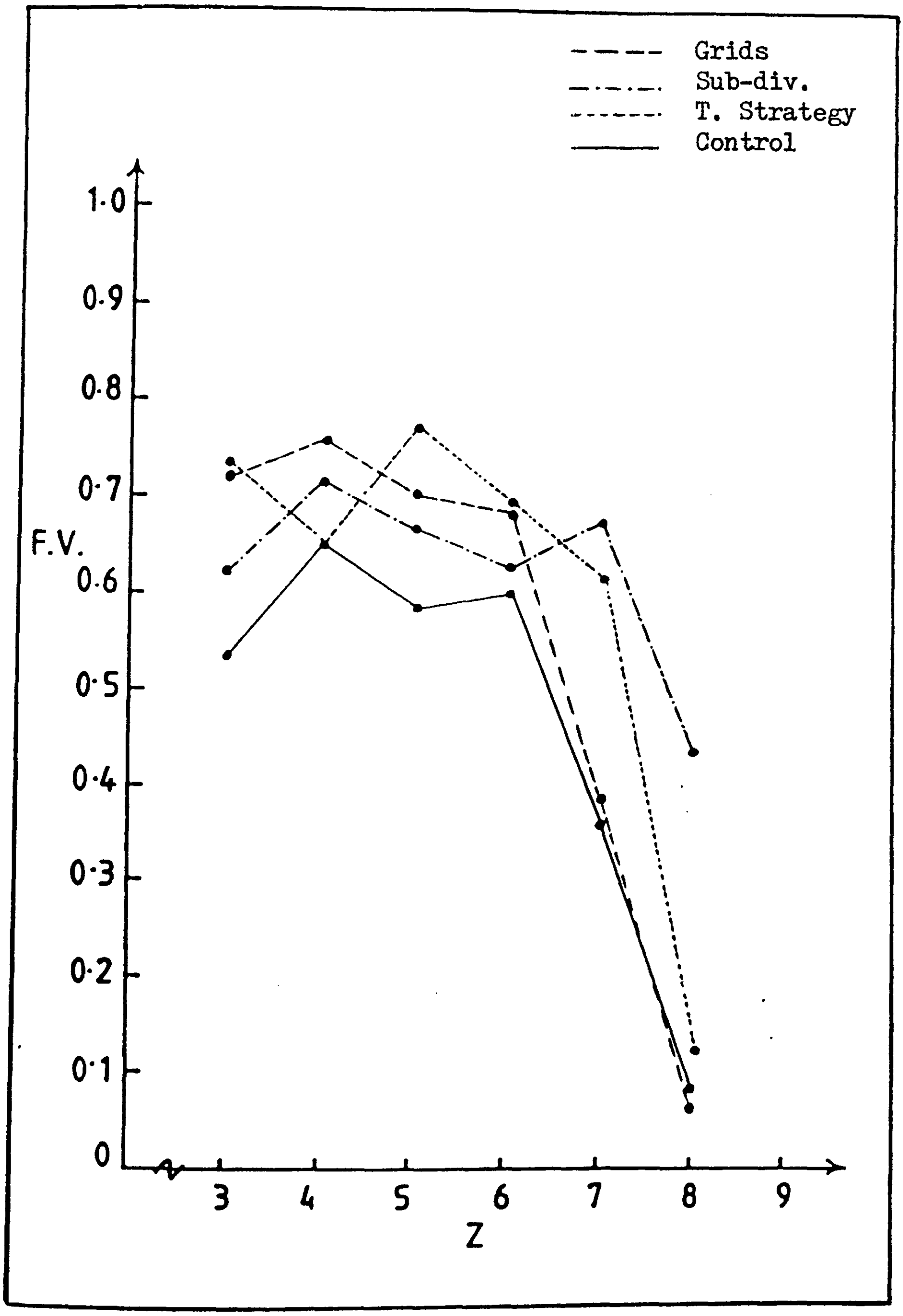


FIGURE 43. Overall Results for Sub-group X = 6 (F.V.)

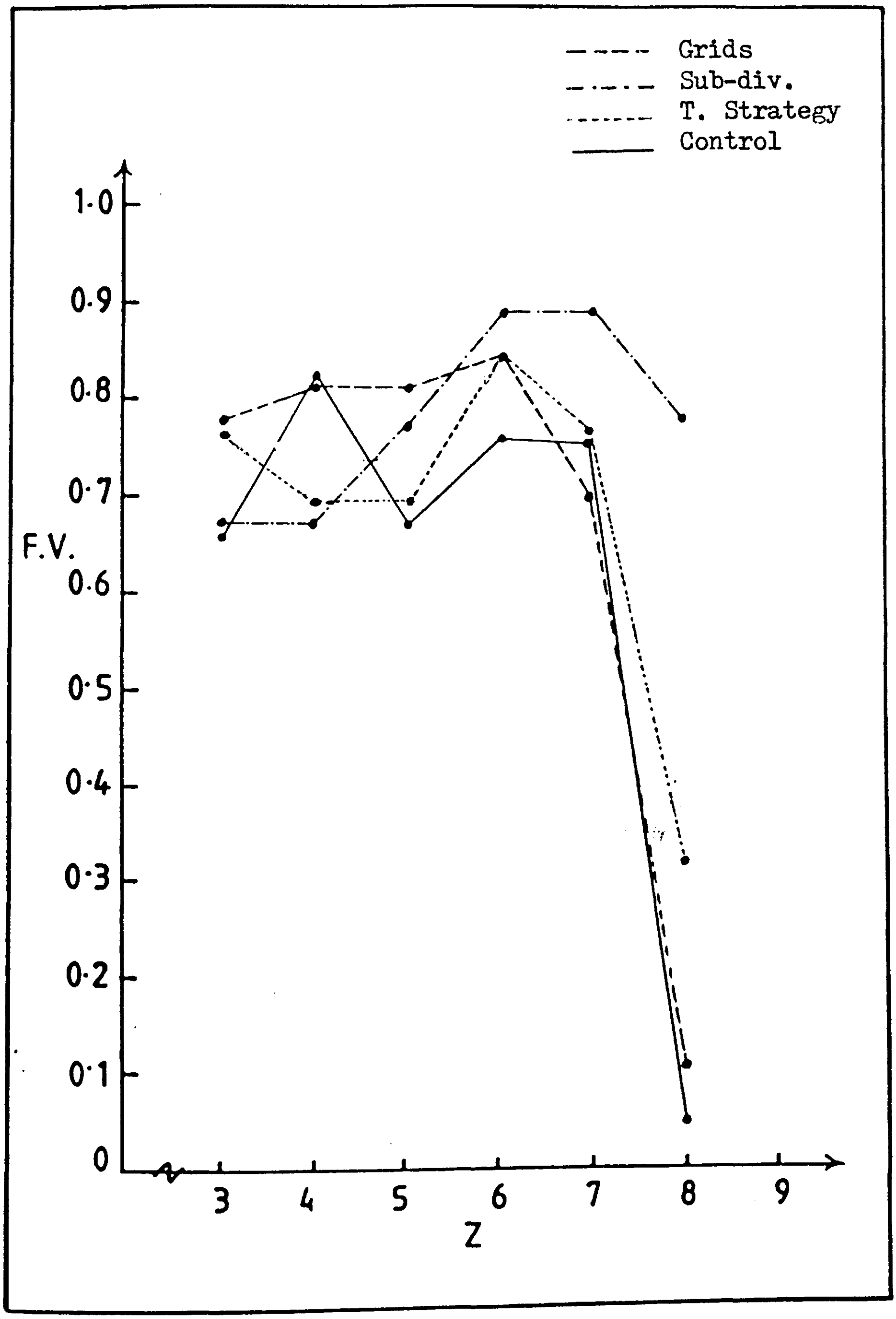


FIGURE 44. Overall Results for Sub-group X = 7 (F.V.)

CHAPTER 6

EXPERIMENT USING UNIVERSITY STUDENTS (A) TESTING THE MODEL

The model developed in the school study, if it has any validity, must be applicable at other educational levels. This chapter deals with the extension of the study into tertiary level and sets out to test the predictive power of the model.

As in the case of the school study, the proposed model was tested using the university sample in exactly the same two stages. The first was to find out whether there is a relationship between the students' holding-thinking space X, and their ability to solve individual questions of different complexity in university chemistry examinations. The second was to find out whether there is a relationship between the students' X-space and their over-all attainment scores in examinations in chemistry, physics, biology and mathematics. A confirmatory study was done during the following year.

6.1 Problems and Hypotheses

In order to test the validity of the working model using the university students, the researcher considered the following questions:

1. Is there any relationship between the students' X-space and their ability to solve individual chemistry questions of different complexity in university examinations?
2. Is there any relationship between the students' X-space and their over-all attainment in conventional university examinations in chemistry, physics, biology and mathematics?

Using the following hypotheses, it was hoped to find an answer to the two questions asked above.

1. There is a direct relationship between the students' X-space and their ability to solve chemistry questions of different Z-demand in university examinations as follows:

   (a) There will be a significant difference in the students' performance (within each X-space group) between the questions of complexity $Z \leq X$ and the questions of complexity $Z > X$.

(b) Whenever Z = X + 1 for a lower group, there will be a significant difference in performance for that group relative to the other higher groups.

2. There will be a significant difference in the over-all student attainment, in conventional university examinations in chemistry, physics, biology and mathematics, between the student groups of different X-space.

6.2 Method Used

6.2.1 Student Sample

The sample consisted of 364 students from Glasgow University. At the time of the investigation, all were currently enrolled in the first year chemistry course. Ages were around 17+. Participating students had to have the same score in the two psychological tests, namely, FIT and DBT. Table 45 shows the comparison of students' scores in both tests. Those who had the same score were divided into groups according to their measured holding-thinking space (X) as can be seen in Table 46.

6.2.2 Variables

6.2.2.1 Independent Variables

It has been shown in Chapter 4, that there were two independent variables: the students' X-space and the questions' Z-demand. The students' X-space is the maximum number of items of information, or discrete "chunks", that they can hold in mind at any one time during the solving of the question assuming that they are not employing efficient strategies. On the other hand, the questions' complexity Z is the maximum number of thought steps which would be employed by the weakest, successful student.

To establish the questions' complexity as the number of thought steps, the researcher asked the examiners, on the basis of their teaching method, how they expected their students to answer these questions before /

TABLE 45

COMPARISON OF STUDENTS' SCORES IN THE PSYCHOLOGICAL TESTS (UNIVERSITY SAMPLE)

Performance between DBT and FIT Scores	Number of Students (N)
Identical score	271
Difference ± 1	40
Difference $> \pm 1$	23
Misunderstood the instructions	18
Did not complete Test(s)	12
Total	364

TABLE 46

UNIVERSITY SAMPLE USED FOR SUBSEQUENT EXPERIMENTS

X-Space Groups	N
X = 5	98
X = 6	110
X = 7	63
Total	271

before the marking was done. In this way, the Z-values for the questions were determined before getting any results from the examiners (Appendix 10).

6.2.2.2 Dependent Variables

The students' achievement, as a dependent variable, was in two forms. The first was that, of the mean score and the F.V. for each question, to test the relationship between the students' X-space and their ability to solve chemistry questions of different complexity, Z. The second was to test the relationship between the students' X-space and their attainment in chemistry, therefore, the students' scores over the two class exams and the degree exam were employed. In the case of their attainment in physics, biology and mathematics, the students' results in the degree examinations only were obtained.

6.2.3 Procedures

The sequence of the procedures using the university sample is similar to that which the researcher followed using the schools sample (Chapter 4). The administration of the psychological tests (DBT and FIT) was in the third week of the first term (October). From two class examinations (January and May), five questions were chosen before the marking was done. The Z-demand of these five questions varied between Z = 4 through Z = 9, but no question was found to have a demand of Z = 6. When the examiners finished marking the students' answers papers, all the data required for each individual was entered into the computer.

In this experiment, it should be noted that:

1. There was no interference from the researcher in determining the Z-demand for the questions which were determined before marking.

2. There was no participation or interference from the researcher in marking or scoring the students' answers.

3. /

3. The students' X-space was measured during the first term (October - December) so that no attempt would be made by the researcher to "match" the results. In addition to this, a list of students' names and their scores on the psychological tests was given to the independent researcher for storage and was not revealed until after the chemistry markers had completed their task.

6.2.4 Data Analysis

The hypotheses presented earlier in this chapter were tested exactly in the same manner as in Chapter 4 by using the method described by Kellet[(42)] (Appendix 6).

6.3 The Results

6.3.1 Testing Hypothesis 1

Table 47, as well as Figures 45 through 48, show the F.V. for all the questions of different complexity Z for all the student groups of different X-space.

The means and the standard deviations are given in Table 48. Figure 49 shows the means for all questions for all the student groups.

Once again, the results illustrated in Figures 45 through 48, as full lines, do not conform exactly to the theoretical curves (dotted lines), but there are strong similarities. In Figure 45, the X = 5 students do quite well in both questions of complexity Z = 4 and Z = 5, but they fall away at questions of Z = 7 and Z = 8 since there is no question of complexity Z = 6. Figure 46, shows the same trends for the X = 6 students. In Figure 47, the X = 7 students maintain a F.V. greater than 75% for the items of complexity $Z \leqslant 7$, but plunge to a F.V. of less than 29% and 18% for questions of Z = 8 and Z = 9.

The remarkable result is that, when the three curves appear together, the predictive power of the model is seen clearly. As has been stated above, no question was found to have a demand of 6 but there /

TABLE 47

THE F.V. FOR THE QUESTIONS OF DIFFERENT Z AGAINST STUDENT GROUPS OF DIFFERENT X

Groups \ Questions		Q.1 Z = 4	Q.2 Z = 5	Q.3 Z = 7	Q.4 Z = 8	Q.5 Z = 9
X = 5	N = 98	0.69	0.68	0.11	0.04	0.06
X = 6	N = 110	0.74	0.72	0.17	0.10	0.14
X = 7	N = 63	0.81	0.79	0.75	0.29	0.18

TABLE 48

MEANS AND STANDARD DEVIATIONS

(Possible Score for Each Question is 10)

Groups \ Questions		Q.1 Z = 4	Q.2 Z = 5	Q.3 Z = 7	Q.4 Z = 8	Q.5 Z = 9
X = 5	Mean	8.5	8.4	5.4	2.4	2.8
	S.D.	2.3	2.8	2.9	2.6	2.8
X = 6	Mean	8.6	8.9	6.1	3.9	3.7
	S.D.	2.7	2.2	2.5	2.9	2.7
X = 7	Mean	9.3	9.0	8.7	5.2	4.4
	S.D.	1.6	2.5	2.5	3.8	3.8

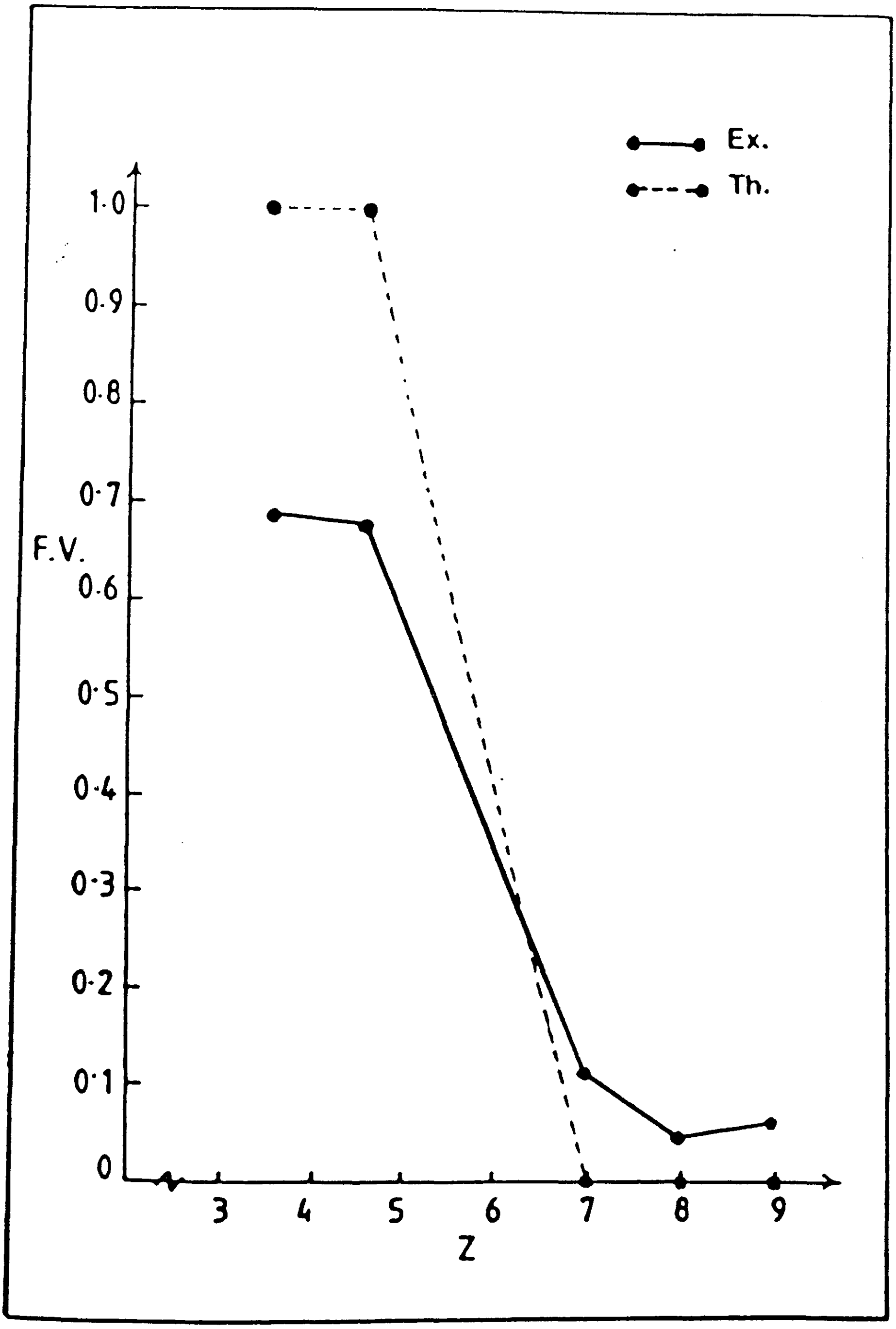


FIGURE 45. Results from X = 5 Students on Conventional University Examination Questions of Different Z-demand.

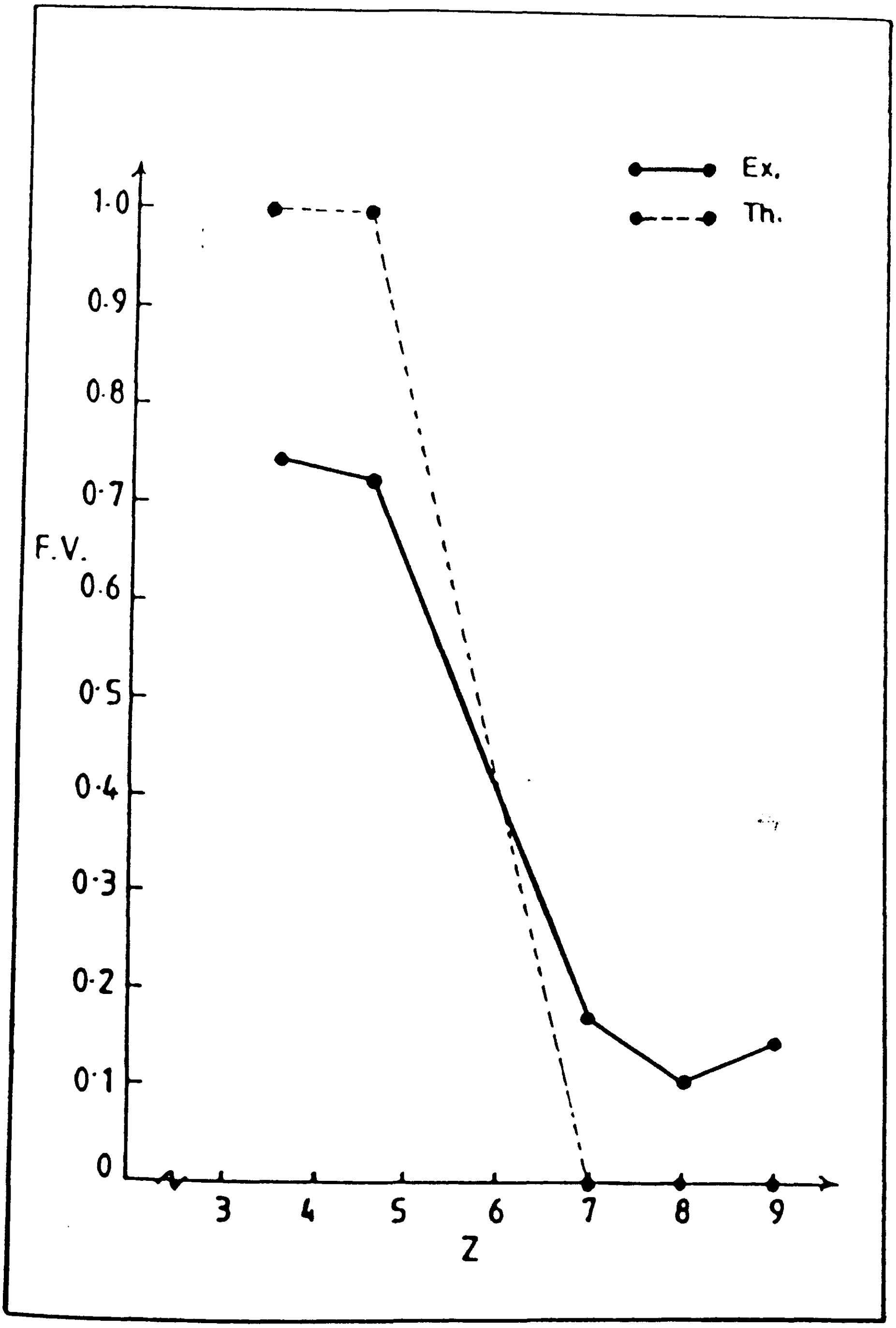


FIGURE 46. Results from X = 6 Students on Conventional University Examination Questions of Different Z-demand.

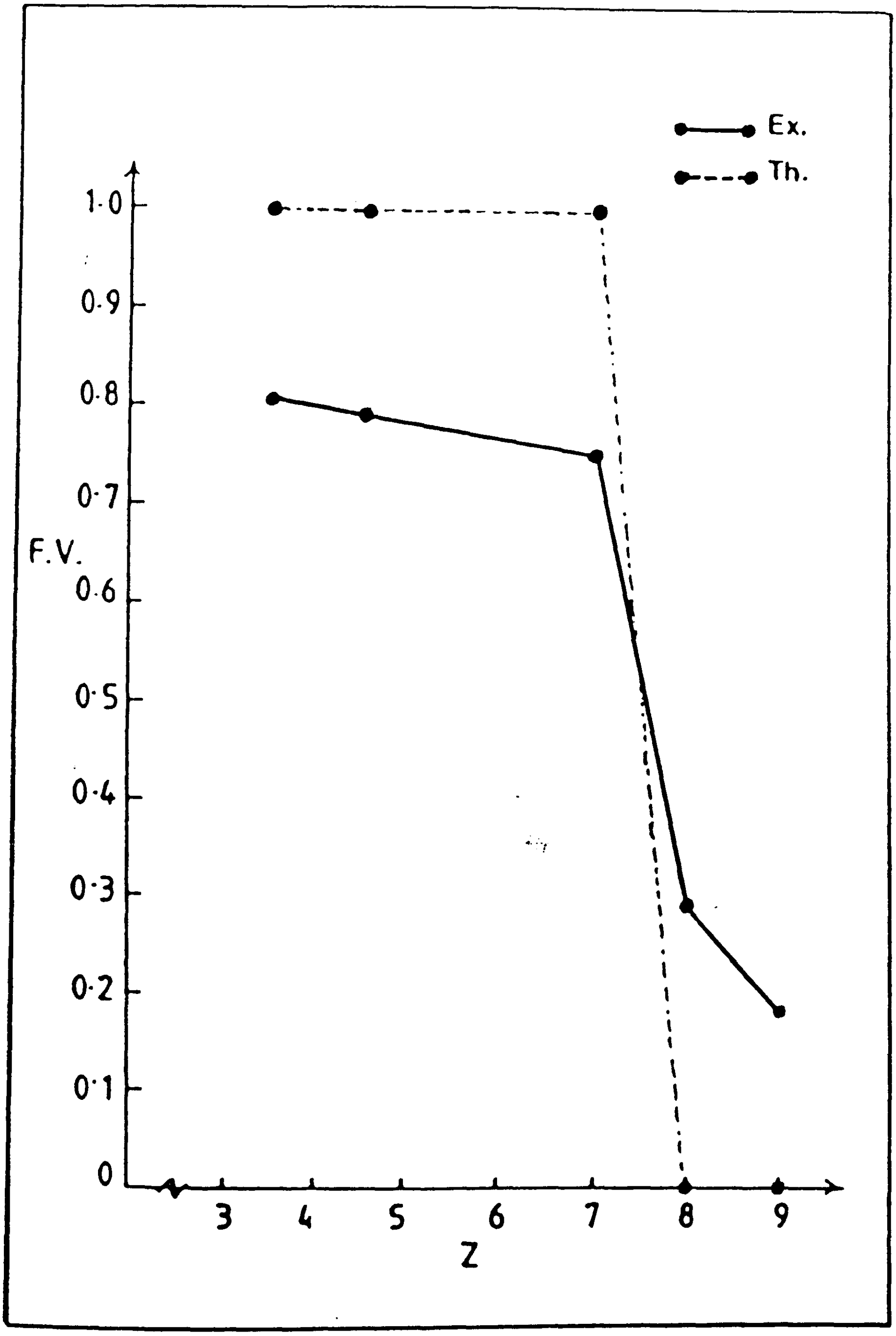


FIGURE 47. Results from X = 7 Students on Conventional University Examination Questions of Different Z-demand.

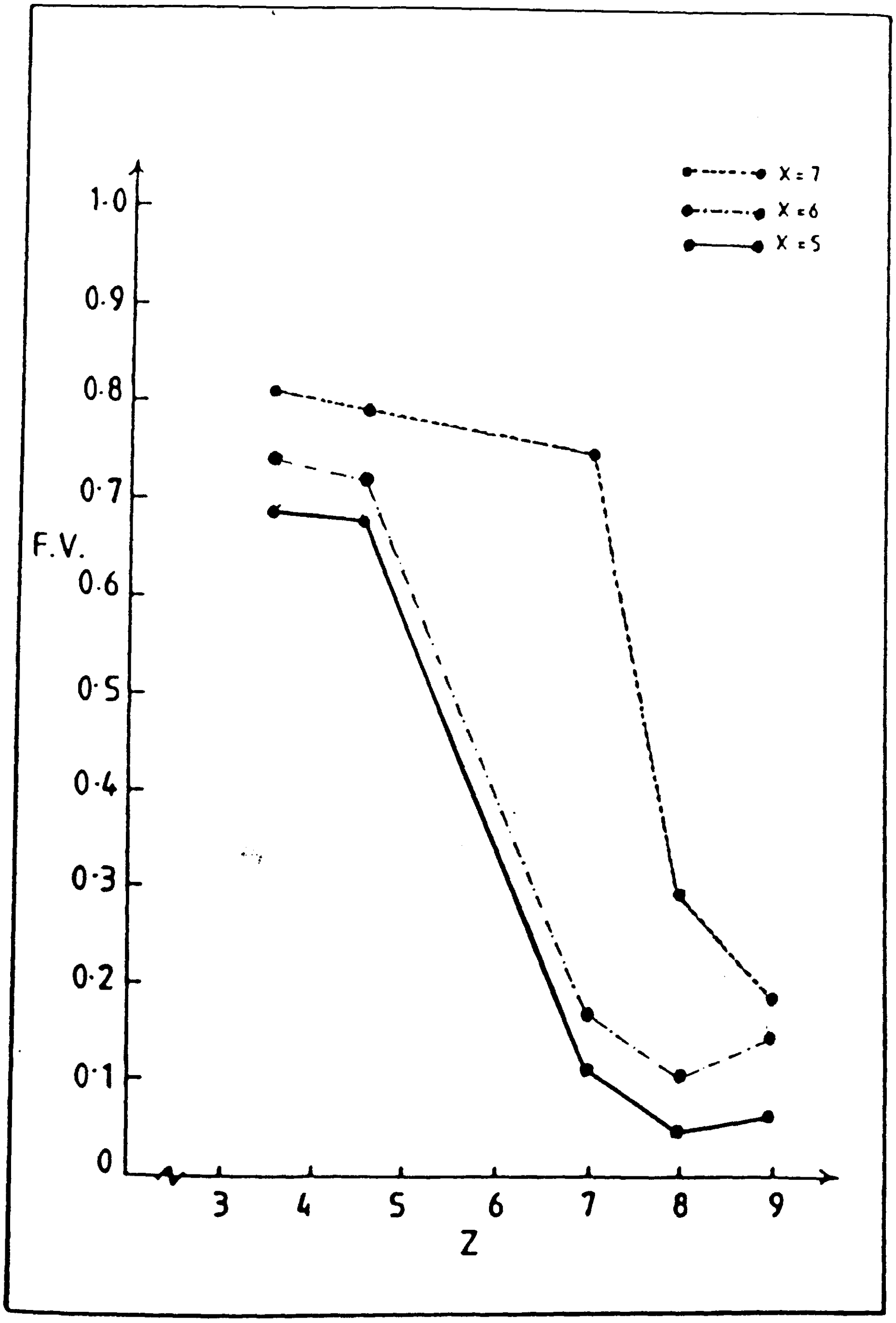


FIGURE 48. Comparison of the Results from University Students of Different X-space on Questions of Different Z-demand (F.V.).

there were questions of Z = 4 through to Z = 9. The prediction was that, since there was no question of Z = 6, the students of capacity X = 6 would not be able to exhibit a superior performance over those of the X = 5. Figure 48, shows how well this prediction was borne out where the curves for the X = 5 and the X = 6 are almost identical, while that for X = 7 students, the curve follows the pattern in that they exhibited their superior performance over those of X = 5 and X = 6 in the question of Z = 7.

The patterns which emerged from Figure 48 and Figure 49 are similar to those in Chapter 4: the X = 7 curve represents better all over performance in all cases than X = 6, and both are better than X = 5. When $Z \leq X$ the students' performance does not reach 100% and when $Z > X$ it does not reach a zero % at once.

At this stage, four comparisons were made to find out the relationship between the students' X-space and their ability to solve questions of different Z-demand. These comparisons were made in exactly the same manner as in Chapter 4. The first two comparisons were made to find out whether the students' X-space significantly affects their ability to solve questions of different Z-demand. Tables 49 and 50 show the results of these two comparisons.

From Table 49, where the significance of the F.V. differences for each question between the student groups can be seen, the results indicate that there is no significant difference between the X = 5 and X = 6 in the performance in all the questions, as has been predicted before, since no question was found to have a demand Z = 6. On the other hand, there are significant differences between X = 5 and X = 7 in questions of Z = 7, 8 and 9. In addition to this, the differences between X = 6 and X = 7 in questions of Z = 7 and 8 are significant.

The significance of the differences in means, for each question, between the students' groups can be seen in Table 50. The results show similar trends to those in the case of the F.V. except that the differences between X = 5 and X = 6 are significant in questions of Z = 8 and 9, and there is no significant difference between X = 6 and /

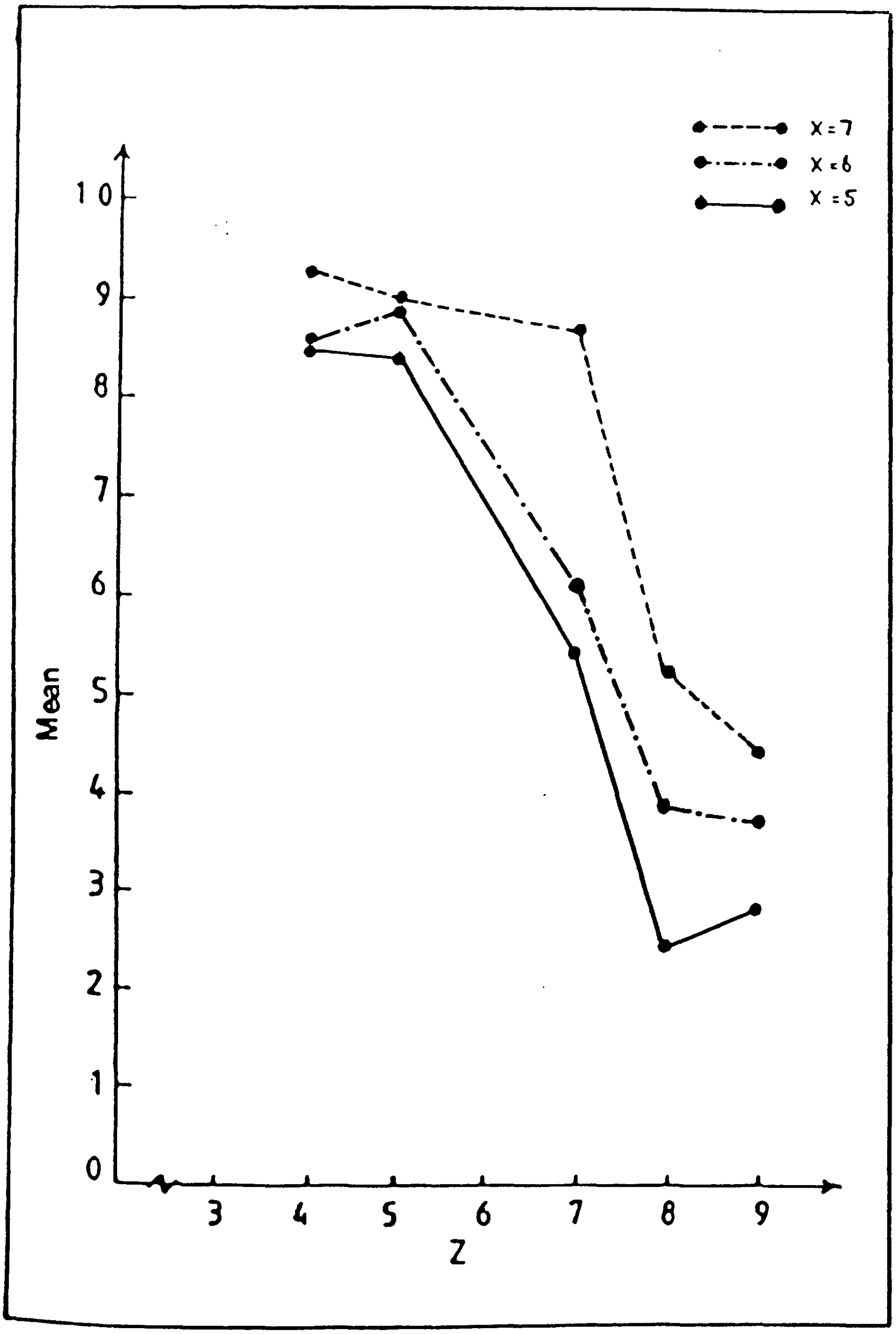


FIGURE 49. Comparison of the Results from University Students of Different X-space on Questions of Different Z-demand (Means).

TABLE 49

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH QUESTION BETWEEN THE STUDENT GROUPS

Questions	Groups' Diff.	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 4	N.S.	N.S.	N.S.
Q.2	Z = 5	N.S.	N.S.	N.S.
Q.3	Z = 7	N.S.	S.**	S.**
Q.4	Z = 8	N.S.	S.**	S.*
Q.5	Z = 9	N.S.	S.**	N.S.

** at 0.01 level

* at 0.05 level

TABLE 50

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS FOR EACH QUESTION BETWEEN THE STUDENT GROUPS

Questions \ Groups Diff		X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
Q.1	Z = 4	N.S.	N.S.	N.S.
Q.2	Z = 5	N.S.	N.S.	N.S.
Q.3	Z = 7	N.S.	S.**	S.**
Q.4	Z = 8	S.**	S.**	N.S.
Q.5	Z = 9	S.*	S.**	N.S.

** at 0.01 level

* at 0.05 level

and X = 7 except in question of Z = 7.

Tables 51 and 52, show the results of the second two comparisons which have been made to find out the effect of the questions' complexity Z on the students' performance. As can be seen, in all groups of different X-space, there are significant differences between the questions of $Z \leqslant X$ and those of $Z > X$. In addition to this, there is no significant difference within the questions when $Z \leqslant X$, or within the group when $Z > X$.

Conclusion

In the comparisons made, the results tend to support hypothesis 1, and at the same time, support the results obtained from the schools' sample. There is strong evidence therefore in favour of there being a relationship between the students' holding-thinking space (X) and their ability to solve questions of different complexity (Z). In addition to this, the results gave strong evidence also for the validity of the model in predicting the students' performance in an individual question.

6.3.2 Testing Hypothesis 2

The hypothesis that "there will be a significant difference in the over-all attainment in the conventional university examinations in chemistry, physics, biology and mathematics, between the students groups of different X-space" was tested in two parts. The first was done by comparing the students' means between the groups of different X in two class examinations in chemistry. The second was done by comparing the students' results in the degree examinations, between the groups of different X, in chemistry, physics, biology and mathematics.

1. Table 53 shows the means and the standard deviations for the students' scores in first and second year chemistry class examinations. Figures 50 and 51 show the means for all groups of different X-space. The results, which can be seen in Table 54, indicate that all the differences are significant /

TABLE 51

THE SIGNIFICANCE OF THE F.V. DIFFERENCES FOR EACH STUDENT GROUP BETWEEN QUESTIONS OF DIFFERENT Z-DEMAND

Groups	Z \ Z	4	5	7	8
X = 5	5	N.S.	-		
	7	S.**	S.**	-	
	8	S.**	S.**	N.S.	-
	9	S.**	S.**	N.S.	N.S.
X = 6	5	N.S.	-	-	-
	7	S.**	S.**	-	-
	8	S.**	S.**	N.S.	-
	9	S.**	S.**	N.S.	N.S.
X = 7	5	N.S.	-	-	-
	7	N.S.	N.S.	-	-
	8	S.**	S.**	S.**	-
	9	S.**	S.**	S.**	N.S.

** at 0.01 level

TABLE 52

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS
FOR EACH STUDENT GROUP BETWEEN
QUESTIONS OF DIFFERENT Z

Groups	Z \ Z	4	5	7	8
X = 5	5	N.S.	-	-	-
	7	S.**	S.**	-	-
	8	S.**	S.**	S.**	-
	9	S.**	S.**	S.**	N.S.
X = 6	5	N.S.	-	-	-
	7	S.**	S.**	-	-
	8	S.**	S.**	S.**	-
	9	S.**	S.**	S.**	N.S.
X = 7	5	N.S.	-	-	-
	7	N.S.	N.S.	-	-
	8	S.**	S.**	S.**	-
	9	S.**	S.**	S.**	N.S.

** at 0.01 level

TABLE 53

MEANS AND STANDARD DEVIATIONS

(1st and 2nd Chemistry Class Exams)

Groups		1st Class Exam	2nd Class Exam
X = 5	Mean	47.0	48.5
	S.D.	16.8	18.6
X = 6	Mean	59.4	62.5
	S.D.	13.4	14.6
X = 7	Mean	71.0	70.5
	S.D.	12.8	14.8

TABLE 54

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS

Groups Diff / Exams	X = 5 and X = 6	X = 5 and X = 7	X = 6 and X = 7
1st Class Exam	Sig.*	Sig.**	N.S.
2nd Class Exam	Sig.*	Sig.**	N.S.

** at 0.01 level   * at 0.05 level

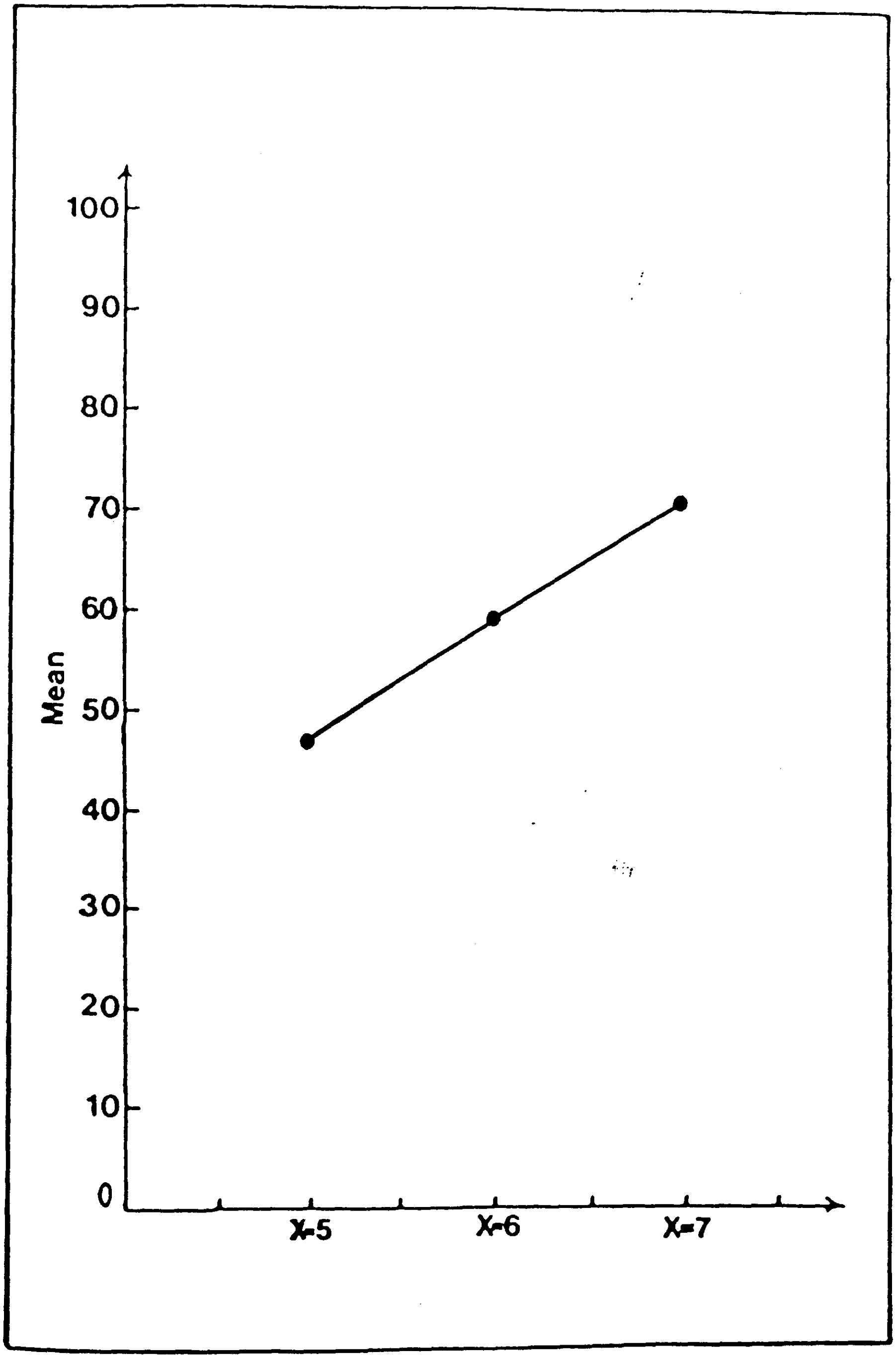


FIGURE 50. Students Means in the 1st Class Chemistry Examination.

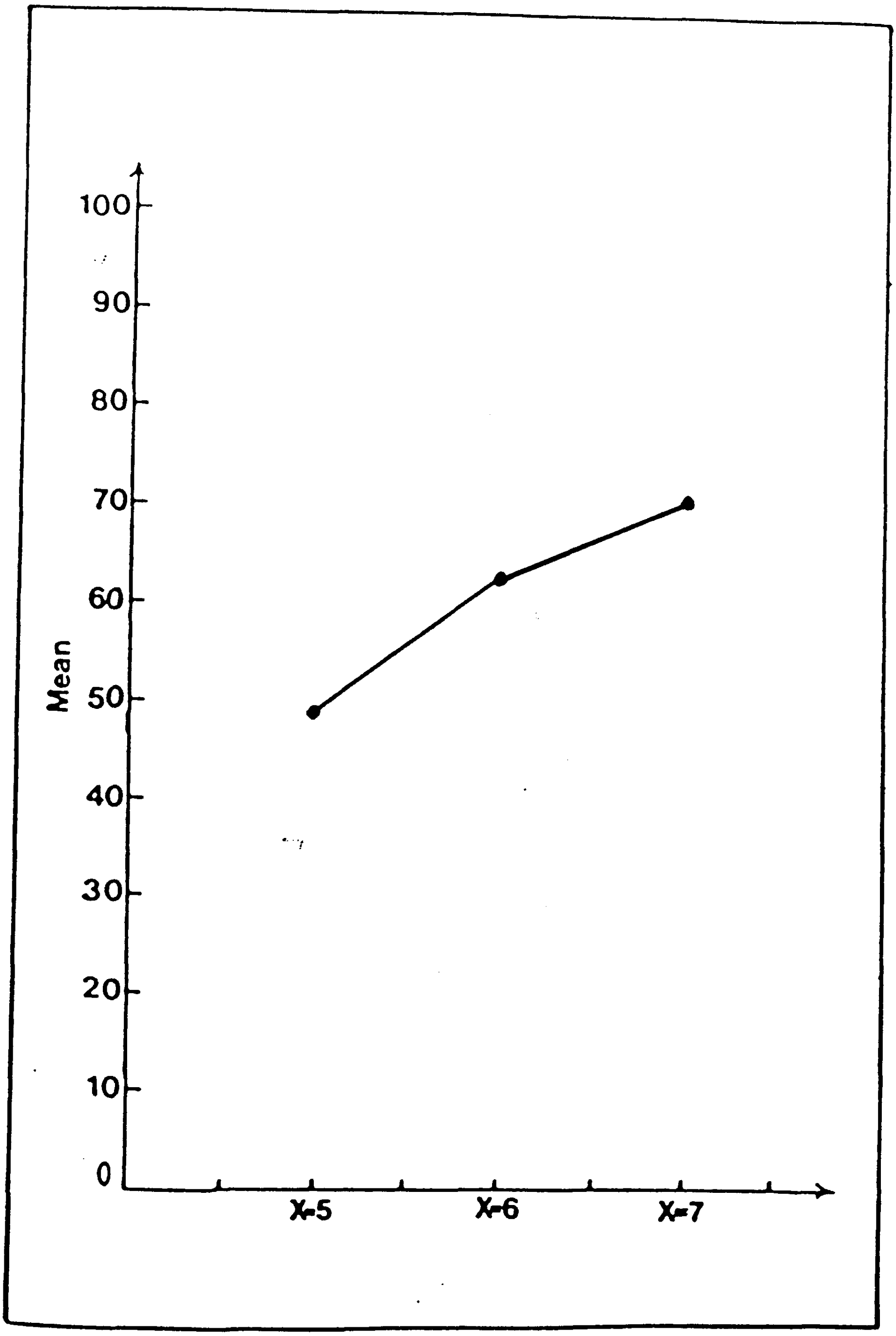


FIGURE 51. Students Means in the 2nd Class Chemistry Examination.

significant in both class exams except that between X = 6 and X = 7

2. It should be noted that on the basis of high performance on the two class examinations, students in the first year are exempt from sitting the final degree examinations. Those who are not exempt, must sit the degree examinations and, on the basis of their performance, are either accepted into second year or rejected. Table 55, shows the results of students in chemistry examinations in Session 1984-1985.

Of the X = 7 students, about 64% were exempt and no one failed after two diets of degree examinations. On the other hand, only about 11% of the X = 5 were exempt, and about one-third failed in both diets of examinations. However, the 11% of the X = 5 students, who were exempt, were performing like the majority of the X = 7 students. The X = 6 students perform in between both X = 5 and X = 7.

It could be argued that the X = 5 students have access to fewer questions (i.e. questions of $Z \leq 5$ only) in the examination paper, and so would have a lower potential maximum score in the examination than those of X = 6 and X = 7, therefore, they have a smaller chance of being exempt. Table 55, shows the compositions of the X = 5, X = 6 and X = 7 from this sample in the second and the third year. As expected the proportion of X = 5 students diminishes as the group proceeds up through the years.

It should be noted that, in Chapter 4, the O-Grade examinations had already fractionated out more than half of the pupils of X = 4. Furthermore, the university entrance examinations also have removed the remainder of the X = 4 students.

Similar patterns would be applied in the case of the university examinations. From Table 56, it can be seen that the first year examinations, as well as second year examinations, have fractionated out some of X = 5 students, and so the composition of the third year is proportionally richer in students of X = 6 and X = 7.

Table /

TABLE 55

RESULTS OF STUDENTS IN CHEMISTRY EXAMINATIONS DURING SESSION 1984-1985

Groups	Exempt	Pass Degree Exam (June)	Pass Degree Exam (Sept.)	Fail
X = 5	11.2%	41.8%	17.4%	29.6%
X = 6	30.9%	52.7%	7.3%	9.1%
X = 7	63.5%	31.7%	4.8%	0.0%

TABLE 56

THE COMPOSITION OF X-SPACE GROUPS
IN CHEMISTRY

Groups \ Years	First Year 84/85 N = 271	Second Year 85/86 N = 109	Third Year 86/87 N = 33
X = 5	N = 98 : 36%	N = 29 : 27%	N = 6 : 18%
X = 6	N = 110 : 41%	N = 42 : 39%	N = 13 : 40%
X = 7	N = 63 : 23%	N = 38 : 35%	N = 14 : 42%

Table 57, shows the significance of the differences between the percentages of students who were exempt and those who passed and failed.

Tables 58 and 59 show a similar pattern, in general, with rather smaller numbers of students in physics, biology and mathematics, who were also studying chemistry. They were sub-sets of the whole physics, mathematics and biology class.

At this stage, it was interesting to see how well these students performed in the previous year when they sat H-Grade (University Entrance) examinations. Table 60 shows the students' grades in school chemistry, physics, biology and mathematics which were collected from the university records office. The significance of the differences between the students' percentages are given in Table 61.

In general, as can be seen from Tables 60 and 61, the patterns of the H-Grade results are very similar to those in the university examinations.

1. The percentage of the X = 7 students in Grade A in all subjects is significantly higher than those of the X = 6, and both are significantly higher than the X = 5.

2. Despite the fact that some of the differences in the percentages of the students in Grade C are not significant, the percentage of the X = 5 students in that grade is higher in all cases than the percentage of the X = 6 and both, in all cases also, are higher than the X = 7.

3. No significant differences can be claimed between the students (in groups of different X-space) at Grade B.

Conclusion

On the basis of the results obtained, the students' holding-thinking space (X) is a good predictor for their attainment in the conventional university examinations as well as the H-Grade examinations in chemistry, physics, biology and mathematics. The results therefore tend to support hypothesis 2.

TABLE 57

THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN THE STUDENTS' PERCENTAGES

Groups' Diff.	Exempt	Pass	Fail
X = 5 and X = 6	S.**	N.S.	S.**
X = 5 and X = 7	S.**	N.S.	S.**
X = 6 and X = 7	S.**	N.S.	N.S.

** at 0.01 level

TABLE 58

RESULTS OF STUDENTS IN PHYSICS, BIOLOGY AND MATHEMATICS
UNIVERSITY DEGREE EXAMINATIONS
DURING SESSION 1984/1985

Subject	Groups	Exempt	Pass	Fail
Physics*	X = 5 (N = 24)	12.5%	66.7%	20.8%
	X = 6 (N = 31)	41.9%	45.2%	12.9%
	X = 7 (N = 24)	50.0%	33.3%	16.7%
Biology	X = 5 (N = 69)	37.7%	34.8%	27.5%
	X = 6 (N = 75)	61.3%	17.3%	21.3%
	X = 7 (N = 32)	78.1%	15.6%	6.3%
Mathematics	X = 5 (N = 46)	10.9%	34.8%	54.3%
	X = 6 (N = 59)	30.5%	39.0%	30.5%
	X = 7 (N = 44)	50.0%	34.1%	15.9%

The results for physics, biology and mathematics were based upon the students of these classes who were also studying chemistry. They may, therefore, not be a typical cross-section of the classes.

* Two different physics courses (Physics A and Physics B) are combined together.

TABLE 59

THE SIGNIFICANCE OF THE DIFFERENCES BETWEEN THE STUDENTS' PERCENTAGES IN THE UNIVERSITY'S EXAMINATIONS

Subjects	Comparisons	Exempt	Pass	Fail
Physics	X = 5 and X = 6	S.**	S.*	N.S.
	X = 5 and X = 7	S.**	S.*	N.S.
	X = 6 and X = 7	N.S.	N.S.	N.S.
Biology	X = 5 and X = 6	S.**	S.**	N.S.
	X = 5 and X = 7	S.**	S.**	S.*
	X = 6 and X = 7	N.S.	N.S.	N.S.
Mathematics	X = 5 and X = 6	S.**	N.S.	S.**
	X = 5 and X = 7	S.**	N.S.	S.**
	X = 6 and X = 7	S.**	N.S.	N.S.

** at 0.01 level
* at 0.05 level

TABLE 60

RESULTS OF STUDENTS IN H-GRADE EXAMINATIONS DURING 1983/1984

Subject	Groups	Grade A	Grade B	Grade C
Chemistry	X = 5 (N = 87)	19.5%	51.7%	28.8%
	X = 6 (N = 99)	29.3%	44.4%	26.3%
	X = 7 (N = 56)	57.1%	37.5%	5.3%
Physics	X = 5 (N = 69)	11.6%	40.6%	47.8%
	X = 6 (N = 80)	27.5%	45.0%	27.5%
	X = 7 (N = 53)	47.1%	35.9%	17.0%
Biology	X = 5 (N = 36)	8.3%	63.9%	27.0%
	X = 6 (N = 33)	27.3%	54.6%	18.1%
	X = 7 (N = 21)	33.3%	52.4%	14.3%
Mathematics	X = 5 (N = 77)*	16.9%	45.5%	35.1%
	X = 6 (N = 94)	26.6%	47.9%	25.5%
	X = 7 (N = 54)	40.7%	44.5%	14.8%

* 2 students were in Grade D (2.5%)

TABLE 61

THE SIGNIFICANCE OF THE STUDENTS' PERCENTAGE IN H-GRADE EXAMINATIONS DURING 1983/1984

Subjects	Comparisons	Grade A	Grade B	Grade C
Chemistry	X = 5 and X = 6	S.*	N.S.	N.S.
	X = 5 and X = 7	S.**	N.S.	S.**
	X = 6 and X = 7	S.**	N.S.	S.*
Physics	X = 5 and X = 6	S.**	N.S.	S.**
	X = 5 and X = 7	S.**	N.S.	S.**
	X = 6 and X = 7	S.*	N.S.	N.S.
Biology	X = 5 and X = 6	S.**	N.S.	N.S.
	X = 5 and X = 7	S.*	N.S.	N.S.
	X = 6 and X = 7	N.S.	N.S.	N.S.
Mathematics	X = 5 and X = 6	S.*	N.S.	N.S.
	X = 5 and X = 7	S.**	N.S.	S.*
	X = 6 and X = 7	S.**	N.S.	N.S.

** at 0.01 level
* at 0.05 level

6.4 Confirmatory Studies

During the following year (1985/1986), three studies were carried out in Glasgow University, Chabot College (U.S.A.), and Mansourah University (Egypt) under the direction of Glasgow University.

1. In Glasgow University: the researcher used DBT to measure the X-space of the new sample of the first year chemistry students. By the same method employed earlier in this chapter, the F.V. of 10 questions of different complexity was determined (Appendix 11). Table 62 shows the F.V. of these questions, illustrated in Figures 52 through 54, which were similar to those obtained during the first year of testing.

   At this stage a consolidation was done between the two years between the two samples of students and all the questions used in the class and degree examinations. Figures 55 through 57 show the combination of the F.V. for the two groups of first year students. The attempt to find lines of best fit were not successful and the curves emerged as before, reminiscent of a pH curve as obtained in Chapter 3. As can be seen, there is a range of F.V.'s represented by error bars, but still there are two plateaux in which error bars overlap and a gap in the middle in which there is no overlap of error bars in all groups of different X-space. This occurs during the rapid fall away of performance when Z becomes X.

   Strong negative correlations are obtained between the percentage of students who answered each question totally correctly, and the number of thought steps required for solving the question (its Z-demand).

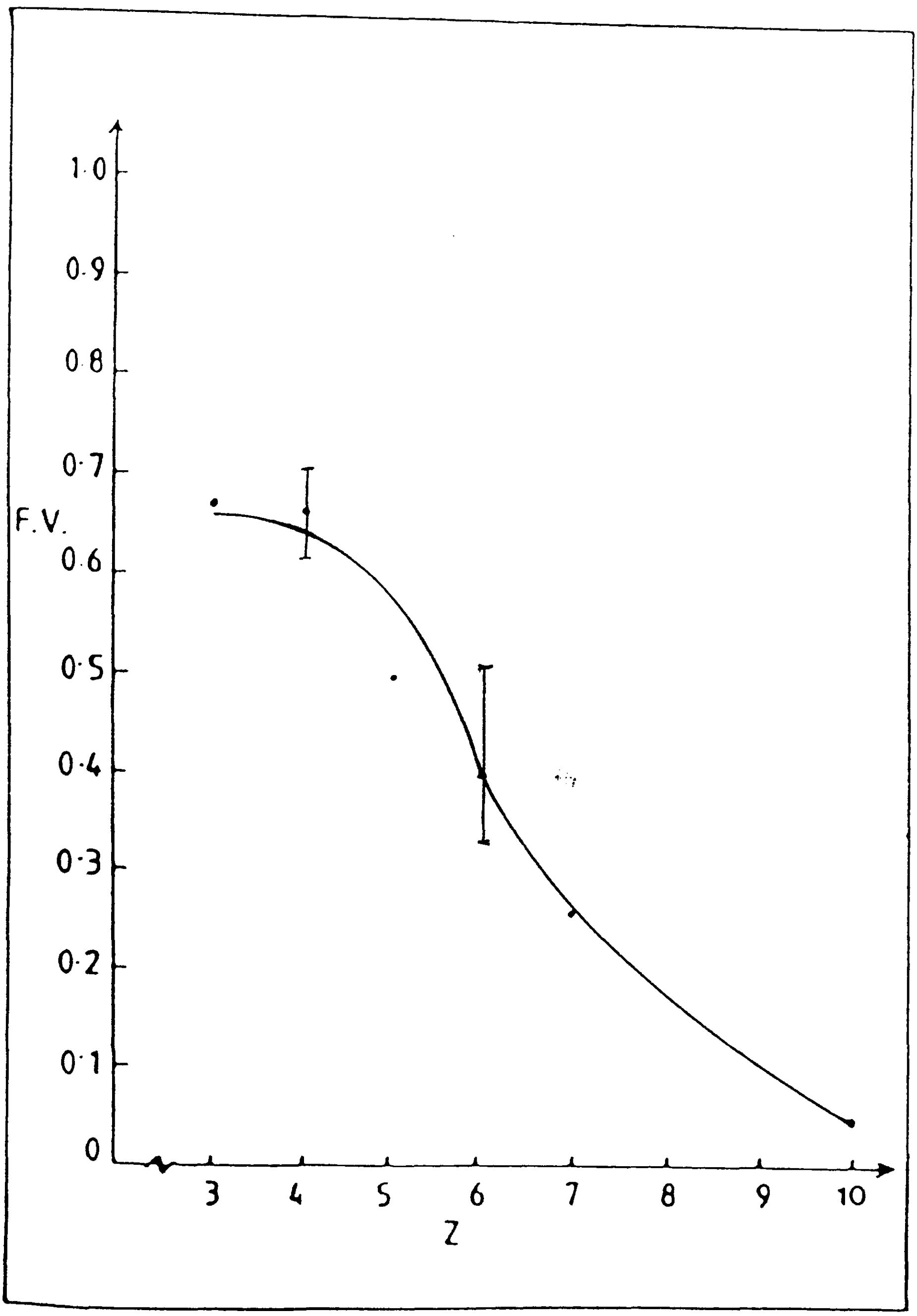
   In Figure 58, the average of the F.V. for the questions of the same complexity Z-demand for all groups of different X-space can be seen. The X = 5 students fall away when Z exceeds 5, and for X = 6 students, this falling comes after questions /

TABLE 62

THE F.V. OF THE QUESTIONS FOR EACH STUDENT GROUP

(Second Year of Testing)

Questions \ Groups		X = 5 (N = 57)	X = 6 (N = 73)	X = 7 (N = 39)
Q.1	Z = 4	0.62	0.57	0.73
Q.2	Z = 6	0.51	0.60	0.69
Q.3	Z = 10	0.04	0.05	0.06
Q.4	Z = 6	0.36	0.56	0.61
Q.5	Z = 4	0.71	0.71	0.72
Q.6	Z = 3	0.68	0.71	0.72
Q.7	Z = 6	0.33	0.49	0.63
Q.8	Z = 4	0.64	0.66	0.64
Q.9	Z = 5	0.50	0.59	0.64
Q.10	Z = 7	0.26	0.29	0.60



<u>FIGURE 52</u>. Results from X = 5 University Students (Second year of Testing)

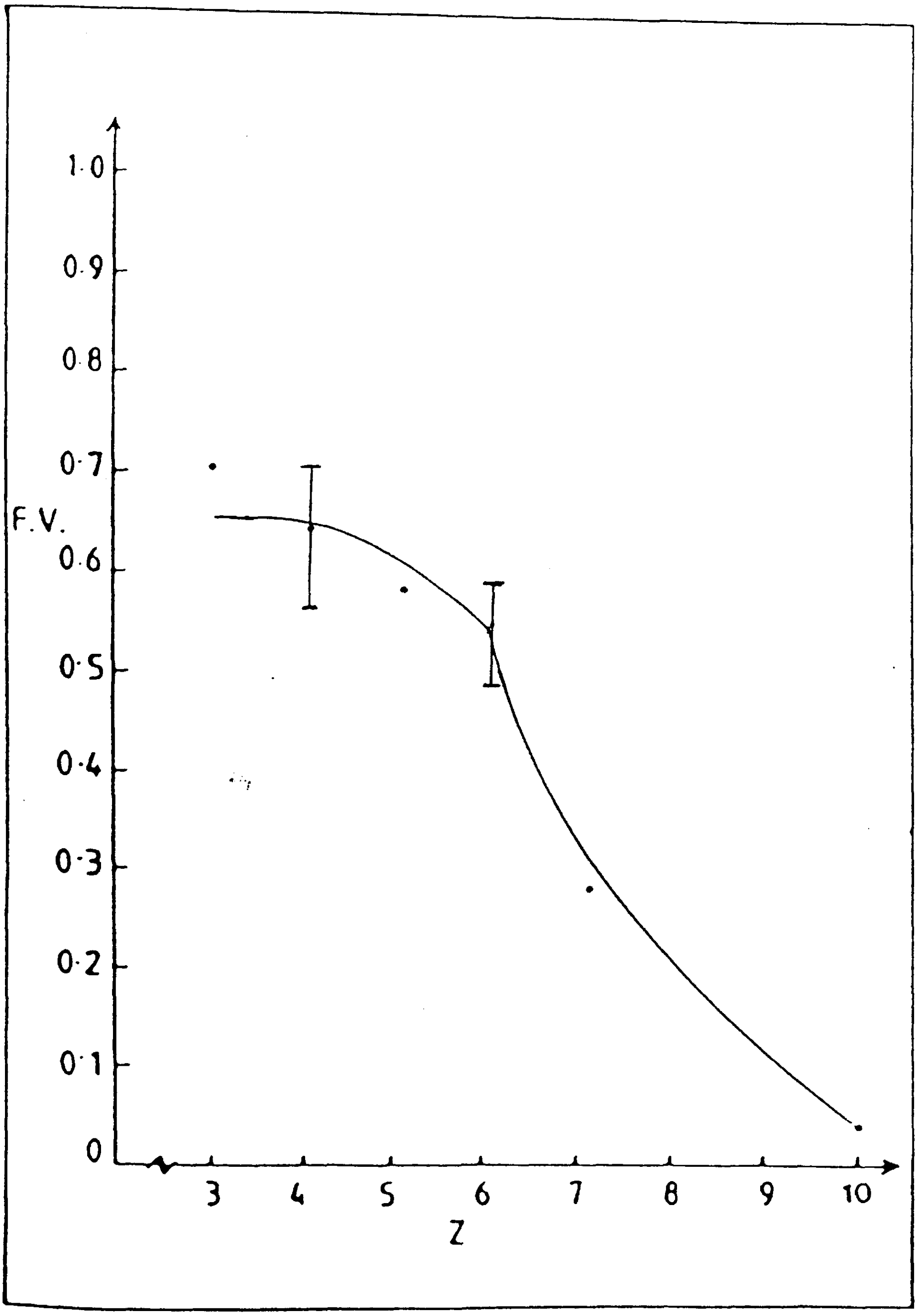


FIGURE 53. Results from X = 6 University Students (Second Year of Testing)

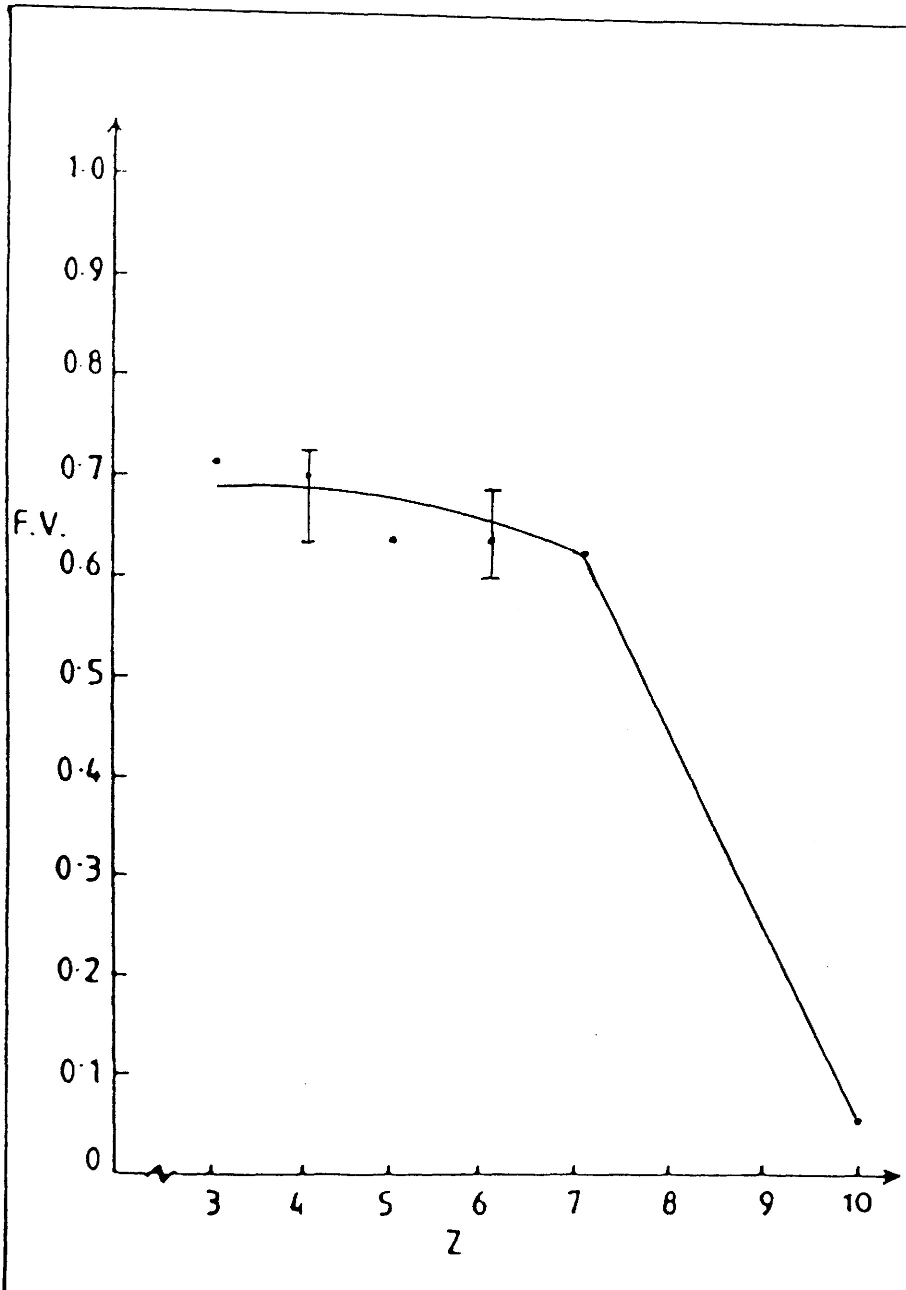


FIGURE 54. Results from X = 7 University Students (Second Year of Testing)

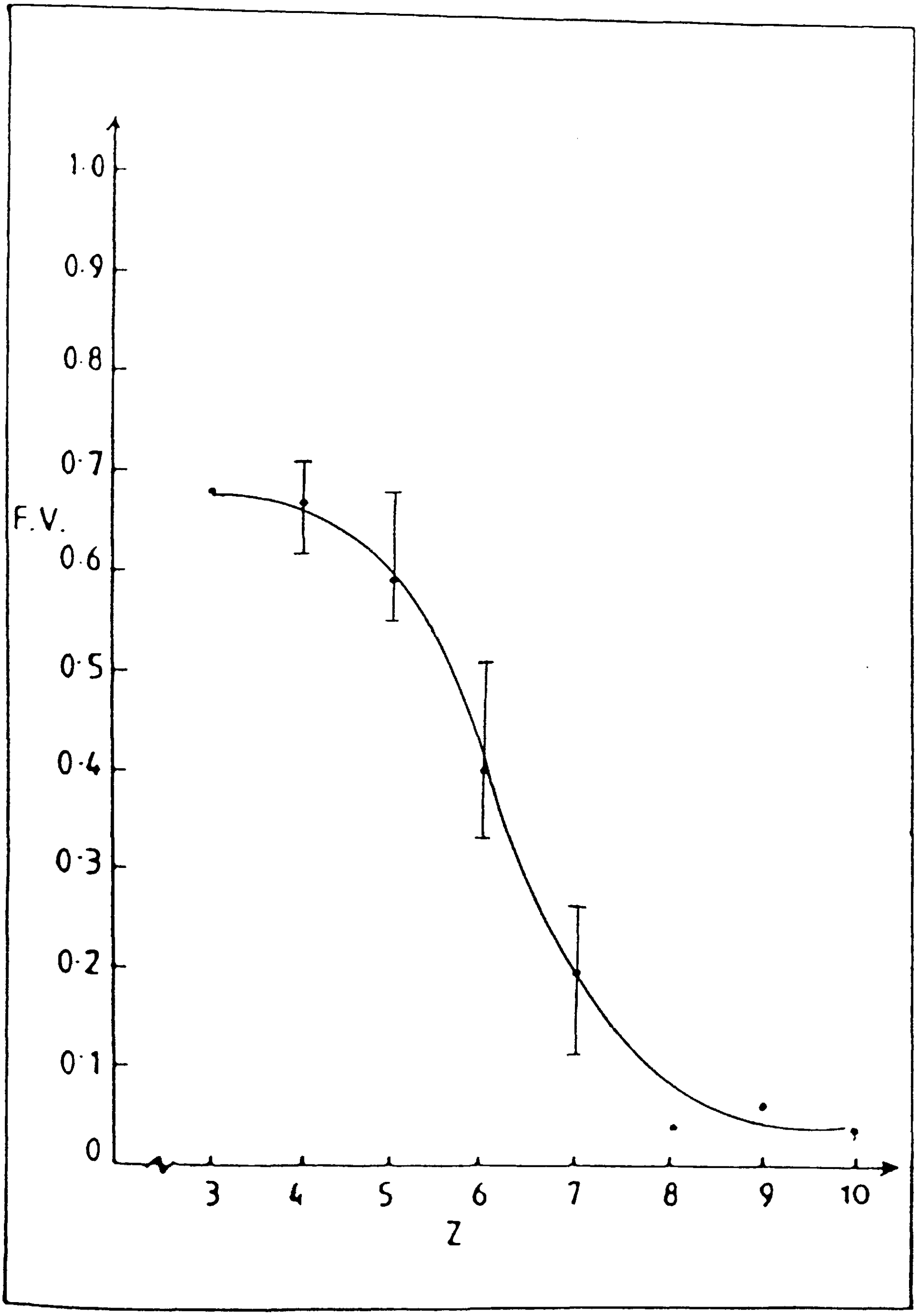


FIGURE 55. Overall Results from X = 5 University Students (Two Years of Testing)

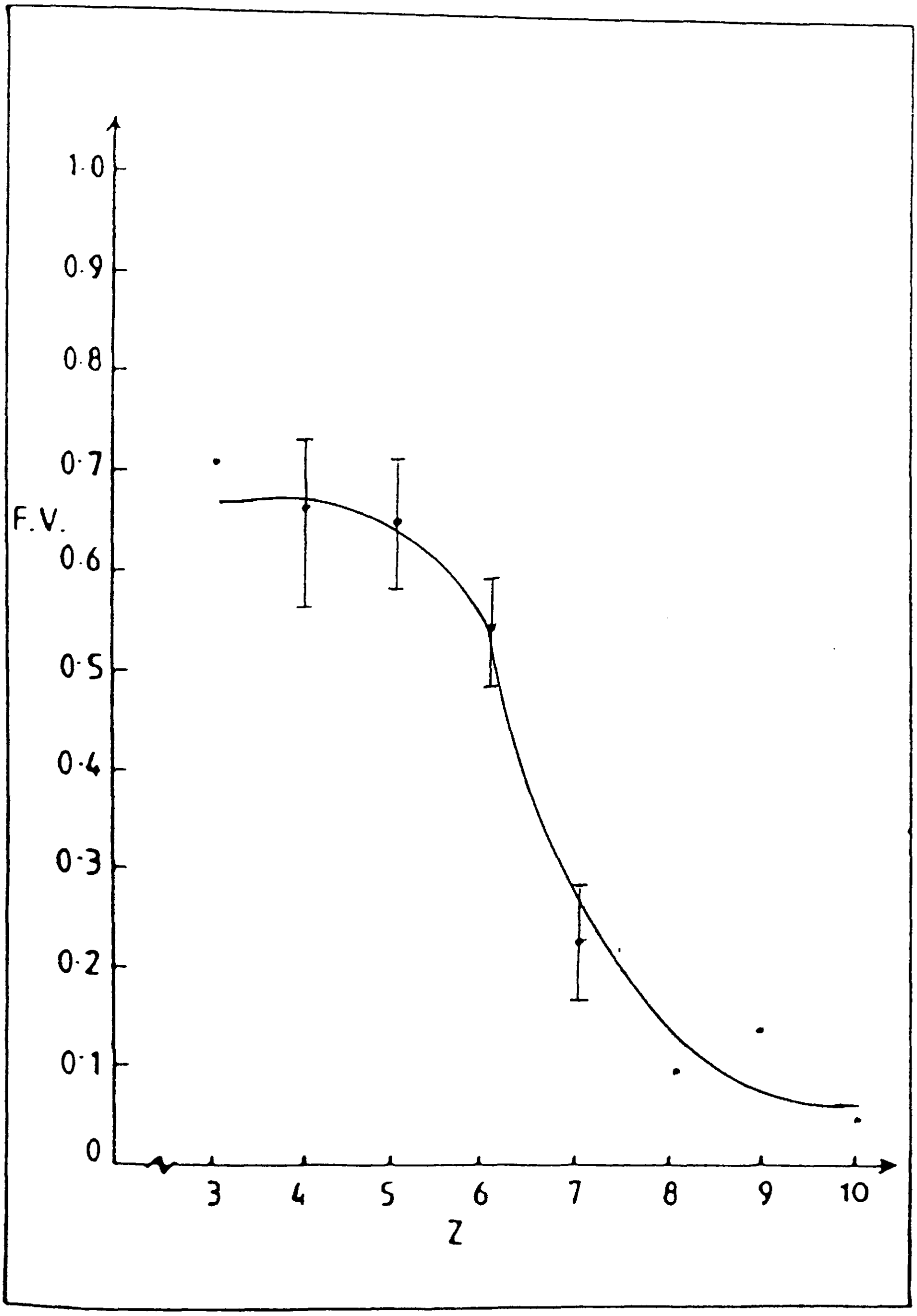


FIGURE 56. Overall Results from X = 6 University Students (Two Years of Testing)

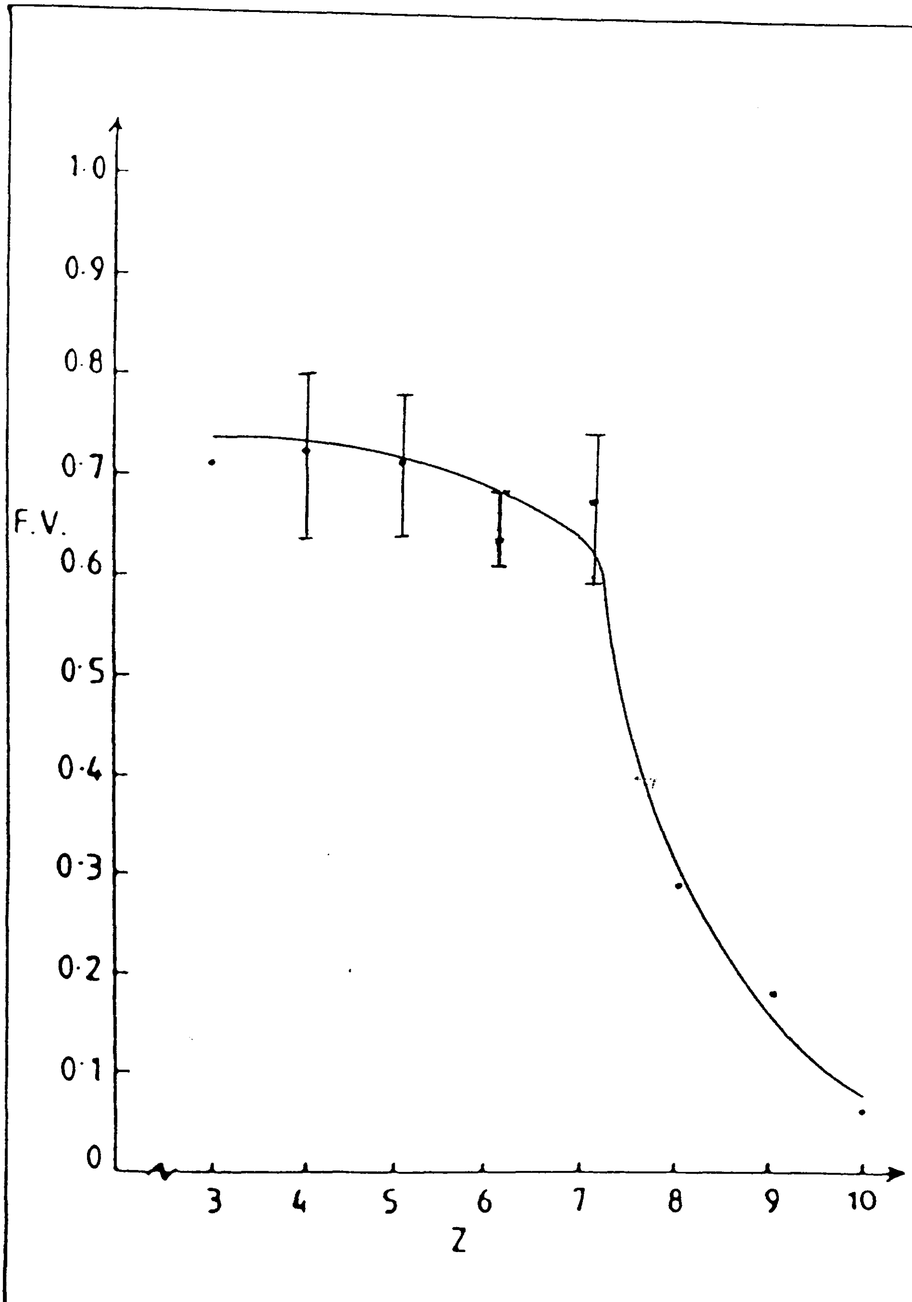


FIGURE 57. Overall Results from X = 7 University Students (Two Years of Testing)

questions of Z = 6. The X = 7 students fall away when Z $\gg$ 8. The interesting thing is that the X = 5 falling is not as sharp as in the case of X = 6 and both are not as sharp as in the case of X = 7. This indicates that about 40% of the X = 5 students have some access to problems beyond their capacity, whereas only about 15% of the X = 7 students give evidence of working beyond their capacity.

2. In Mansourah University (Egypt), the researcher used the FIT to measure the X-space for the fourth year chemistry students (Faculty of Education) during September, 1985. The students' scores in the chemistry degree examination were obtained. The results are given in Table 63 and in Figure 59.

3. In Chabot College (U.S.A.), the X-space of a sample in first year chemistry class was measured by using both psychological tests (DBT and FIT) in exactly the same manner employed in Glasgow University during the first year of testing. This was done by an independent researcher (who had been a visitor in the Science Education Department in Glasgow for about nine months). After students had finished their degree examination in chemistry (summer term), their score was obtained. Table 64 shows the overall results of students in the examination. The results are shown in Figure 60.

Conclusion

The results of these three studies support, once again, the power of the suggested model to predict students' performance in both ways: their ability to solve individual questions (Glasgow) and their attainment scores in over-all examinations (Chabot and Mansourah)

6.5 /

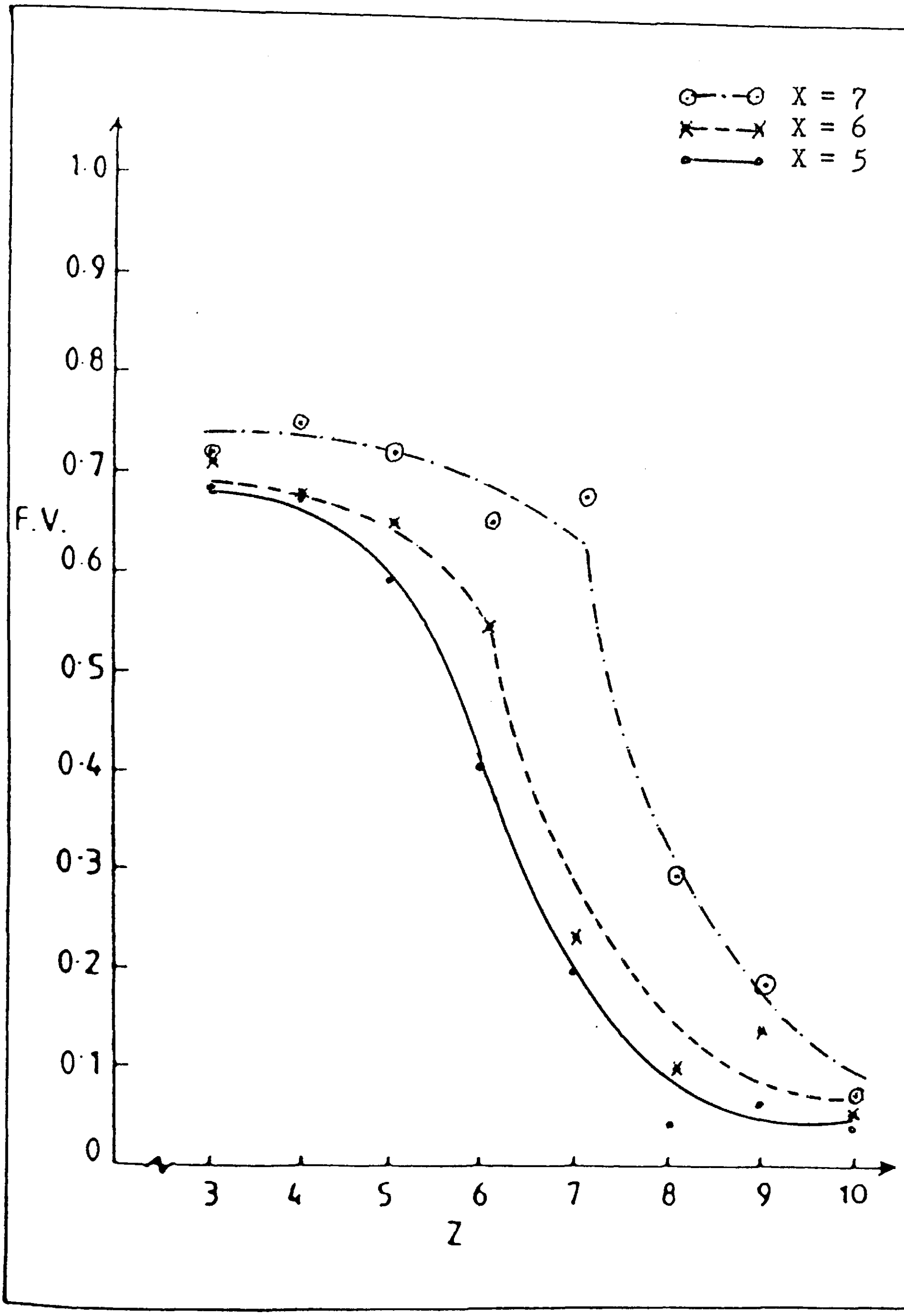


FIGURE 58. Comparison of the Average of the F.V. for all Groups of Different X-space.

(Two Years of Testing)

TABLE 63

MEANS AND STANDARD DEVIATIONS

(4th year Chemistry - MANSOURAH)

Groups	Means	S.D.
X = 5 (N = 13)	59.0%	8.4
X = 6 (N = 15)	64.0%	10.3
X $\geq$ 7* (N = 12)	72.0%	8.7

* 3 Students were in X = 8 group, and
9 Students were in X = 7 group.

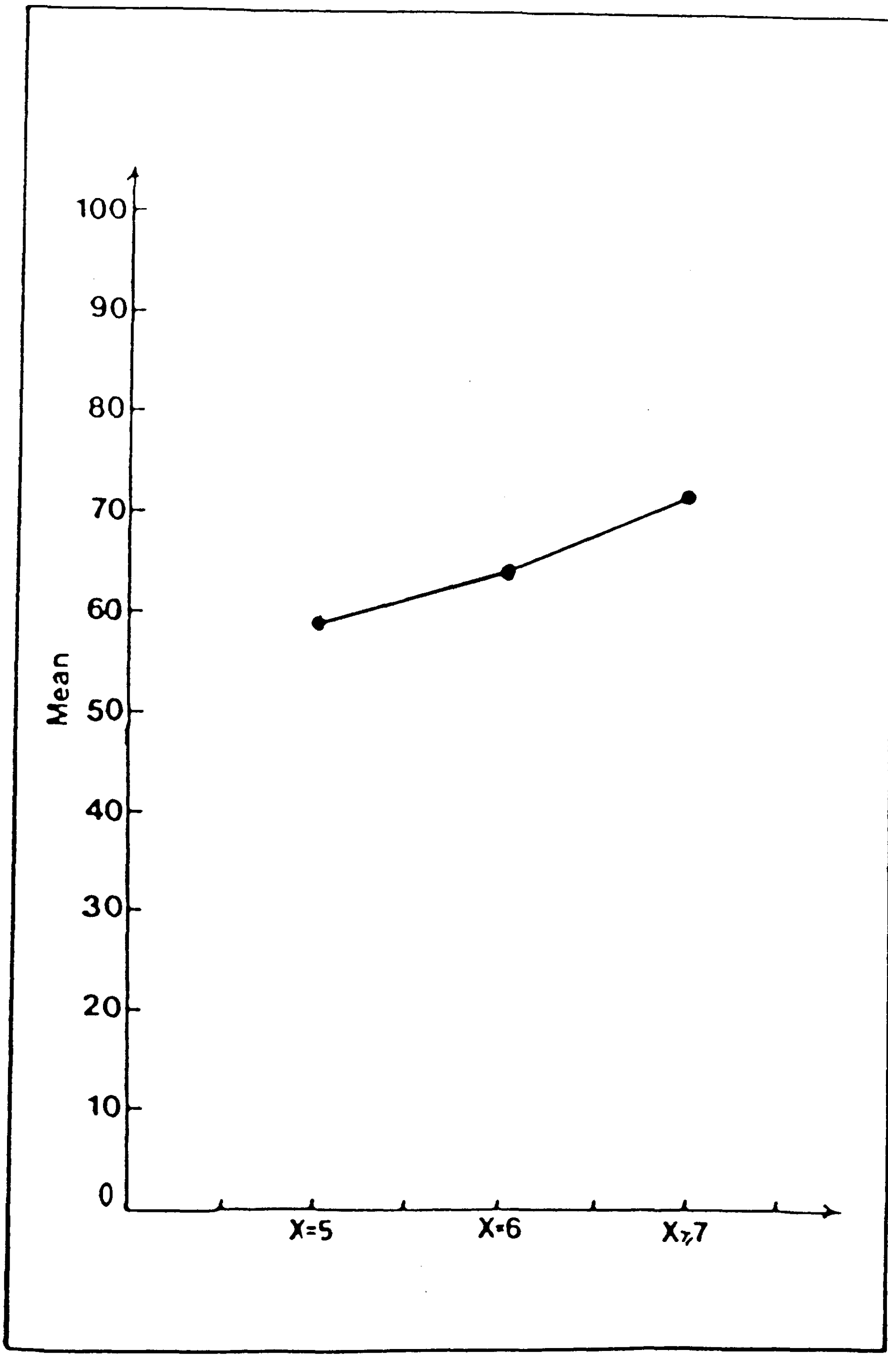


FIGURE 59. Results from Mansourah University (Chemistry Degree Examination)

TABLE 64

MEANS AND STANDARD DEVIATIONS

(1st year Chemistry - CHABOT COLLEGE)

Groups		Mean	S.D.
$X \leqslant 6$*	(N = 6)	62.0%	4.6
X = 7	(N = 9)	67.8%	8.4
X = 8	(N = 11)	74.3%	9.9

* 3 Students were in X = 5 group, and
3 Students were in X = 6 group.

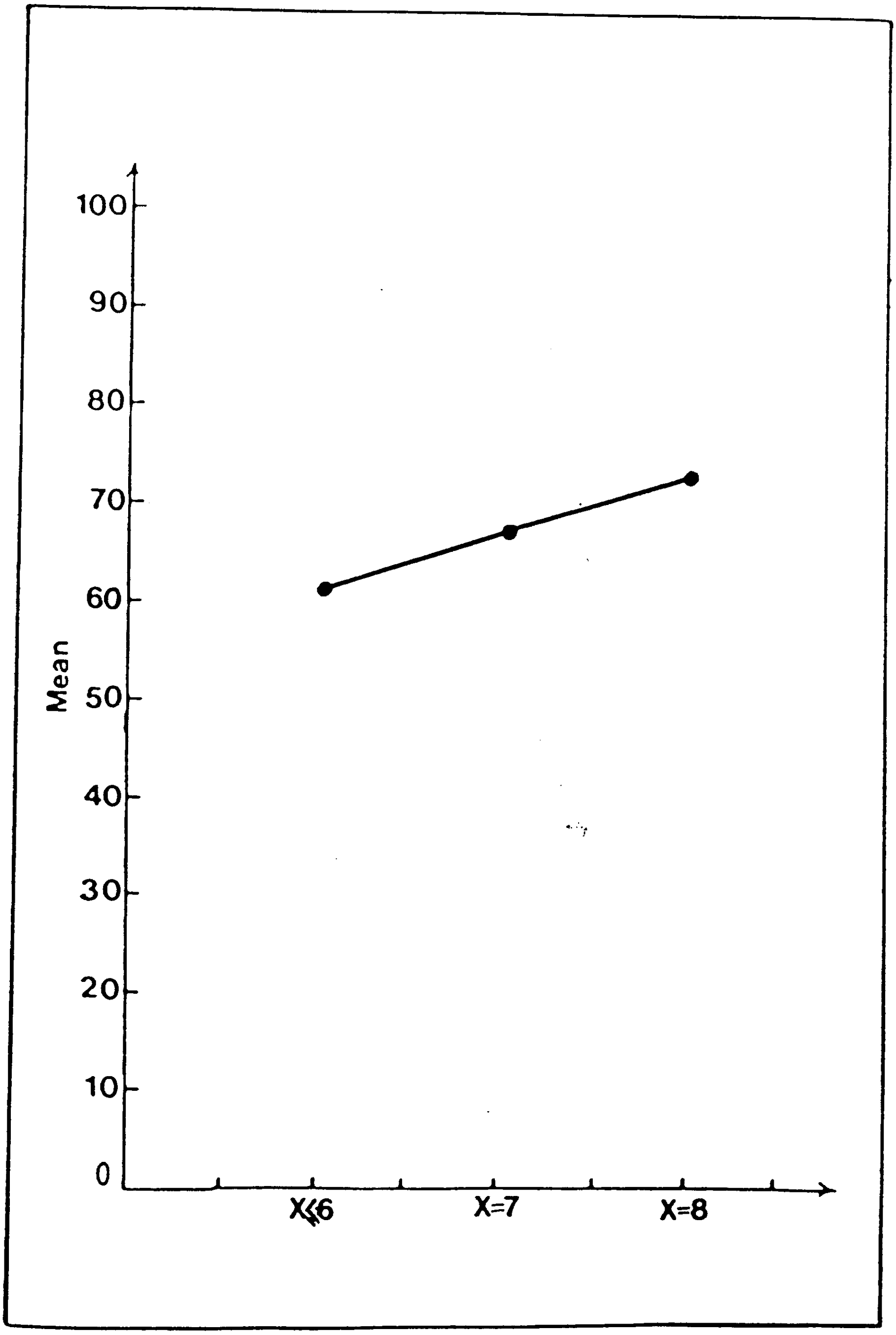


FIGURE 60. Results from Chabot College (Chemistry Degree Examination)

6.5 Over-all Conclusion

1. The patterns which emerged from the results in this experiment using the university sample are similar to the schools sample which indicated that:

   (a) The X = 7 curves represent better all-over performance than X = 6, and both are better all-over performance than X = 5.

   (b) When Z exceeds X, there is a fall in students' performance. When $Z \leq X$, there is a good performance but it does not reach to a 100%, and when $Z > X$ the performance does not fall to a zero

   (c) There is strong evidence in favour of there being a relationship between the students' X-space and their ability to solve questions of different Z-demand. At the same time, the students' performance in questions of the same complexity is quite similar in each group of different X-space.

2. The fluctuation in performance in questions of $Z \leq X$ in the schools' experiment, disappeared in the university first year of testing, since only one lecturer taught the content of each question.

3. The students' X-space is considered a good predictor for success in the conventional university examinations, as well as in H-Grade examinations, not only in chemistry but also in physics, biology and mathematics.

4. It is worth emphasising, again, that when $Z \leq X$, we have a necessary but not sufficient condition for success which depends on other factors. Factors such as teaching strategy, breaking down the questions into a series of sub-questions, and organization of the thinking before doing /

doing a calculation. One of the other factors, which the researcher believes affects the students ability to solve the questions of different complexity, is that of the students' perceptual field for the questions. It was, therefore, decided to concentrate further investigations on studying the effect of the students' perceptual field on their performance in chemistry. The investigation will be reported in the next chapter.

CHAPTER 7

EXPERIMENT USING UNIVERSITY STUDENTS
(B) A FURTHER TEST OF THE WORKING MODEL
FIELD-DEPENDENCE/INDEPENDENCE

One of the conclusions in Chapter 4 and in Chapter 6 is that some students do not solve questions of complexity Z less than or equal to their measured X-space and, therefore, the F.V. of these questions does not reach a 100%. Pascual-Leone[81] suggests that the cognitive style field-dependence/independence (FD/FI) may be acting as a moderator to the use of the full mental space. Field-dependent subjects frequently function below the potential expected from their measured capacity.

It could be that the field-dependent students will not be capable of choosing relevant from irrelevant information (signal from noise). Since both the signal and the noise have to share the students' limited holding-thinking space, the field-dependent students will not be able to analyze the question's data in a complex situation, nor to synthesise simultaneously the thought steps, required to solve the question. The results of two studies reported by Kempa[139], tend to support the importance of the field-dependence/independence cognitive style as a factor influencing students' learning.

Relevant to the students' holding-thinking space X, it is very important to test the influence of this cognitive style on the students' success in chemistry. To do this, two steps are required. The first is to construct a test to measure the degree of students' perceptual field (FD/FI), and the second is to find out the relationship between the students' degree of FD/FI and their attainment in chemistry examinations.

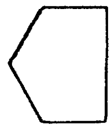
7.1 Measure of Students' Degree of FD/FI

A test for measuring the students' degree of FD/FI was designed by the researcher (Appendix 12). The Hidden Figures Test (HFT) is a group administered, paper and pencil test using materials similar to those of Witkin et al.[140] The design of the test is based on their definition of FD/FI cognitive style. This postulates that, the subjects who find difficulty in overcoming the influence of a surrounding field, or in separating an item from its context, have a perception which is called field-dependent. On the other hand, subjects who are able to distinguish an item from its context, or who easily break up an /

an organized perceptual field, have a perception called field-independent.

7.1.1 Description of the Test

1. There is a set of 7 simple geometric and non-geometric shapes which are embedded in complex figures. There is more than one complex figure for each of these simple shapes. Two examples of these simple shapes are given below:



2. The Hidden Figures Test (HFT) consists of 18 items (complex figures) plus 2 introductory items as examples. Each item has a simple shape embedded in it. In some items there is more than one example of the same simple shape embedded. What students have to do is to locate and outline the simple shapes in the complex figures and trace them in pencil directly over the lines of the complex figures. The simple shape has to be of the same size and proportions and in the same orientation within the complex figures as when it appears alone in the specimen example.

7.1.2 Administration

The HFT is a group administered test which may be given to students age 15 years and over. The instructions of the test are oral and written.

Materials /

Materials

Each student is given an HFT test booklet and pencil. The booklet pages should be thick enough to prevent "show-through" from the next page, otherwise figures would be made much more complex by the superimposition of one on the other.

Instructions

The two introductory items appearing on Pages 1 and 2 of the test booklet are used for instruction purposes. At the beginning, students are told that "this is a game with shapes to test your ability to find out a simple shape when it is hidden within a complex figure. Read the written instructions carefully before you start. You are not allowed to use a ruler or any other measurements".

Testing

The tester(s) should circulate among the students during the test to answer questions and watch for certain errors which should be prevented, but no further information will be given about solving the test items. Errors which should be watched for during the testing include:

1. Tracing more than one simple shape in each item (complex figure).
2. Using any measurement tools.
3. Transferring the simple shapes list on to the test items themselves.

Timing

Most students finish the test within about 15 minutes. Tests, however, should be collected after 20 minutes.

Scoring /

Scoring

Each item is first scored as pass or fail; and then the over-all test score is computed. The total score equals the number of items passed, 18 being the maximum score.

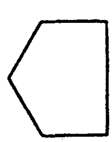
AN ITEM IS PASSED IF -

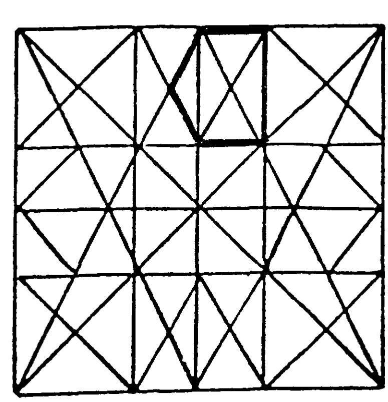
(a) A simple shape of the same size, in the same proportions and facing in the direction (as the given specimen) within the complex figure has been located.

(b) There is no extension of this simple shape into another shape.

(c) No other wrong shape in the complex figure has been traced.

An example of a passed item would be as follows, if the shape being sought is -





AN /

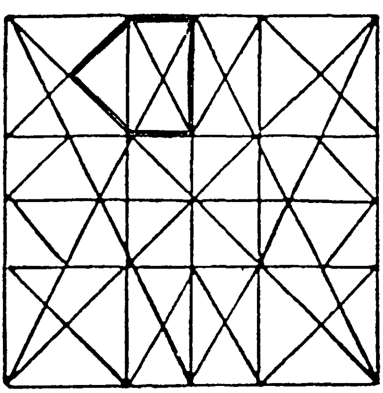
AN ITEM FAILS IF -

(a) There is no simple shape traced.

(b) The simple shape outlined is not of the same size, proportions or orientation as the specimen.

(c) There is an extension of the correct simple shape into another shape.

An example of a failed item would be as follows -



→ The proportions are wrong.

Describing Test Performances

Figure 61 shows the distribution of the HFT total scores for a sample of 747 first year university students. The mean is 9.2 and the standard deviation is 3.3. The indices of difficulty and the index of discrimination for each of the items are given in Table 65.

7.1.3 Reliability

The strictest test of reliability would be that each student should have gained the same total score in exactly the same way in two administrations /

TABLE 65

INDEX OF DIFFICULTY AND INDEX OF DISCRIMINATION FOR THE HFT ITEMS

Items No.	Index of Difficulty	Index of Discrimination*	Items No.	Index of Difficulty	Index of Discrimination*
1	0.58	0.35	10	0.60	0.42
2	0.82	0.25	11	0.32	0.35
3	0.67	0.37	12	0.65	0.41
4	0.51	0.39	13	0.37	0.53
5	0.68	0.51	14	0.81	0.36
6	0.59	0.38	15	0.21	0.61
7	0.38	0.39	16	0.70	0.61
8	0.44	0.27	17	0.53	0.59
9	0.13	0.39	18	0.45	0.41

* Top $\frac{1}{3}$ - Bottom $\frac{1}{3}$

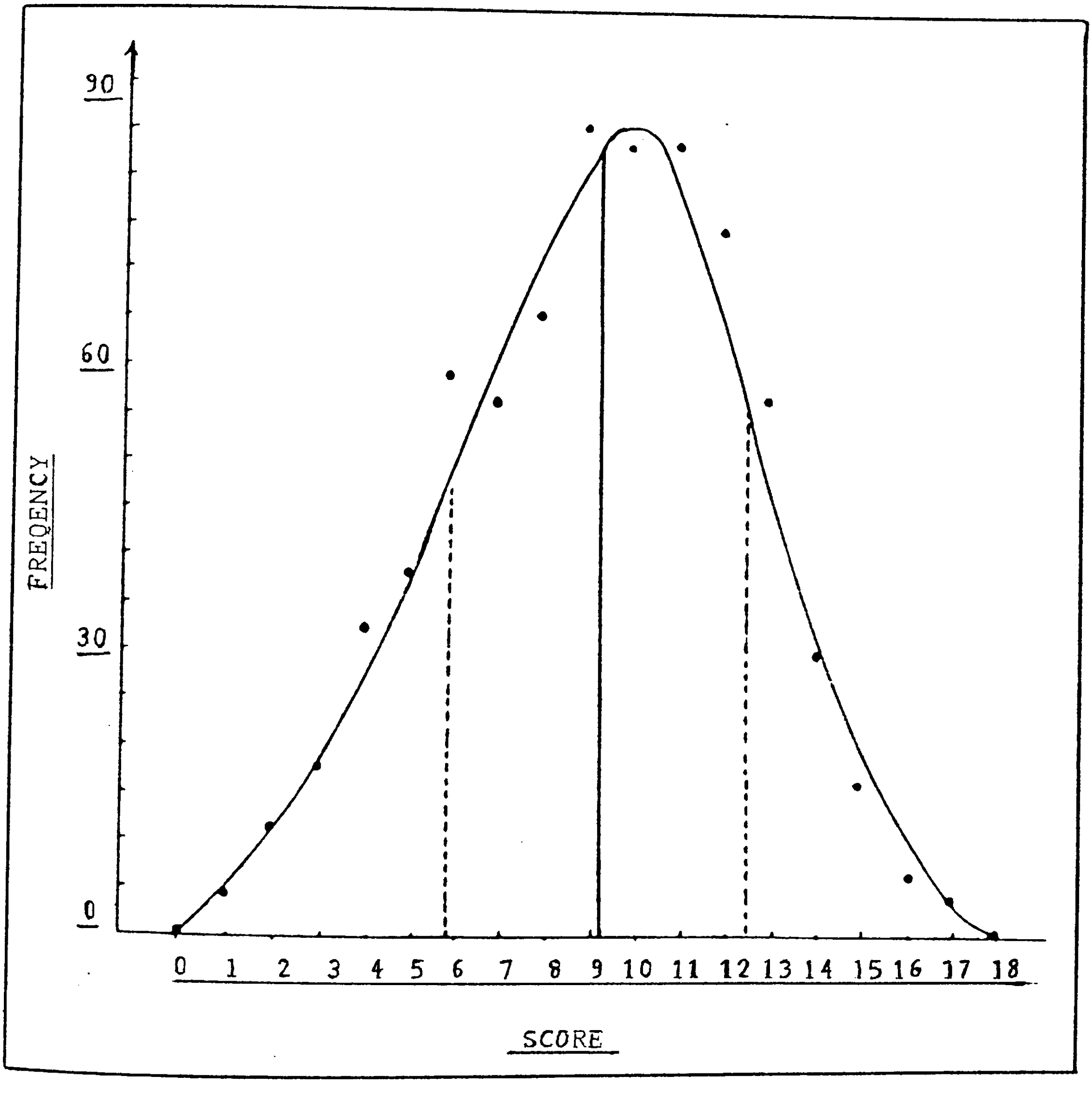


FIGURE 61. The Distribution of the H.F.T. Total Scores for a Sample of 747 First Year University Students.

administrations of the same test. This was applied in a test/retest situation and the coefficient was 0.6. The split-half reliability for HFT score, and Cronbach α were also calculated.[141] They were 0.72 and 0.71 respectively which were quite acceptable. By all three statistical tests the FD/FI test was reliable.

7.1.4 Validity

The test validity means that the test measures what it sets out to measure. The test depends upon the Group Embedded Figures Test (GEFT) developed by Witkins et al,[140] which is considered as a criterion measure of field dependence/independence. The test also has face validity.

Having constructed a tool for measuring the students' perceptual field, it would be useful to find the relationship between students' perceptual field and their attainment scores in chemistry examinations.

7.2 Problems and Hypotheses

To find out, on the basis of the working model, whether there is a relationship between the students' degree of field-dependence/ independence and their achievement in chemistry, the researcher considered the following questions:

1. Is there any relationship between the students' degree of field-dependence/independence and their attainment in chemistry examinations?
2. If the answer of the above question is YES, to what extent does this relationship influence the success of the students (with different X-space) in chemistry examinations?

Using the following two hypotheses, it was hoped to find an answer to the two questions asked above.

1. /

From this sample, the holding-thinking space of 271 students has been measured. This sample, used in Chapter 6, was further divided into sub-groups according to their degree of FD/FI as can be seen in Table 67.

TABLE 67

CLASSIFICATION OF FD/FI STUDENTS IN EACH GROUP OF DIFFERENT X-SPACE (N = 271)

Group	FD	F Intermediate	FI
X = 5	19	70	9
X = 6	9	86	15
X = 7	7	37	19

7.3.2 Variables

1. The independent variable, the students' degree of field-dependence/independence, was determined by using the HFT as explained above. It is the students' ability to separate and distinguish an item from its context. In terms of the chemistry, it is the students' ability to analyze the data and pick up the relevant while discarding the irrelevant.

2. /

1. There is a direct relationship between the students' degree of field-dependence/independence and their attainment in chemistry examinations.

2. Field-independent students will perform better in chemistry examinations in all groups of different X-space than those who are field-dependent.

7.3 Method Used

7.3.1 Student Sample

The subjects were 364 students enrolled in the first year at university (Glasgow University). The sample was divided into three groups according to their degree of field-dependence/independence measured by the HFT. To meet the criterion of field-independence, students had to score at least one standard deviation above the mean for their sample population. This is the criterion used by Scardamalia(83), Case(118) and Case and Globerson(124). On the other hand, students who had a score less than one standard deviation were classified as field-dependent, and between ± 1 standard deviation were those who were field-intermediate. Table 66 shows the number of students in these three groups.

TABLE 66

CLASSIFICATION OF STUDENT SAMPLE

Group	Number of Students
F.D.	47
F. Int.	258
F.I.	59
Total	364

2. The moderator variable, the students' X-space, was determined as explained in Chapter 6. It is the maximum number of items of information or discrete "chunks", which the student can hold in mind at any one time during the solving of the question.

3. The dependent variable, the students' achievement in chemistry examinations. These were their scores on two conventional university class examinations.

7.3.3 Procedures

The HFT testing was in the first term (October). On the basis of the students' scores in the test, they were divided into three categories: field-dependent; field-intermediate and field-independent. The holding-thinking space (X) was determined before, for a sample of 271 first year students. The students scores were obtained from two chemistry class examinations.

The first hypothesis was tested using Kellett's method (Appendix 6) and the second hypothesis was tested in two ways: scatter diagrams and the Pearson Product-Moment Correlation Coefficient.

7.4 The Results

The hypothesis "there is a direct relationship between the students' degree of field-dependence/independence and their attainment in chemistry examinations" was tested by comparing the students' mean scores within the three groups of different degrees of field-dependence/independence in two class examinations.

Table 68, as well as Figures 62 and 63, show the results of students in the two class examinations. The results indicate that the mean scores of the field-independent students is higher than the field-intermediate and both are higher than the field-dependent students. Comparisons were made between the means to find out the significance of these differences. Table 69 shows the results of these comparisons which indicate that there are significant differences between the field /

TABLE 68

STUDENTS' MEANS SCORES AND THE STANDARD DEVIATIONS IN TWO CHEMISTRY CLASS EXAMINATIONS

(Possible score = 100)

Group	1st Class Ex.		2nd Class Ex.	
	Mean	S.D.	Mean	S.D.
F D (N = 134)	51.5	16.3	53.1	18.0
F Int. (N = 110)	55.4	19.8	54.0	16.5
F I (N = 120)	62.9	12.0	65.6	14.8

TABLE 69

THE SIGNIFICANCE OF THE DIFFERENCES IN MEANS IN TWO CHEMISTRY CLASS EXAMINATIONS

Group	F D		F Int.	
	1st Class Ex.	2nd Class Ex.	1st Class Ex.	2nd Class Ex.
F Int.	N.S.	N.S.	-	-
F I	Sig.**	Sig.**	N.S.	N.S.

** at 0.01 level

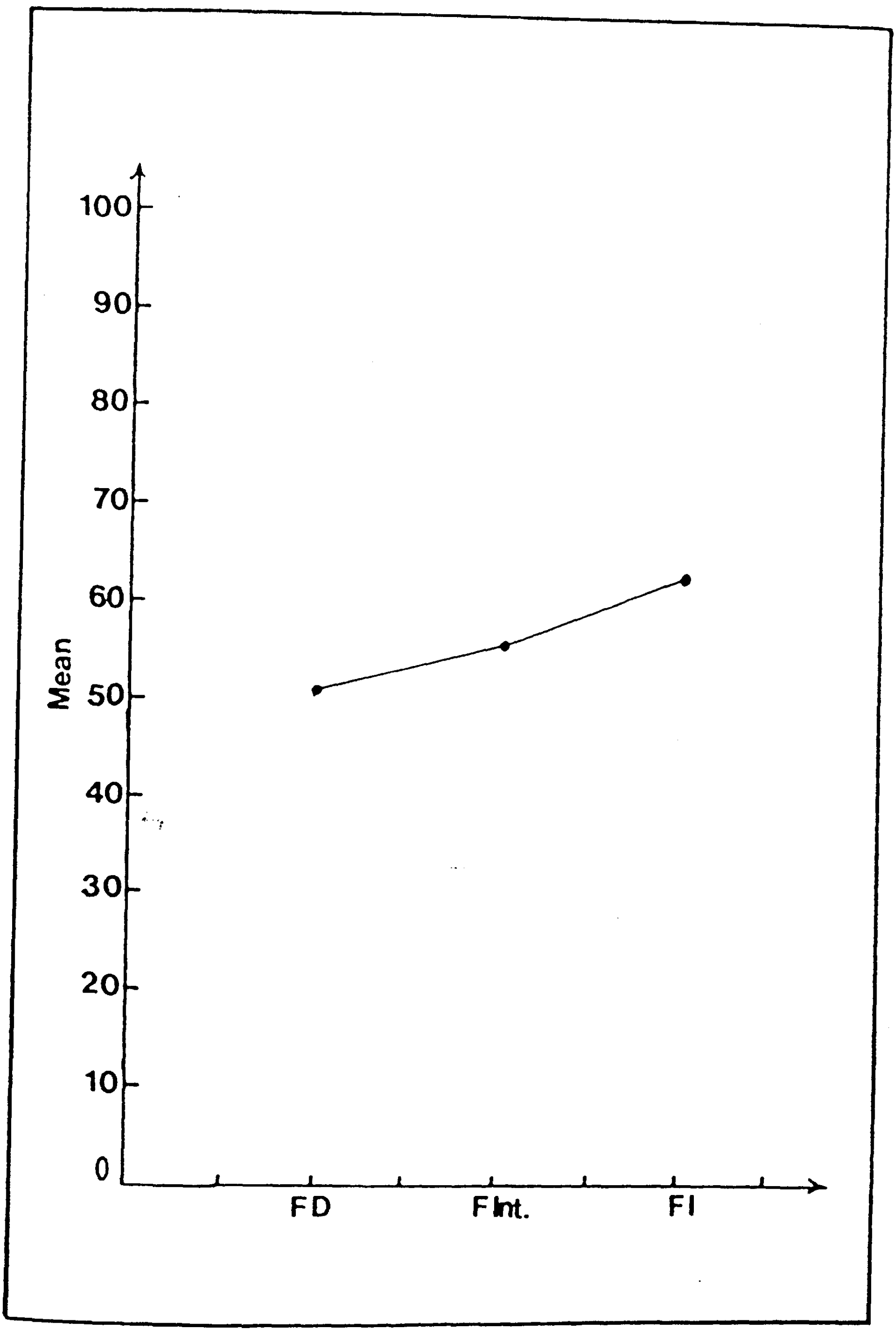


FIGURE 62. Students' Mean Scores
(1st Class Chemistry Examination)

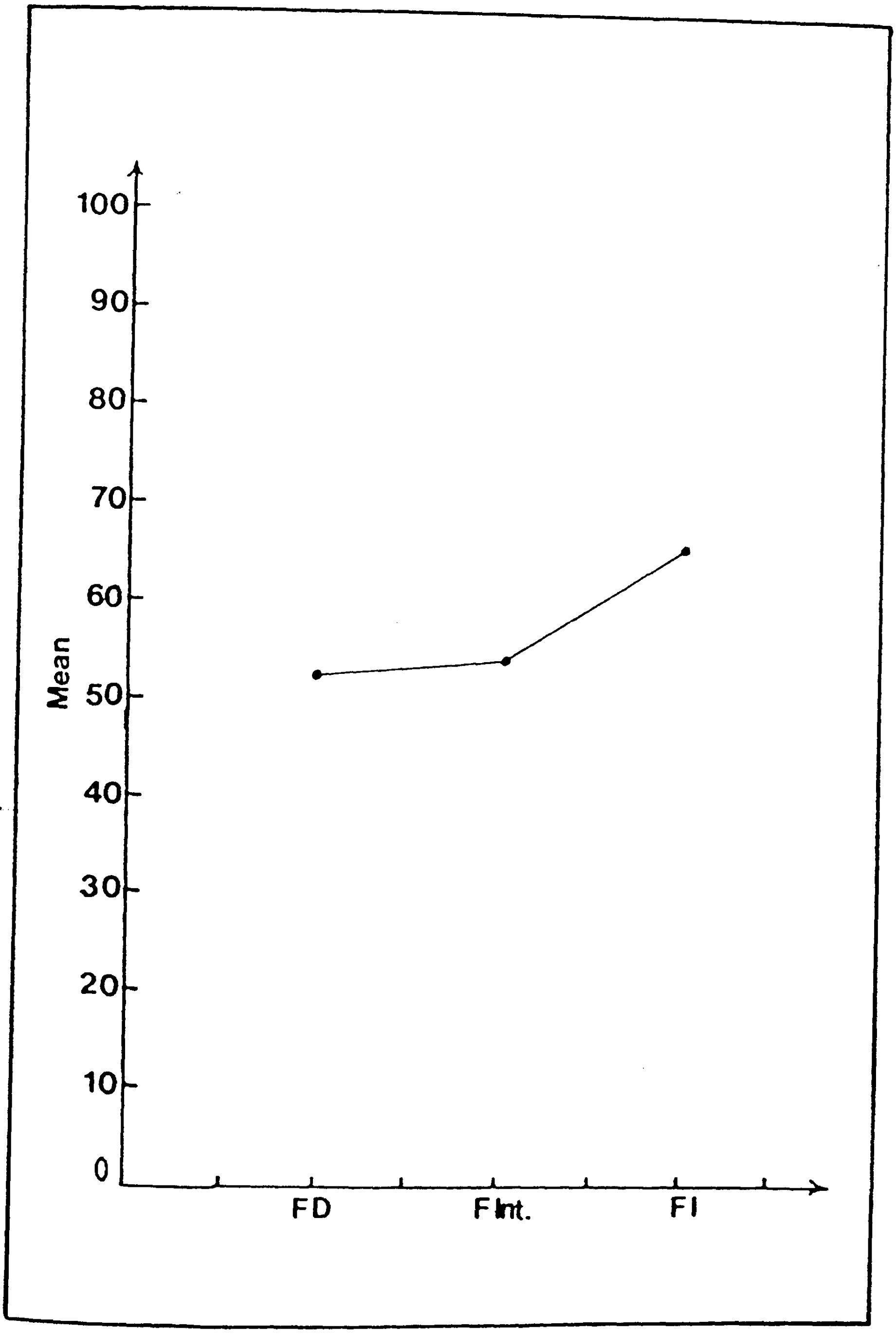


FIGURE 63. Students' Mean Scores (2nd Class Chemistry Examination)

field-dependent students means scores and the field-independent students in both class examinations. No difference was found to be significant between the field-intermediate students and both the other groups. However, the data tend to support the hypothesis and indicate the importance of the field-dependence/independence cognitive style in test situations.

The second hypothesis "the Field-independent students will perform better in chemistry examinations in all groups of different X-space than those who are field-dependent", was tested in two ways:

(i) scatter diagrams between the students' scores in HFT test and their scores in chemistry examinations, and,

(ii) the Pearson Product-Moment Correlation Coefficient between these two scores. Table 70 shows the means and the standard deviations. Figures 64 and 65 show the mean scores in two chemistry class examinations for all groups of different X-space.

As can be seen in Figures 64 and 65, there are trends in which the FD/FI factor seems to affect the X = 5 students' achievement more than in the case of X = 7. To check these trends, scatter diagrams were drawn. Figures 66 through 71 represent these scatter diagrams. The scatter diagrams in the case of X = 5 are in fact more elongated than in the case of X = 6. These elongations disappeared in the case of X = 7 students.

After having assessed visually the degree of the relationship between the students' scores in chemistry examinations and their scores in the HFT, the Pearson Product-Moment Correlation Coefficients were calculated and supported the hypothesis that there is a relationship between the two variables for students of X = 5 and X = 6 since the correlation coeffecients are significant at 0.001 level for X = 5 and at 0.05 level for X = 6 as can be seen in Table 71. On the other hand, the results tend to reject the hypothesis in the case of X = 7 students.

TABLE 70

MEANS AND STANDARD DEVIATIONS FOR STUDENTS OF DIFFERENT X-SPACE IN TWO CHEMISTRY CLASS EXAMINATIONS (N = 271)

(Possible Score = 100)

Groups		F D		F Int.		F I	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
X = 5	1st C. Ex.	41.6	15.5	48.3	16.2	50.2	18.7
	2nd C. Ex.	41.3	15.3	49.03	18.3	58.9	23.6
X = 6	1st C. Ex.	52.95	12.6	59.7	13.0	62.7	11.6
	2nd C. Ex.	52.7	14.9	62.8	11.6	66.4	12.3
X = 7	1st C. Ex.	69.9	8.7	70.6	13.9	70.8	12.0
	2nd C. Ex.	69.6	9.8	70.5	15.2	70.8	17.2

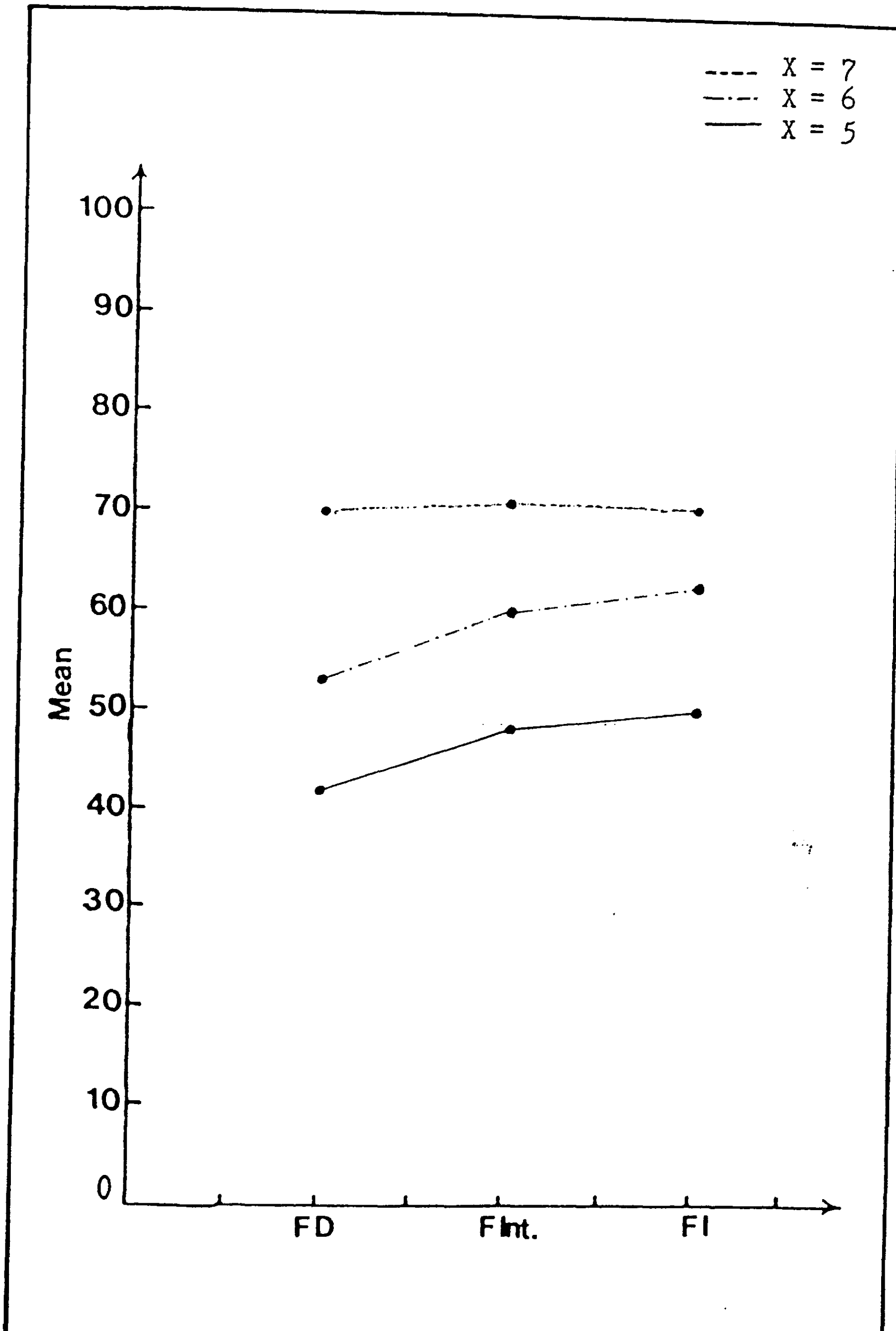


FIGURE 64. The Mean Scores for the Students of Different X-space and Different Degree of Field-dependence/Independence.

(1st Class Chemistry Examination)

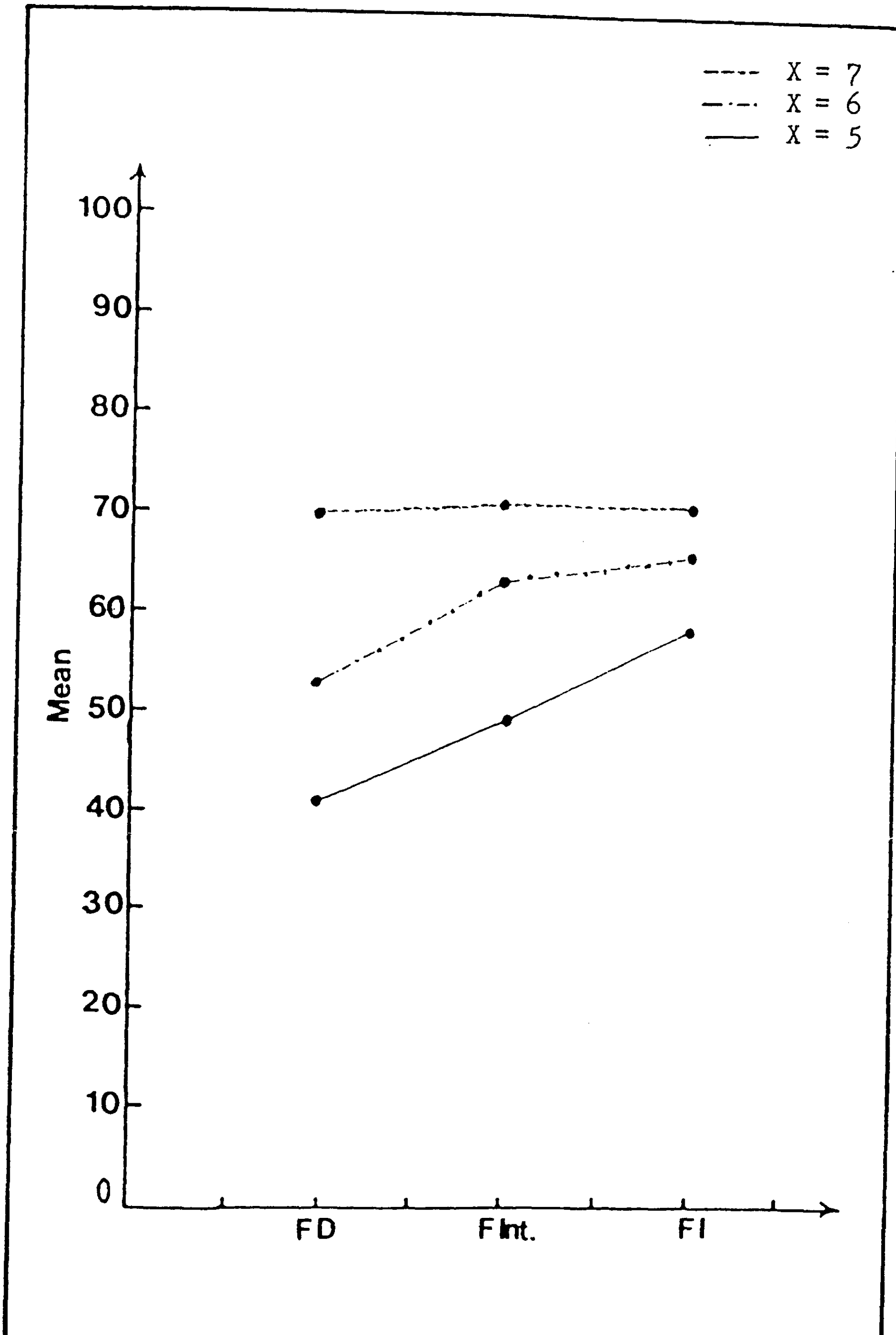


FIGURE 65. The Mean Scores for the Students of Different X-space and Different Degree of Field-dependence/Independence.

(2nd Class Chemistry Examination)

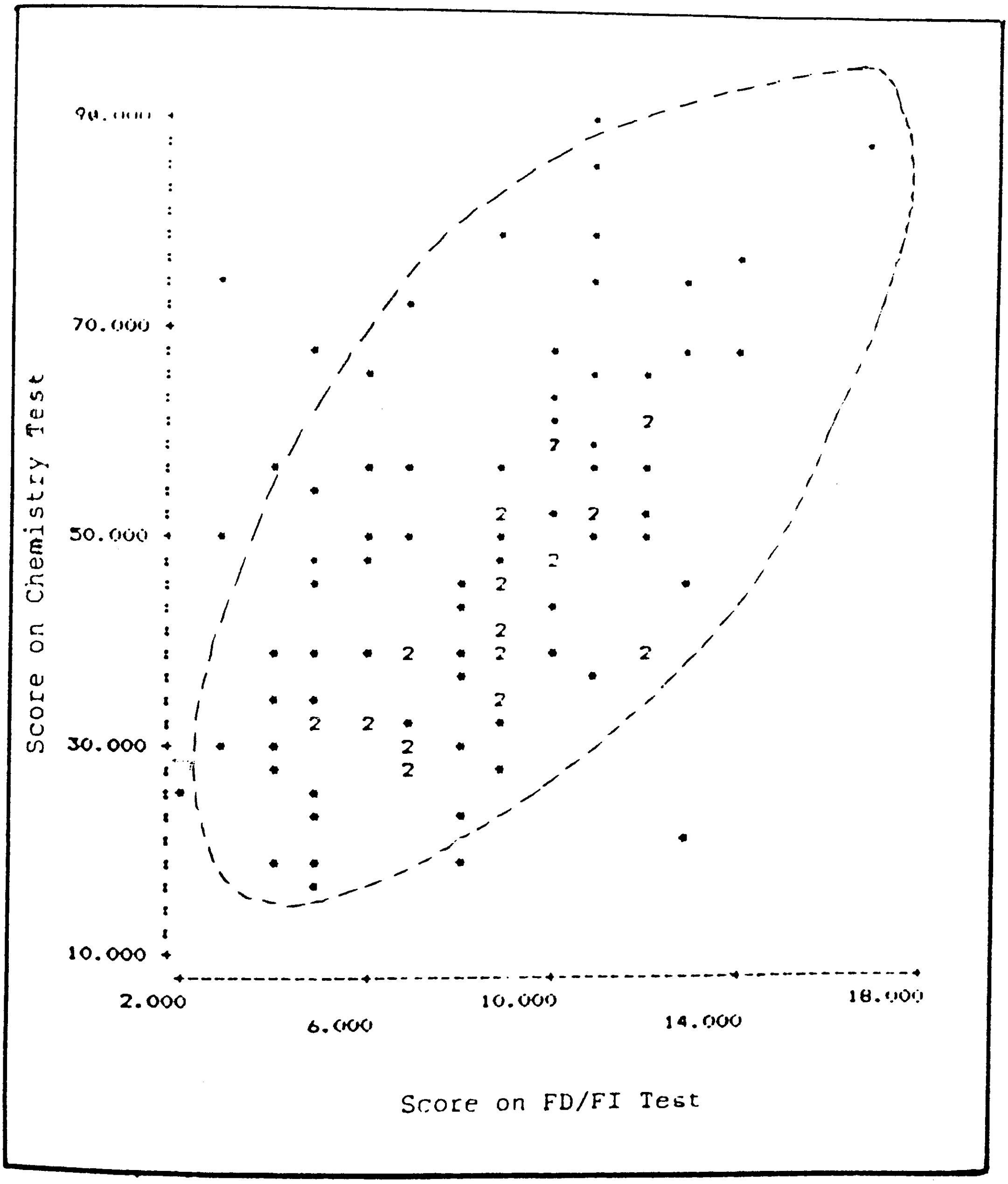


FIGURE 66. Scatter Diagram for X = 5 Students
(1st Class Chemistry Examination)

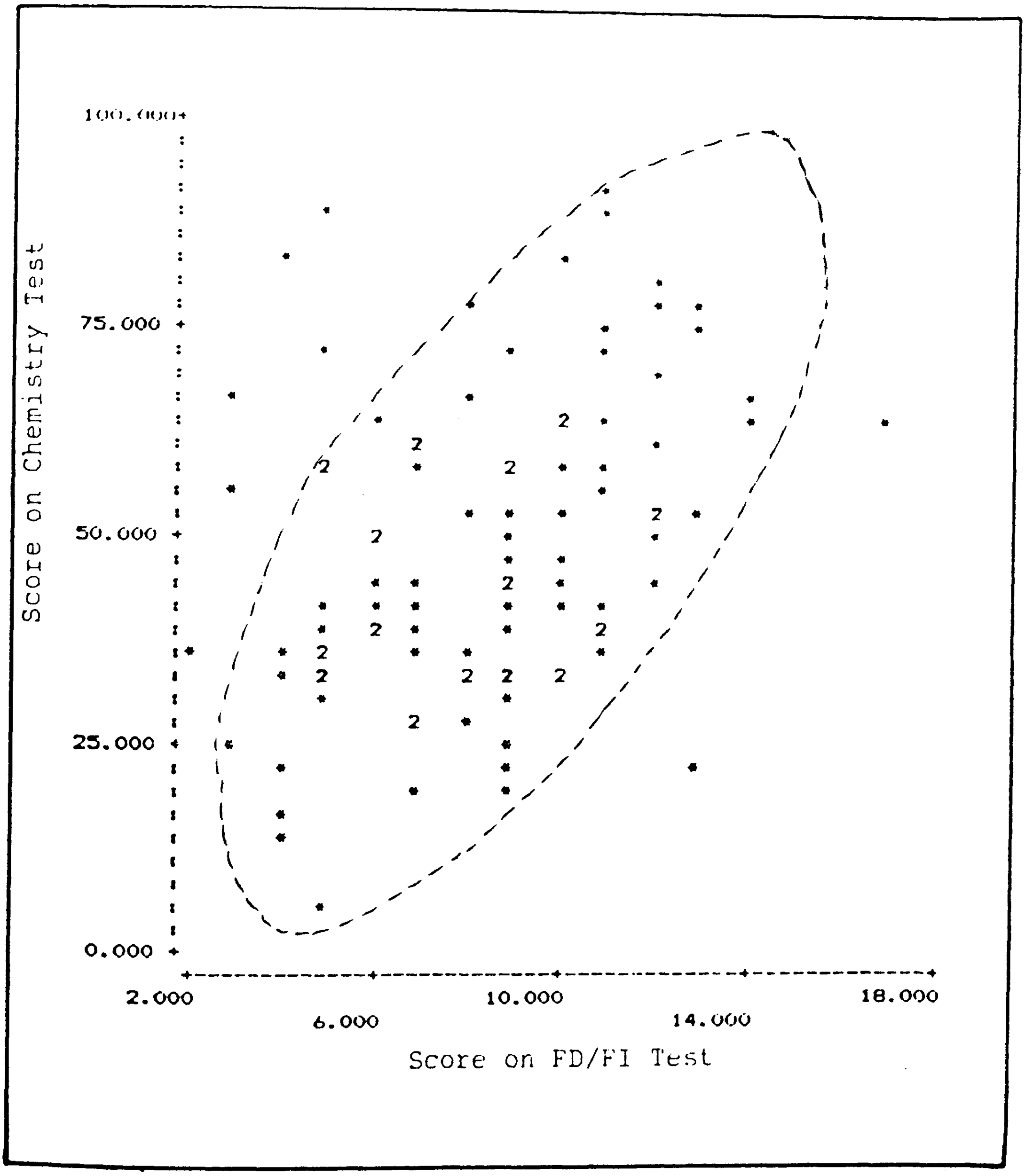


FIGURE 67. Scatter Diagram for X = 5 Students
(2nd Class Chemistry Examination)

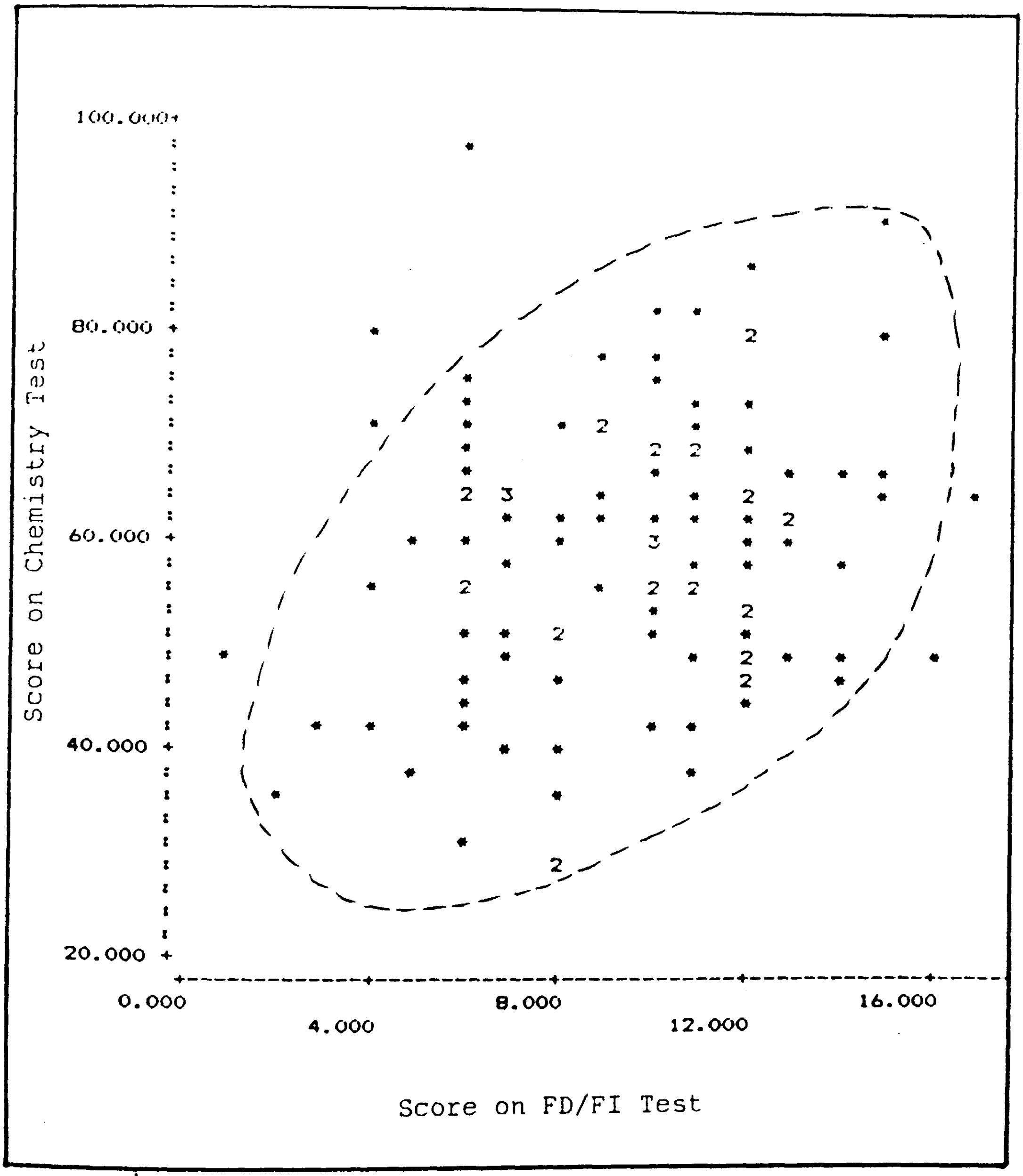


FIGURE 68. Scatter Diagram for X = 6 Students (1st Class Chemistry Examination)

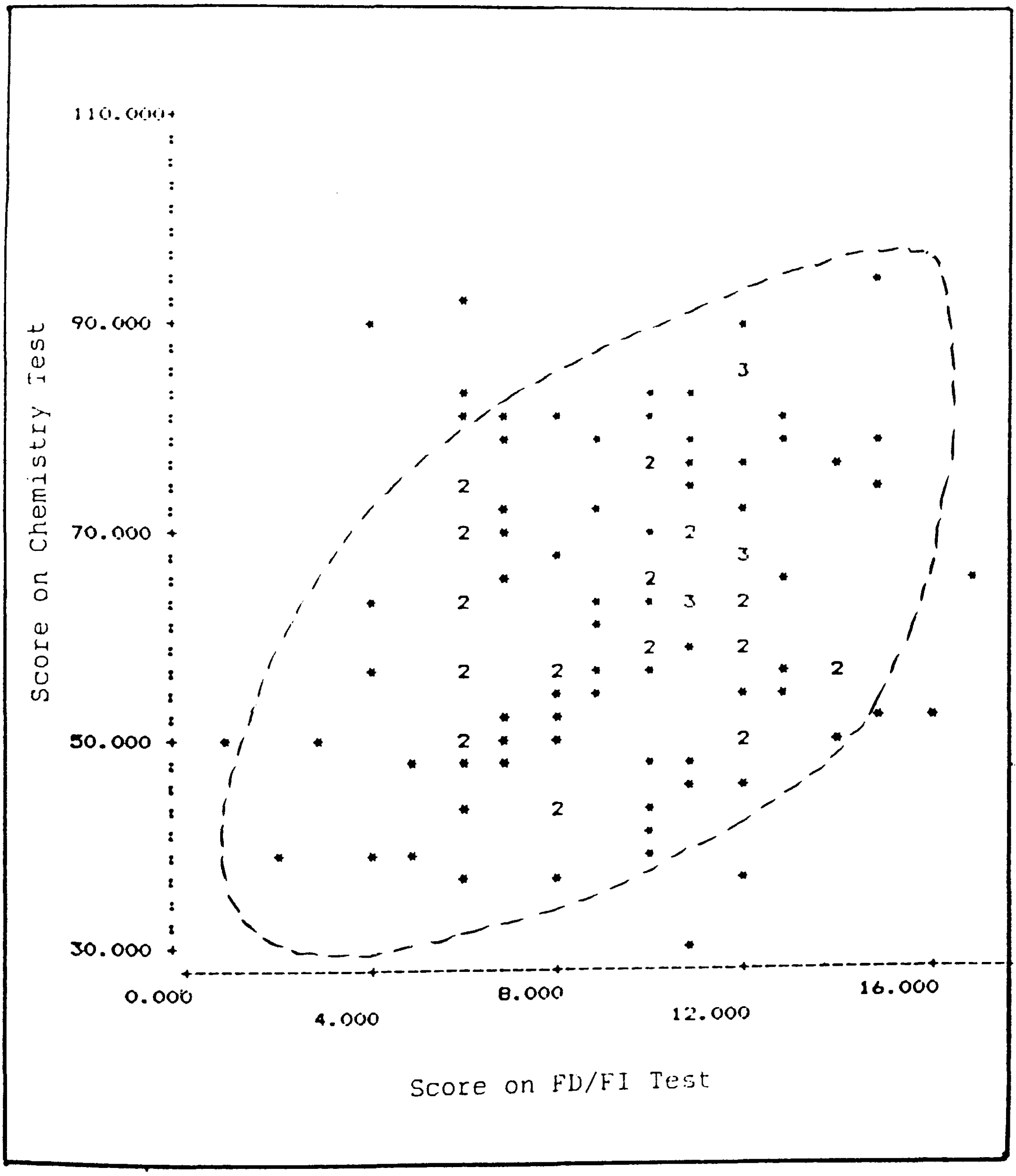


FIGURE 69. Scatter Diagram for X = 6 Students
(2nd Class Chemistry Examination)

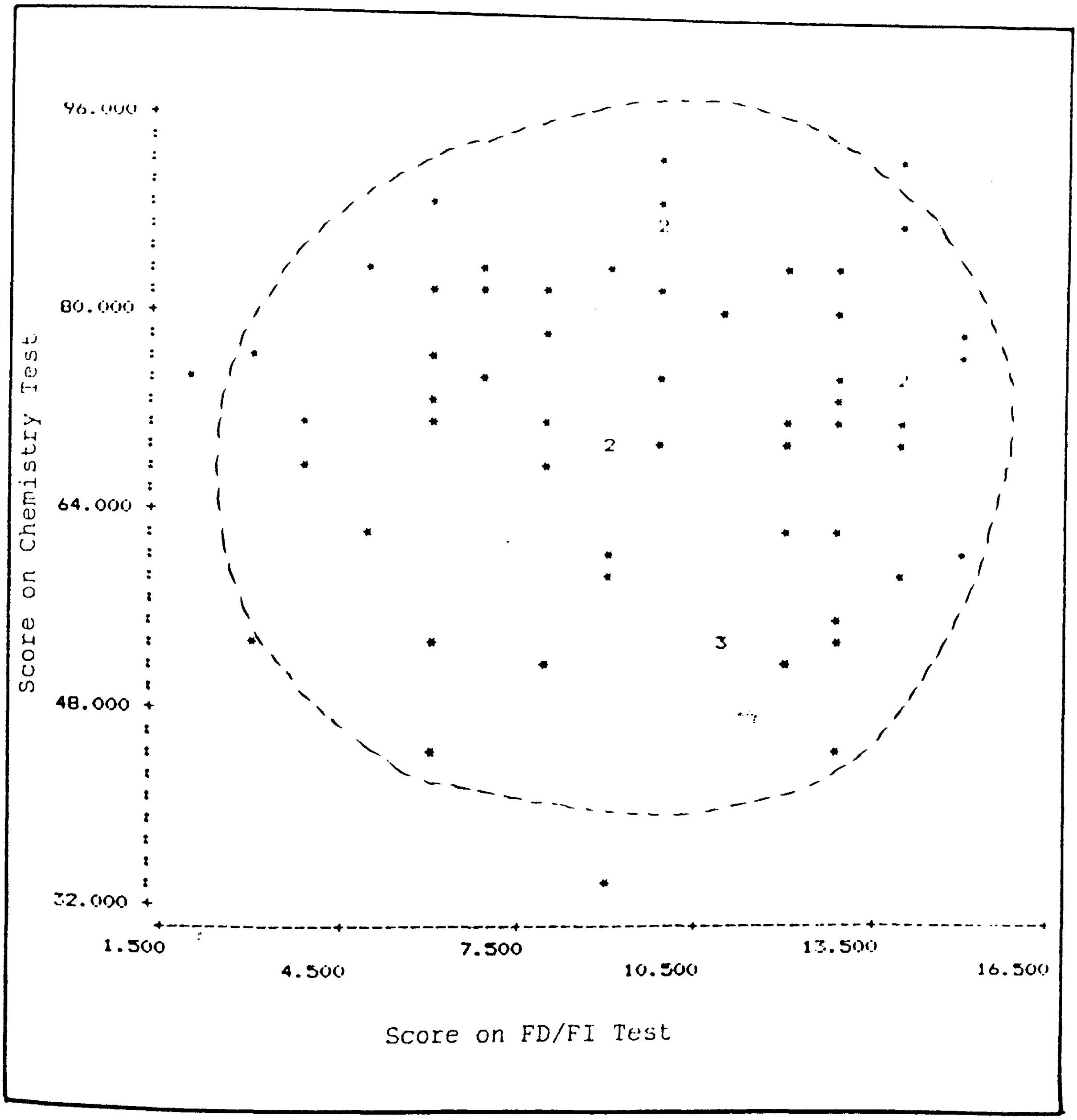


FIGURE 70. Scatter Diagram for X = 7 Students (1st Class Chemistry Examination)

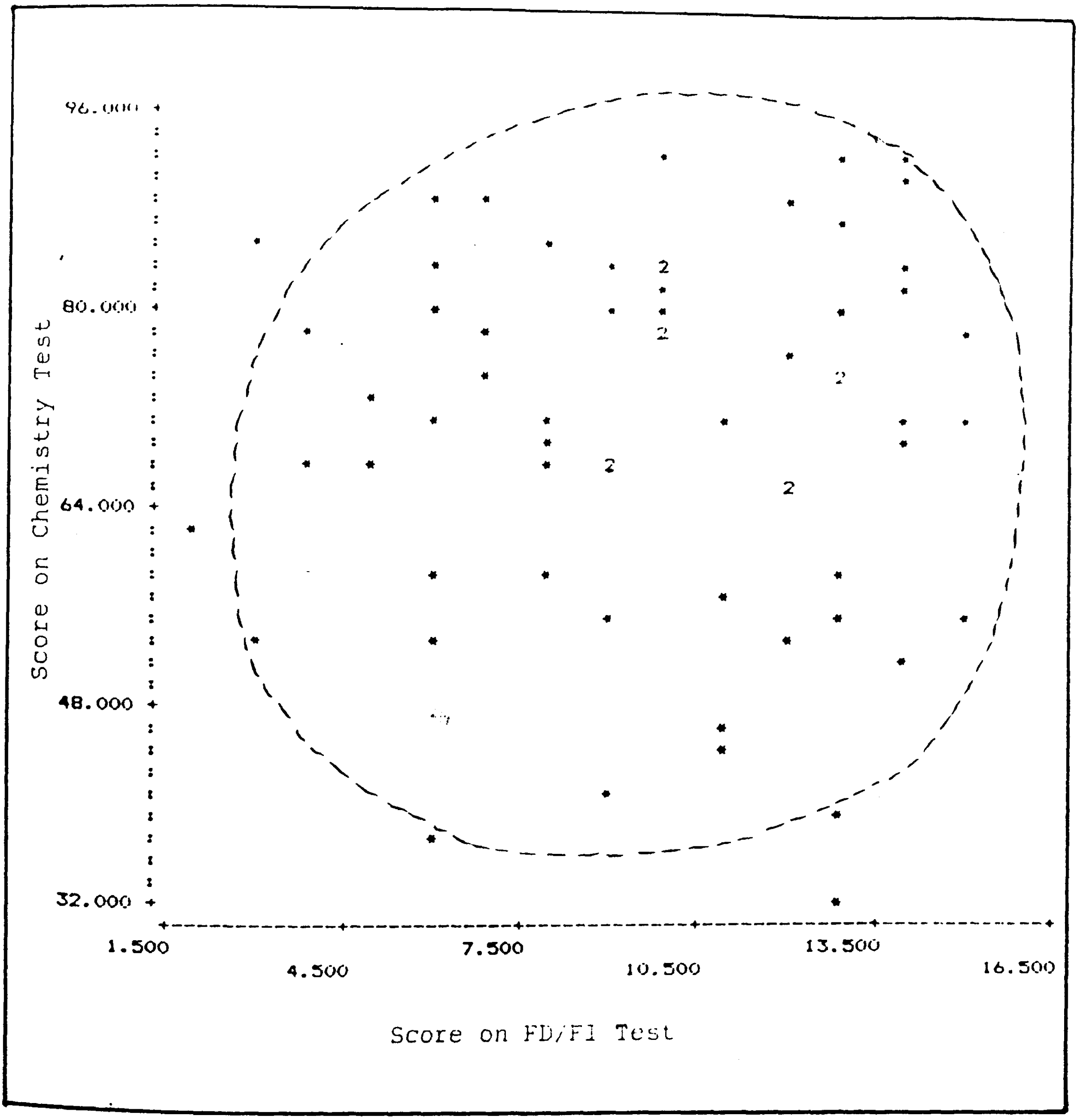


FIGURE 71. Scatter Diagram for X = 7 Students
(2nd Class Chemistry Examination)

TABLE 71

THE CORRELATION COEFFICIENT FOR EACH GROUP OF X-SPACE BETWEEN CHEMISTRY SCORES AND HFT Scores

Groups	1st Class Ex.	2nd Class Ex.
X = 5	**0.5	**0.4
X = 6	*0.2	*0.2
X = 7	0.0	0.0

** Sig. at 0.001 level
* Sig. at 0.05 level

7.5 Conclusions

The findings in this chapter lead to the following conclusions.

1. There is strong evidence in favour of there being a relationship between the students degree of field dependence/independence and their attainment scores in chemistry examinations.

2. Since there is no correlation between the students' scores in HFT and their scores in chemistry examinations in the case of X = 7 students, it could be that they have enough X-space to tolerate some irrelevant material in the data given or required to solve the question. On the other hand, for both X = 5 and X = 6, there is an indication that, because of their having less processing space, the FD students perform worse than the FI ones. They do not have enough space to handle irrelevant material.

3. In all groups of different degree of FD/FI, the mean scores of X = 7 students are higher than X = 6 and both are higher than X = 5 students.

CHAPTER 8

CONCLUSIONS, IMPLICATIONS AND SUGGESTIONS

8.1 Conclusions

8.2 Implications

8.3 Suggestions

8.1 Conclusions

The findings of this study lead to the following conclusions.

1. There is a limited holding-thinking space for an individual which can limit his ability to solve problems of different complexity.

2. The question's complexity (Z-demand) affects the students' ability to solve it completely correctly. As soon as the Z-demand exceeds their measured holding-thinking space (X-space), they cannot solve the question unless they have a strategy to reduce Z and make it less than their X-space.

3. There is a gradual fall off (when Z exceeds X) in the case of X = 5 students' performance, whereas the X = 6 students fall away more rapidly, and, in the case of X = 7 students, there is the sharpest fall. This fall does not immediately reach zero % in all groups of different X-space.

4. In questions of complexity less than or equal to the students' X-space, there is a good performance in all groups of different X-space, but the performances do not reach to 100% success. It seems that when $Z \leqslant X$, a necessary but not sufficient condition for problem solving success has been fulfilled.

5. There is strong evidence for the validity of the suggested model in that it can predict the students' performance in an individual question.

6. The students' X-space was found to be a good predictor of the students' success in over-all examination provided that the paper had questions of a range of Z-demands. There is strong evidence in favour of there being a relationship between the students' X-space and their success in conventional university examinations /

examinations as well as in 'H' and 'O' Grade school examinations, not only in chemistry but also in physics, biology and mathematics.

7. Students' performance, if they use the strategy of organizing their thinking before doing a calculation, is better than the performance of students who attempt to plan and to calculate at the same time.

8. When a question of high Z-demand is broken into sub-questions, student performance is better than when they have to deal with the question as a whole.

9. The performance of the students who have been taught a strategy while using specially written material on the mole is better than the performance of students who have not.

10. The performance of field-independent students in conventional university chemistry examinations is significantly better than the performance of the field-dependent students. However, this factor seems not to affect the X = 7 students' performance. It might be that they have enough space to deal with both relevant and irrelevant information.

8.2. Implications

The idea behind the working model is that a beginner approaching any piece of learning must be given that learning in such a form as to keep the demand of the task (Z) below the capacity of the learner X. The experimental results obtained in this study revealed a degree of consistency in the predictive power of the working model, and these results are of quite sufficient magnitude to suggest that care must be taken to allow for the learner's limitations. Although it seems likely that nothing can be done to extend the absolute capacity of the students' holding-thinking space, or alter their degree of perceptual field, the following implications would seem to follow.

1. Implications for the Content Structure of the Material to be Learned.

(i) The way in which scientific facts and concepts have been traditionally presented has to be re-examined in order to keep the demand of the task at each stage of the learning process within the range of students' X-space.

(ii) The sequence of the course might have to be re-arranged to help students to be able to "chunk" the information into processable size. Organized knowledge has to be provided for the students. The information should be presented in small portions, and a summary should be provided to help students to grasp this information in smaller and meaningful "chunks".

The order of the O-Grade chemistry syllabus in the text "Chemistry About Us"[143] is an example of how information content can be reduced by altering the sequence. It begins by using the minimum of theory to enable students to start upon the experimental investigations. Then the organic chemistry is introduced which needs only four elements to be considered: C, H, O and N, and, at the same time, it does not require balanced equations. Additional theory of bonding, balancing of equations, oxy-anions, and ionic equations are introduced only when required to help in understanding.

(iii) The information content should be introduced to the students in language which should be easy enough to be understood. A study by Cassels and Johnstone[142] showed that the language problems for pupils lie not so much in technical words, but in familiar words like "volatile", "correspond" and "spontaneous". Such words, which change their meaning in science, cause more trouble than "titrate", "pipette", or "alkali" because students assume that the meaning of the first group of words is unchanged in science. Therefore, care should be taken to explain the changes of meanings of words /

words which may cause conflict for students, and so occupy scarce processing space.

(iv) In some cases, according to the nature of the material to be learned, the information content may, of necessity, be high. However, the information could be presented in the form of diagrams, graphs or concept maps which then function as "chunking devices".

2. Implications for Teaching Methods

(i) It is worth emphasising that the teaching of strategies is a very important part of the teaching processes. Indeed the teaching of strategies may be as important as the content itself.

(ii) Opportunities should be given to the students to practise how to break a task into a smaller number of information units, and to link between them in diagrams or maps or graphs.

(iii) Opportunities should be also given to the students to practise how to organize their thinking before doing calculations.

(iv) Teachers should devote more attention to teaching students specific strategies for dealing with high information loads; for example, the strategies used in this thesis in both stoichiometry and neutralization calculations.

(v) Within the context of practical work, strategies which help students to separate relevant from irrelevant information, have to be consciously taught. This could be done by keeping the teaching of skills away from their use until they are mastered. The potential for overload is high when skills, observations and interpretation are dealt with simultaneously.

(vi) /

(vi) In writing a laboratory manual, care should be taken to enhance the relevant by giving a clear statement of the point of the experiment, and suppressing the irrelevant by stating clearly what is preliminary, peripheral and preparatory.[144] A clear statement of what the students have to do and to observe during the experimental investigation is essential.

3. Implications for Assessment

(i) A question of high complexity (Z) is testing both the X-space and the Y (strategy). If Y has not been taught to the students, the question measures the students' X-space rather than their chemical ability and hence the question is invalid. Teachers and examiners should be sensitive in designing questions, and questions of high Z-demand should be reconsidered or eliminated.

(ii) Care should be given to the language of the questions, as well as the order in which the data is given in the question. Unfamiliar language introduced in the question makes it of high Z-demand.

(iii) It is important that the questions should be checked with a view to their drastic simplification and omission of all of the negative or double negative forms. Such forms occupy more X-space than positive forms.

8.3 Suggestions for Further Work

From the findings of this work, a great deal of further research is necessary, since there are many problems which still remain unsolved. The suggestions for further work can be put in questions briefly as follows:

1. Is there any relationship between the students' degree of field /

field-dependence/independence and their ability to solve questions of different complexity of Z-demand?

2. Is there any relationship between the students' X-space and their thinking style?

3. Is there any relationship between the students' X-space and their ability to solve non-numerical questions of different Z-demand?

4. Why does the performance of students in questions of $Z \leqslant$ their measured X-space not reach a 100%?

5. Why are the $X = 7$ students better in all-over performance than $X = 6$ and both are better all-over performance than $X = 5$?

6. To what extent does the information given and the arrangement of the data in the question affect the question's demand?

7. To what extent can the relationship between the students' X-space and their ability to solve questions of different Z-demand be applied in subjects other than chemistry?

8. What strategies do students use to enable some of them to perform successfully in questions where $Z > X$? Can these strategies be transferred to other students? Are the strategies generalisable or are they subject specific?

9. How can the general theory be used to give direction to the improvement of all forms of teaching and learning?

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APPENDICES

APPENDIX 1

* MAJOR U.K. SCIENCE CURRICULUM DEVELOPMENTS FOR THE SECONDARY LEVEL

Curriculum development (date)	Age range in years	Ability range	Headquarters
Schools Council 5 - 13 Project (1967 - 1974)	5 - 13	All levels	School of Education, University of Bristol
Nuffield Combined Science (1965 - 1969)	11 - 13	All levels	City of Birmingham. College of Education
Nuffield Combined Science Continuation Project (1972 - 1973)	11 - 15	All levels	City of Birmingham. College of Education
Nuffield 'O' Level Biology, Chemistry, Physics (1962 - 1967)	11 - 16	Upper 15%	Biology: School of Education, University of Bath. Chemistry and Physics: Nuffield Lodge
Nuffield 'O' Level Revision (1970 -	11 - 16	Upper 25%	Centre for Science Education, Chelsea College

A P P E N D I X 1 (cont'd)

Curriculum development (date)	Age range in years	Ability range	Headquarters
Scottish Integrated Science: First Cycle (1969 - 1972)	12 - 14	All levels	Scottish Education Department
Scottish Integrated Science: Second Cycle (1969 - 1972)	14 - 16	Lower 50%	Scottish Education Department
Schools Council Project Technology (1967 - 1972)	11 - 18	All levels	National Centre for School Technology, Trent Polytechnic, Nottingham
Nuffield Secondary Science (1965 - 1970)	13 - 16	Lower 75%	Centre for Science Education, Chelsea College
Schools Council Integrated Science Project: SCISP (1969 - 1975)	13 - 16	Upper 25%	Centre for Science Education, Chelsea College

* Extracted from Reference No. 53, pp 68-69

APPENDIX 2

DATE FROM SCOTTISH EXAMINATION BOARD (NATIONAL BANK ITEMS)

24 Multiple Choice Items

Item No.	No. of Thought Steps	F.V.	Ability	Item No.	No. of Thought Steps	F.V.	Ability
1	3	0.82	Co.	13	13	0.09	Co.
2	3	0.83	Co.	14	7	0.28	Co.
3	5	0.77	Co.	15	6	0.26	Co.
4	3	0.87	Co.	16	4	0.92	Kn.
5	1	0.83	Co.	17	5	0.90	Kn.
6	1	0.86	Co.	18	1	0.93	Kn.
7	4	0.80	App.	19	4	0.83	Kn.
8	2	0.92	Co.	20	5	0.83	Co.
9	1	0.90	Co.	21	3	0.79	App.
10	6	0.34	App.	22	3	0.90	App.
11	6	0.35	App.	23	6	0.32	App.
12	9	0.15	App.	24	7	0.23	Co.

Kn = knowledge
Co = comprehension : Bloom Levels
App = application

APPENDIX 3

DIGIT SPAN TEST

The following tests, Digits Forward and Digits Backward, are administered separately. For both, say the digits at the rate of one per second, not grouped. Let the pitch of voice drop with the last digit of each series. The series denotes the number of digits in an item.

DIGITS FORWARD

Directions - Start by saying -

"In a fairly simple game, I'm going to say some numbers. Listen carefully to them, and when I stop speaking you write them down in the space provided in the sheet that you have been given.

Are you ready then? Let us begin."

Series:

3	5	8	2						
	6	9	4						
4	6	4	3	9					
	7	2	8	6					
5	4	2	7	3	1				
	7	5	8	3	6				
6	6	1	9	4	7	3			
	3	9	2	4	8	7			
7	5	9	1	7	4	2	8		
	4	1	7	9	3	8	6		
8	5	8	1	9	2	6	4	7	
	3	8	2	9	5	1	7	4	
9	2	7	5	8	6	2	5	8	4
	7	1	3	9	4	2	5	6	8

DIGITS BACKWARD

Directions - Start by saying -

"Now I'm going to give another set of numbers, but this time there's a complication. When I've finished saying each set of numbers, I want you to write them down in reverse order. For example, if I say, "719", you would write down 917. Now, no cheating. Do not write from right to left. You listen carefully, turn the number over in your mind and write from left to right. Have you got that? Then let's begin."

Series:

2	2	4						
	5	8						
3	6	2	9					
	4	1	5					
4	3	2	7	9				
	4	9	6	8				
5	1	5	2	8	6			
	6	1	8	4	3			
6	5	3	9	4	1	8		
	7	2	4	8	5	6		
7	8	1	2	9	3	6	5	
	4	7	3	9	1	2	8	
8	9	4	3	7	6	2	5	8
	7	2	8	1	9	6	5	3

APPENDIX 3 (cont'd)

NAME :

SEX :

DATE OF BIRTH :

DIGIT FORWARD

Series	NUMBERS								
3									
4									
5									
6									
7									
8									
9									

DIGIT BACKWARD

Series	NUMBERS							
2								
3								
4								
5								
6								
7								
8								

APPENDIX 4(A)

* FIGURAL INTERSECTION TEST

FIT (RAC 794)

NAME:

SEX:

SCHOOL:

DATE OF BIRTH:

CLASS:

This is a test of your ability to find the overlap of a number of simple shapes.

There are two sets of simple geometric shapes, one on the right and the other on the left.

The set on the right contains a number of shapes separated from each other.

The set on the left contains the same shapes (as on the right) but overlapping, so that there exists a common area which is inside all of the shapes.

Look for and shade in the common area of overlap.

Note these points:-

(1) The shapes on the left may differ in size or position from those on the right, but, they match in shape and proportions.

(2) In some items on the left some extra shapes appear which are not present in the right hand set, and which do not form a common area of intersection with all of the other shapes. These are present /

present to mislead you but try to ignore them.

(3) The overlap should be shaded clearly by using a pen.

(4) The results of this test will not affect your schoolwork in any way.

---

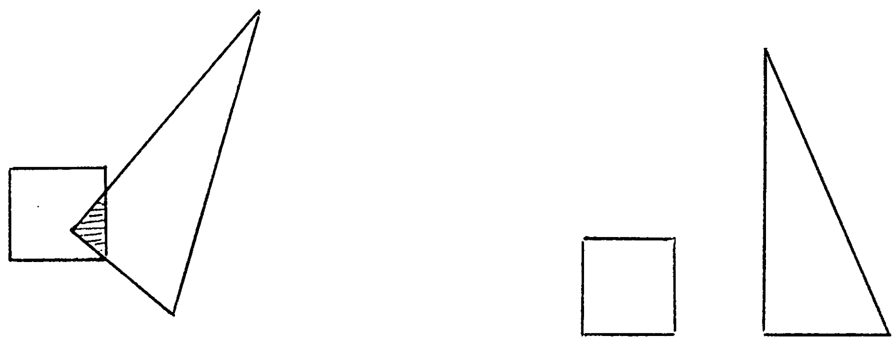
* This test may not be used without permission from:

Professor J. Pascual-Leone, Room 246 B.S.B., York University,
4700 Keele Street, Downsview,
Ontario, M3J 1P3.

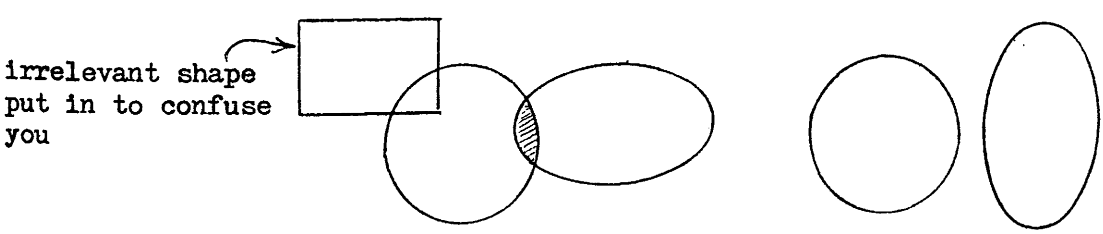
* This test is photo-reduced to fit the pages of this thesis.

Here are some examples to get you started.

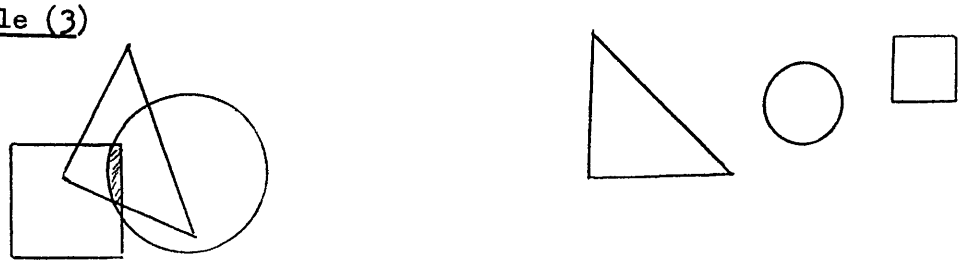
Example (1)



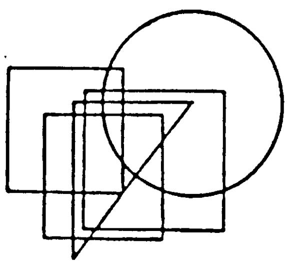
Example (2)

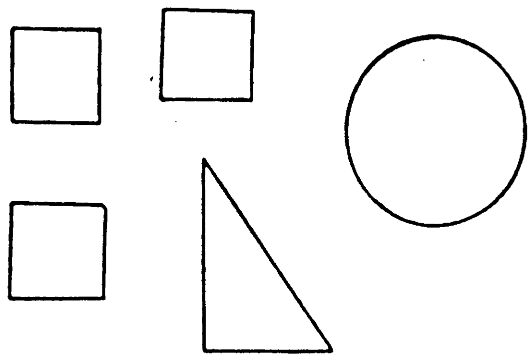


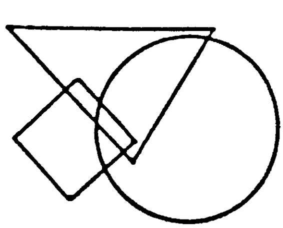
Example (3)

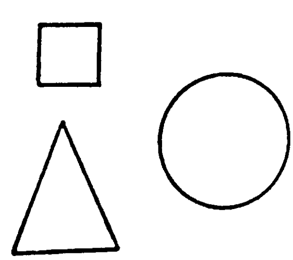


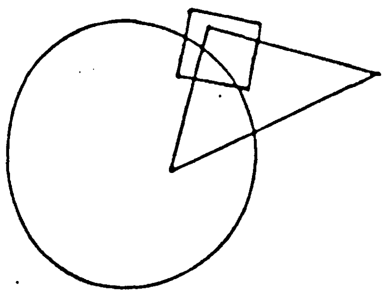
Now attempt each of the items on the following sheets.

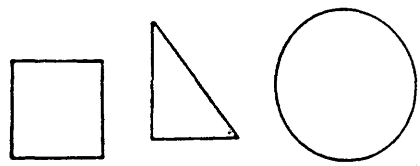


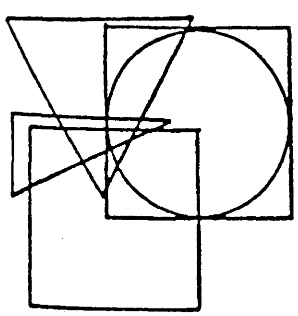


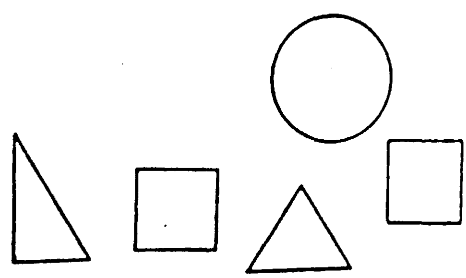


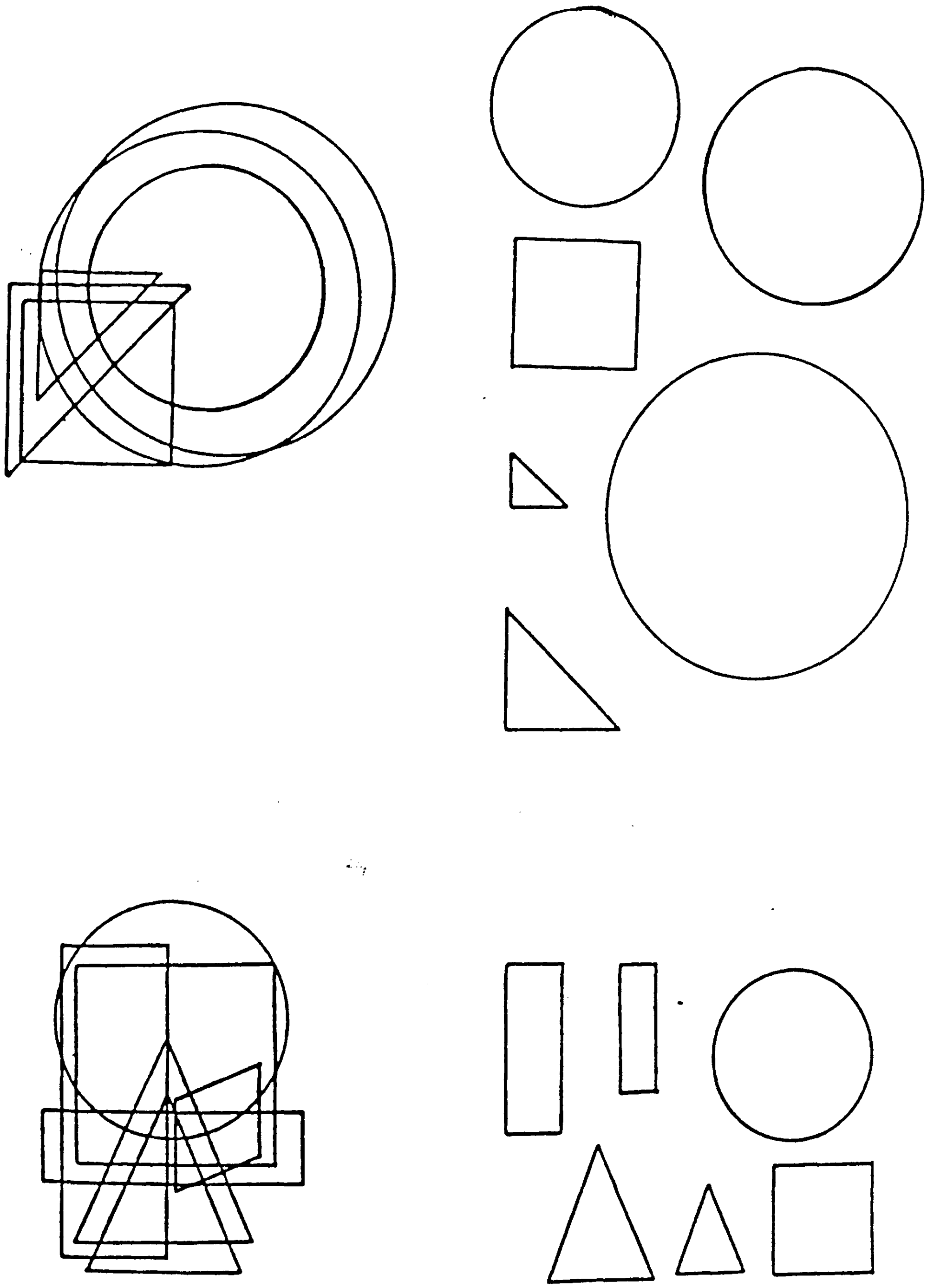


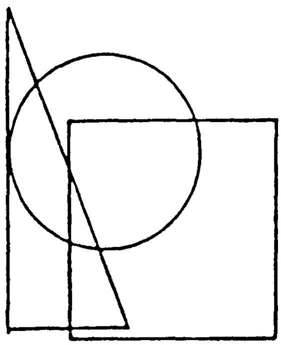


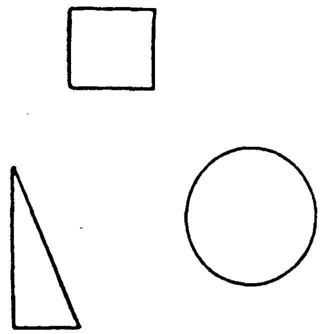


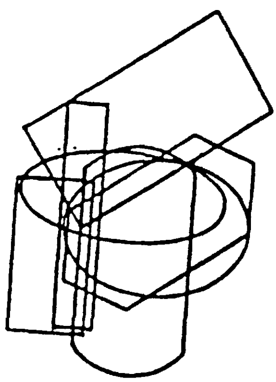


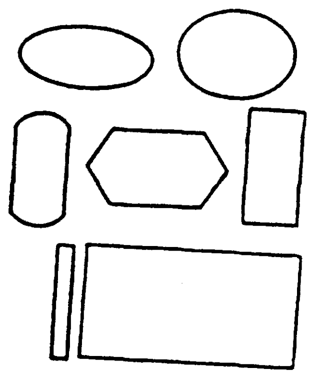


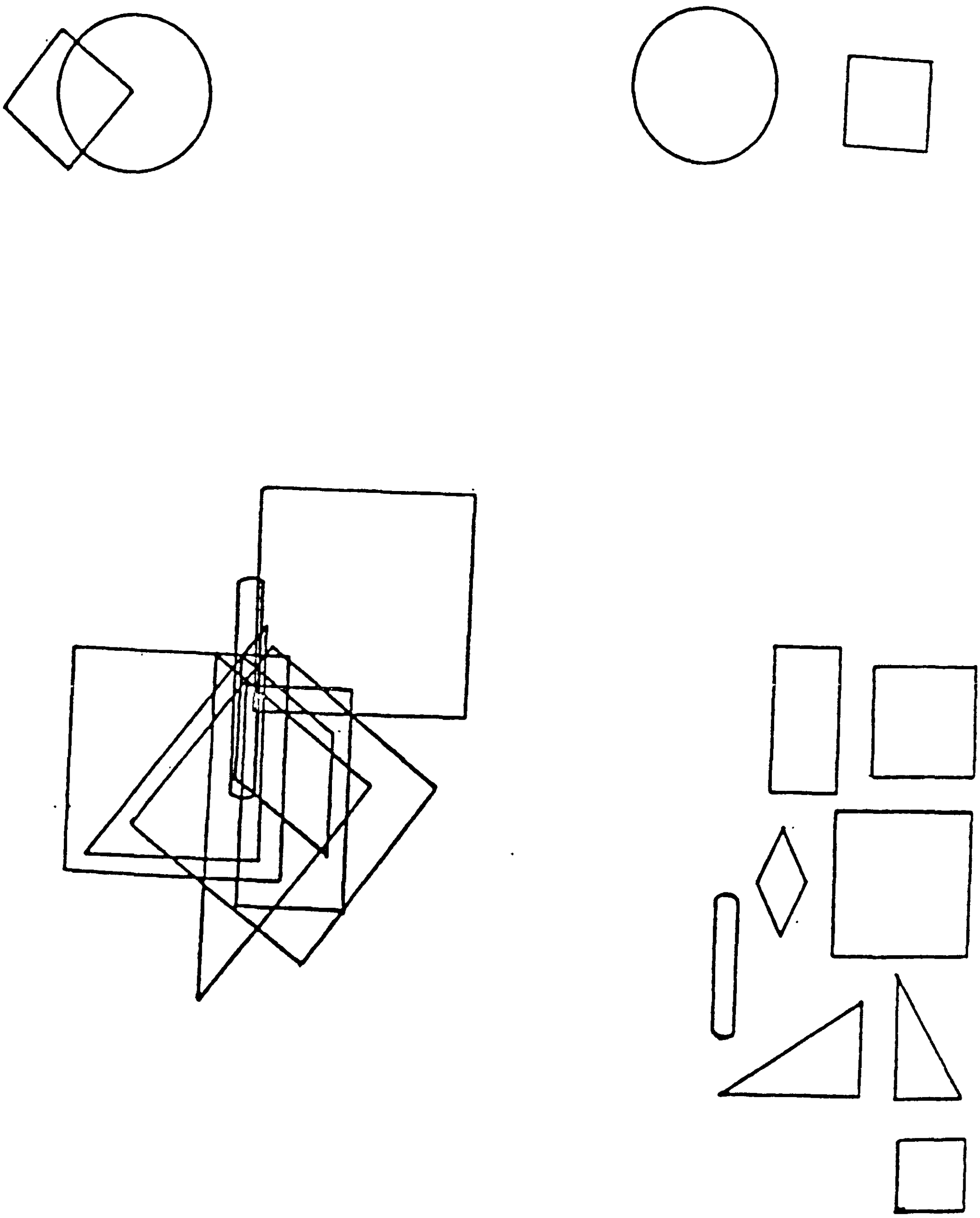


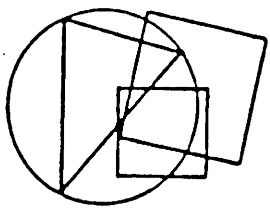


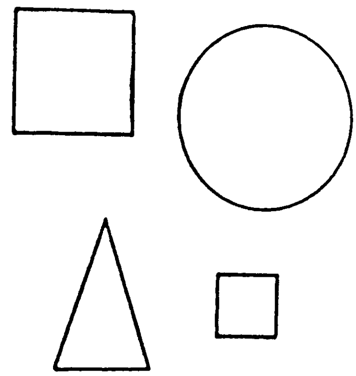


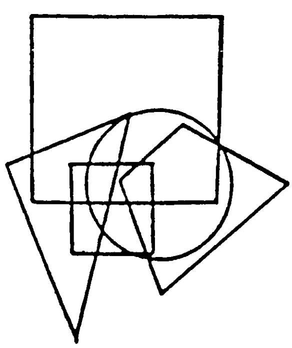


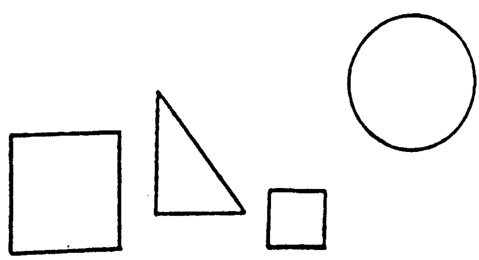


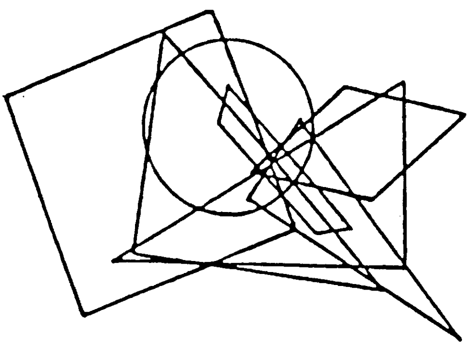
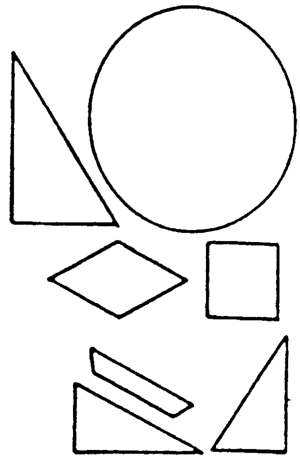
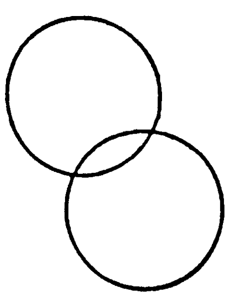
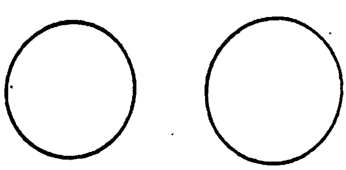


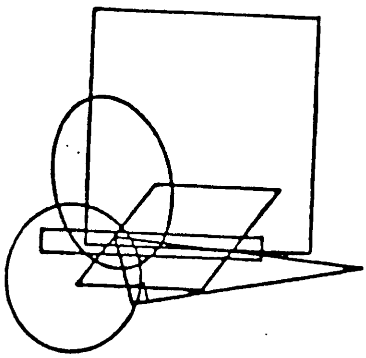


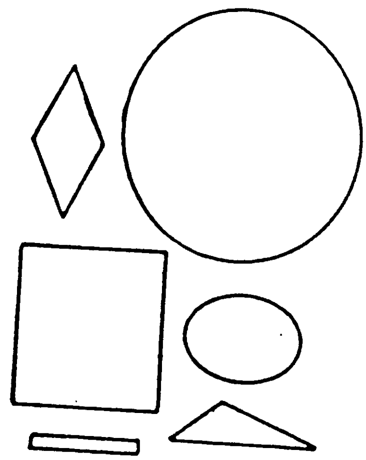


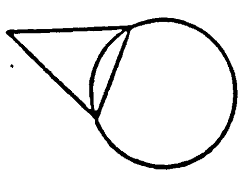


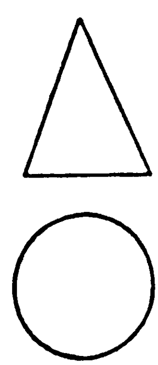


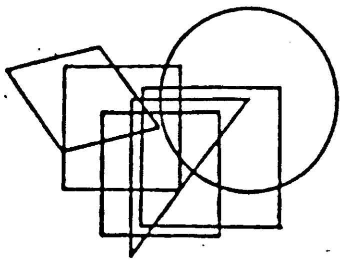





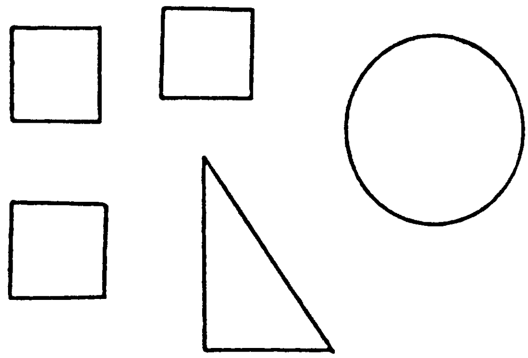


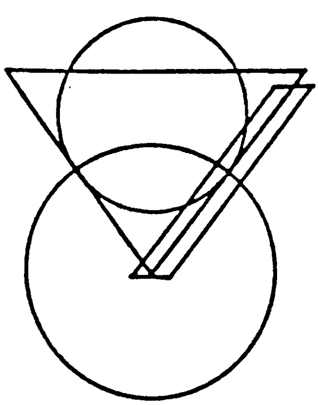


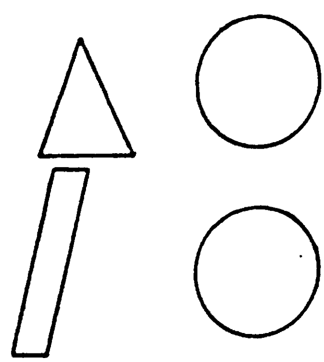


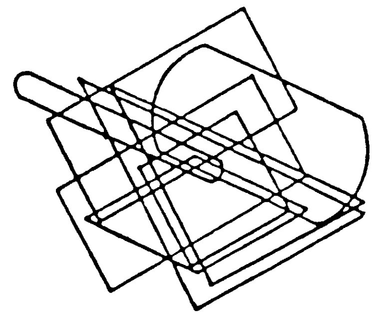


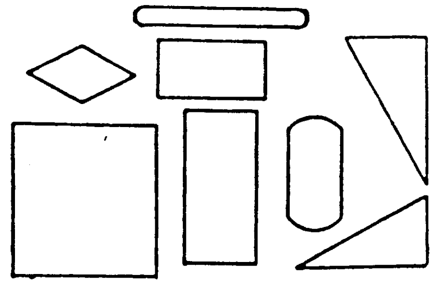


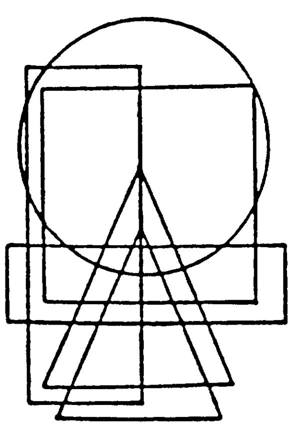


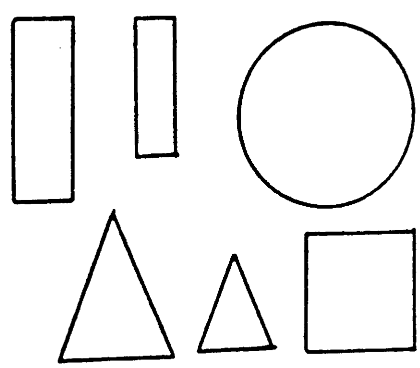


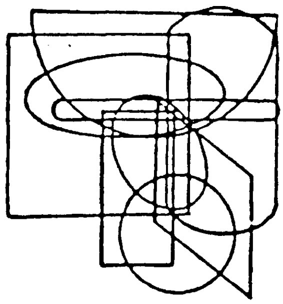


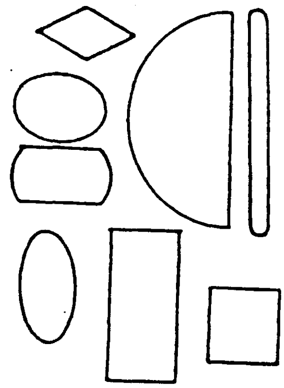


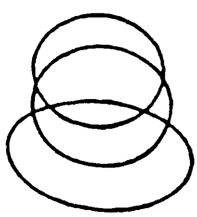


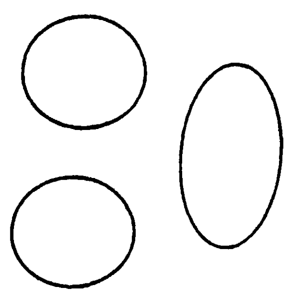


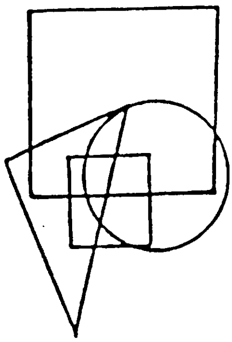


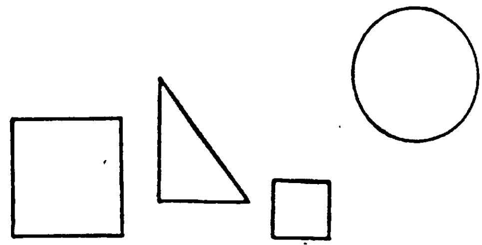


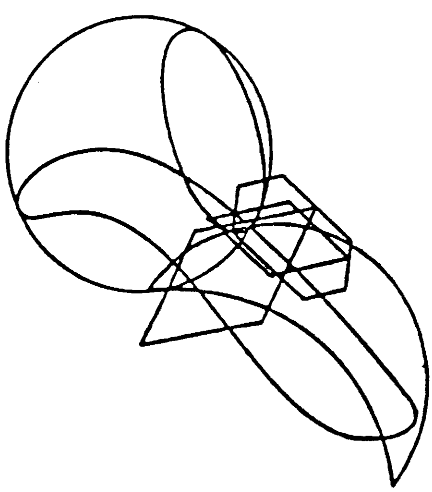


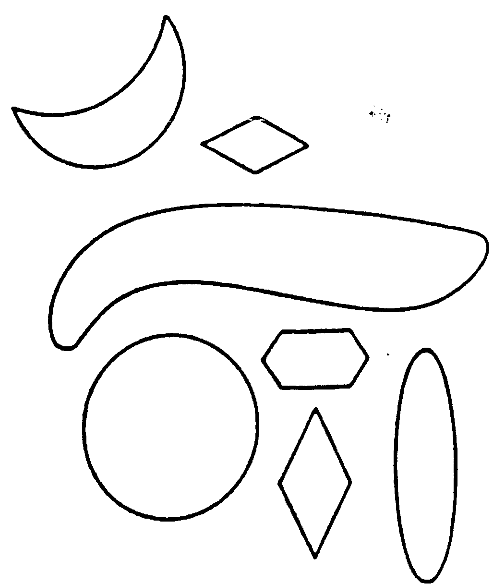


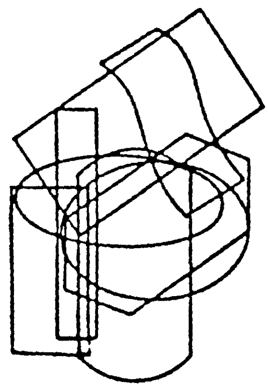


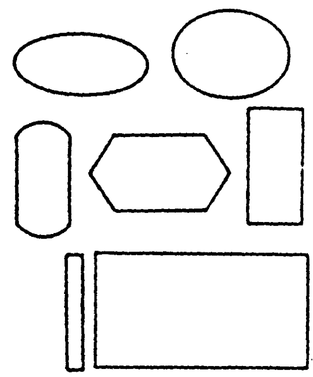


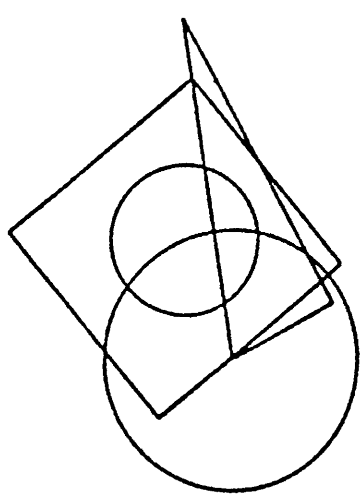


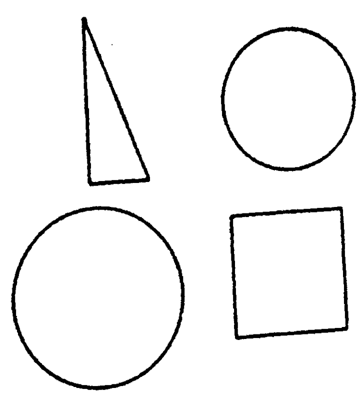


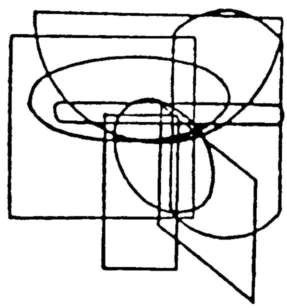


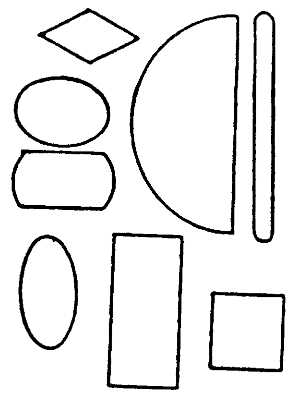


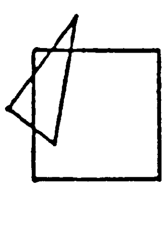


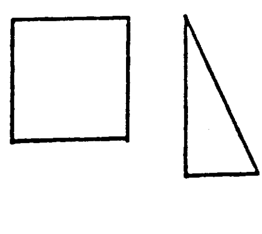


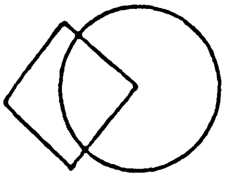


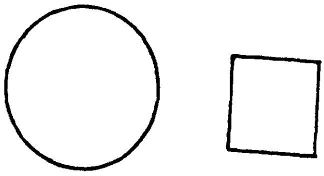


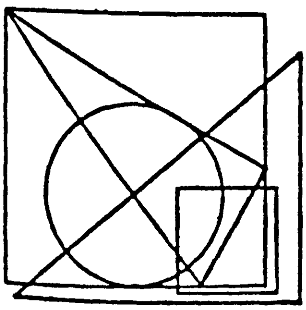


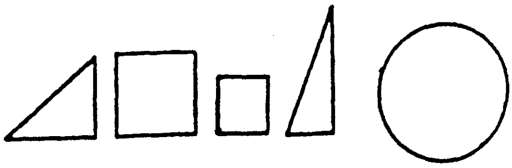


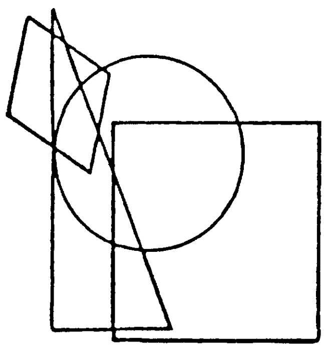


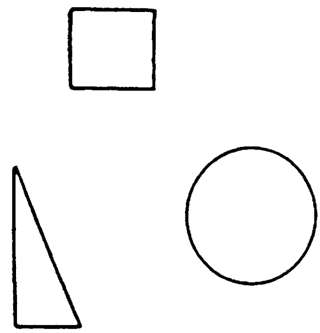


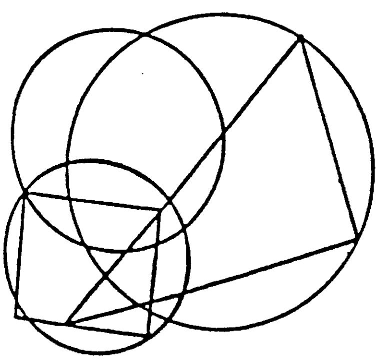


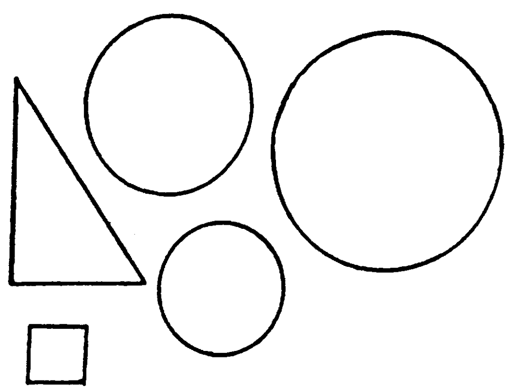


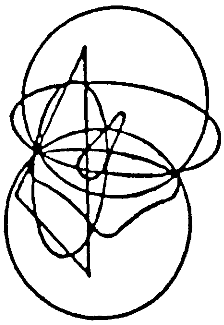


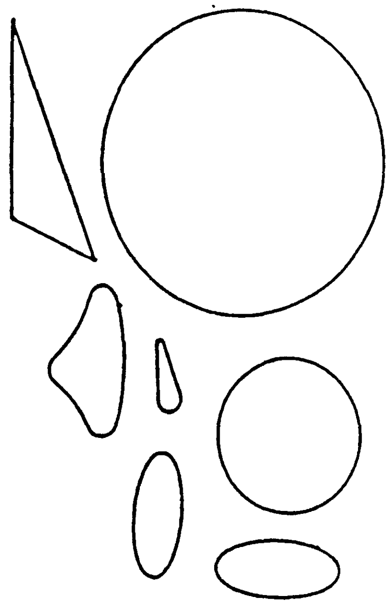


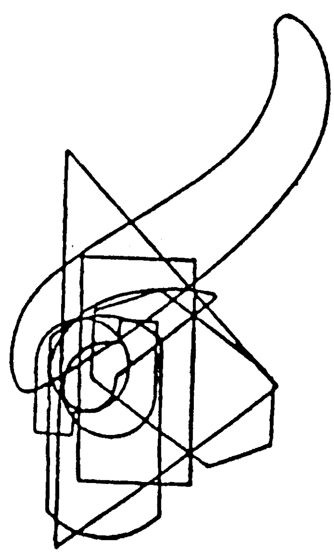


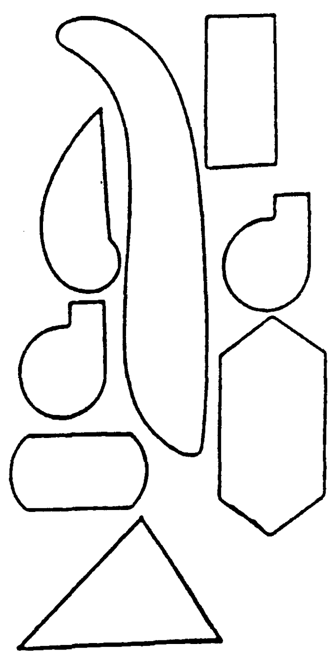


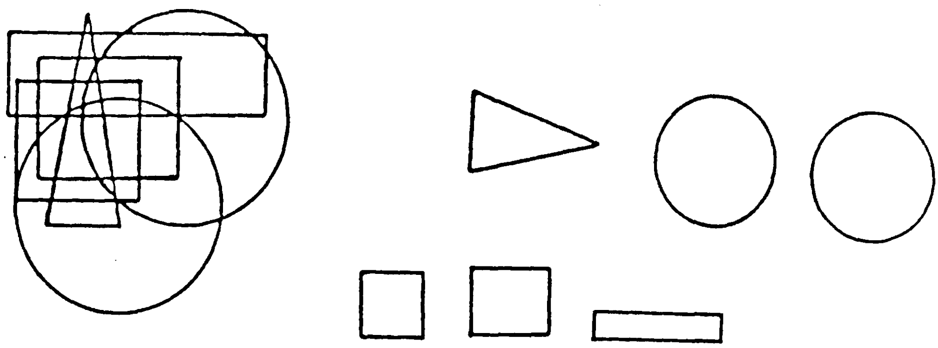


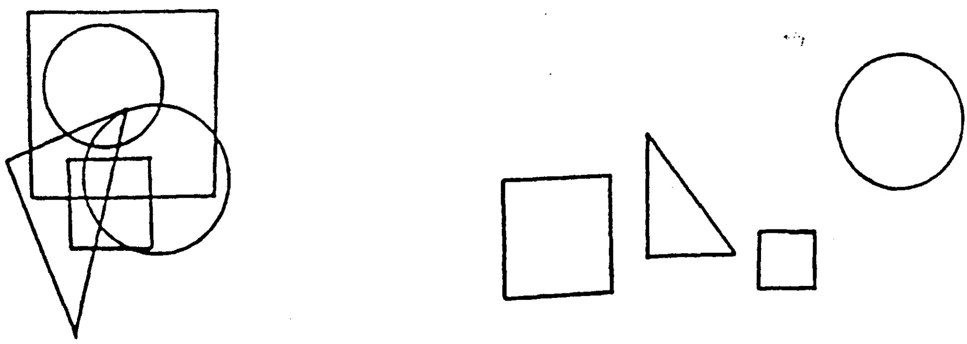












APPENDIX 4(B)

ASSIGNMENT OF k ESTIMATES ON THE BASIS OF FIT PERFORMANCE

Four k scores were initially assigned to each subject on the basis of his/her FIT performance; a single k score was then computed for each subject based on the four scores. Each item class in the FIT version used (except class 2) contained at least one item with an irrelevant figure: the irrelevant figure appeared in the compound-form set but not in the discrete set for the item. In grouping items into classes, items with x relevant figures and one irrelevant figure may either be put into class x or into class x + 1, depending on whether or not one assumes that the irrelevant figure adds to task demand (i.e. Md of item = x or X + 1). The strategy of placing items with x + 1 figures in the compound into class x has typically been used in scoring the FIT. However, there is some evidence that items with an irrelevant shape in the compound actually have an Md of x + 1.

In the present study scores were computed for each of the two ways of classifying items. These two ways of grouping items into classes are referred to as x scaling (x relevant + 1 irrelevant = class x) and x + 1 scaling (x relevant + 1 irrelevant = class x + 1).

Two kinds of k scores were computed for each way of scaling the item classes. One kind of score was the $K_{.75}$ score which repeatedly has been found to provide k estimates close to theoretically-appropriate values. This score is obtained by grouping the items into classes and obtaining for each class the percentage of items passed in that class. The $K_{.75}$ score is the highest stimulus class at which at least 75% of the items are passed, provided that all (or all but one) of the lower classes also have 75% pass rates (a drop to 60% /

60% pass in one lower class is allowed). (This score is sometimes referred to as the $K_{.80}$ score, however, given the number of items in each FIT class, there is no practical difference between using a pass rate of 75% and one of 80%.) This way of scoring yielded two scores: $K_{.75}$ - x and $K_{.75}$ - x + 1.

The second kind of k score is the SI-theoretical (or SIT) score. This score is based on the strong theoretical assumption that a child will solve all and only those items with class values less than or equal to his/her Mp (e.g. if a child has an Mp of 3, s/he should solve all class 2 and 3 items, but no items of class 4 or higher). The score is computed by first summing the number of items solved across stimulus classes 2 through 7. One then uses a raw-score distribution to determine what SIT score corresponds to the (summed) raw performance score. Table A.4.1 lists the distributions for assigning SIT scores for the x and x + 1 scaling methods for the FIT version used in the present study. (The distributions were constructed based on the strong theoretical assumption stated above.) I call the SIT scores SIT - x and SIT - x + 1.

Pascual-Leone suggests that the SIT score may be more reliable, because it is based on data from all the passed items. The $K_{.75}$ score, however, may be more valid, because it is sounder semantically, pegging k at the highest item class that is reliably passed. A single composite FIT - K score for each subject was constructed in the following manner. The four k-estimates for the subject were examined, and if at least three of the four scores had the same value then that majority value was assigned as the FIT - K score (e.g. scores of 3, 3, 3, and 4 yielded a FIT - K of 3). If there was no majority score value, then the mean of the four scores was assigned as the FIT - K score (e.g. scores of 2, 2, 3, 4 yielded a FIT - K of 2.75); decimal values were retained.

TABLE A.4.1

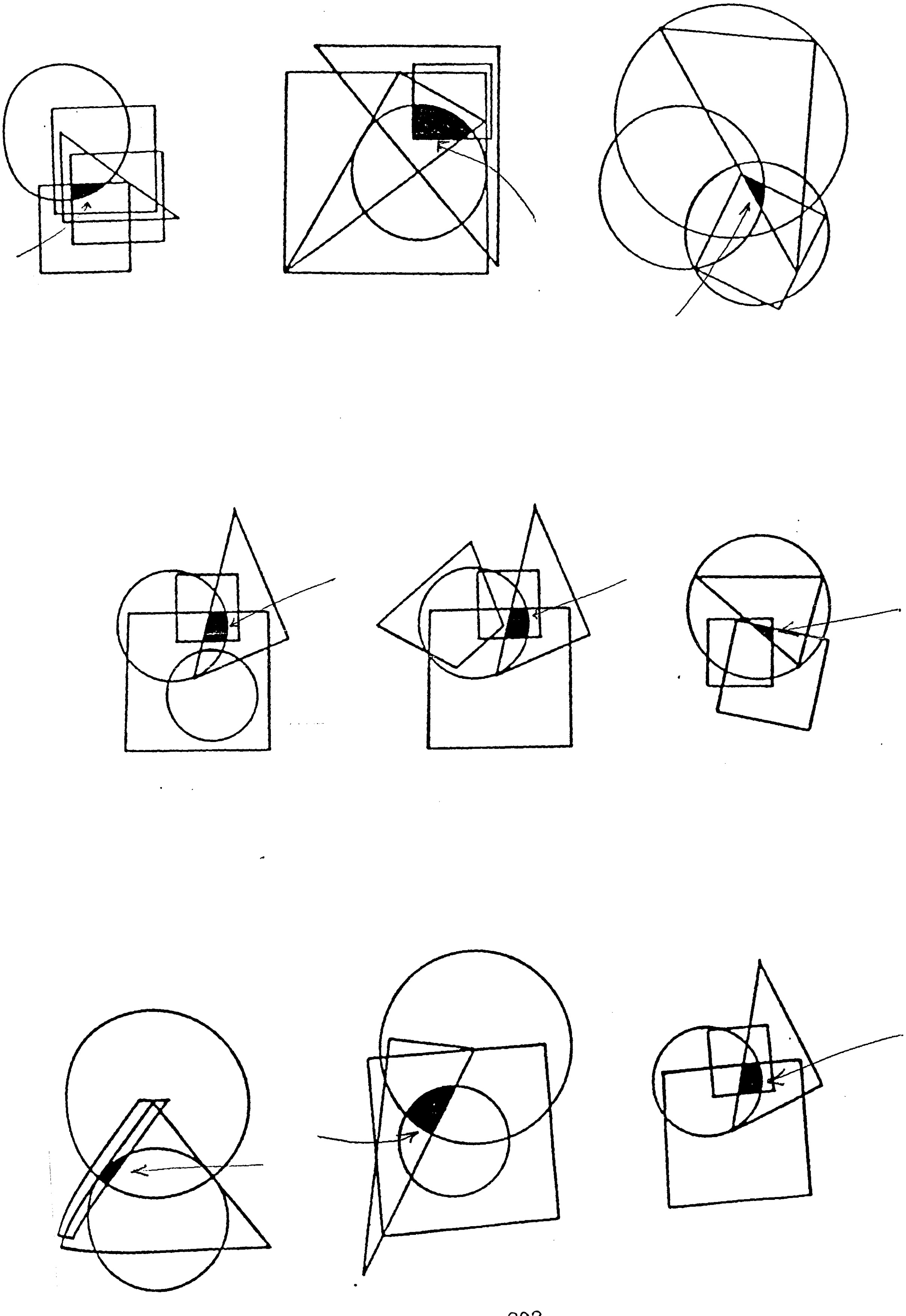
RAW SCORE DISTRIBUTIONS FOR ASSIGNMENT
OF SIT SCORES ON THE BASIS OF
FIT (RAC 794) PERFORMANCE

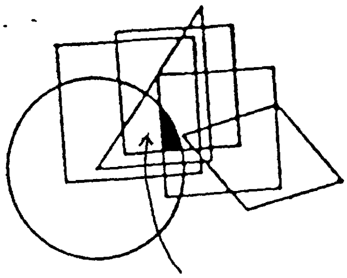
SIT	Number of Correct Items (Classes 2 through 7)	
	x scaling	x + 1 scaling
1	4	4
2	5 - 9	5 - 8
3	10 - 15	9 - 13
4	16 - 20	14 - 19
5	21 - 15	20 - 14
6	26 - 30	25 - 29
7	$\geqslant$ 31	$\geqslant$ 30

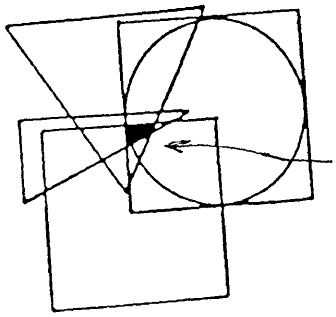
* Extracted from Ref. No. 136

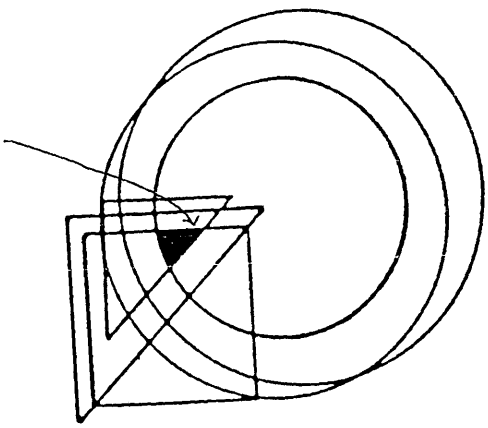
APPENDIX 4(C)

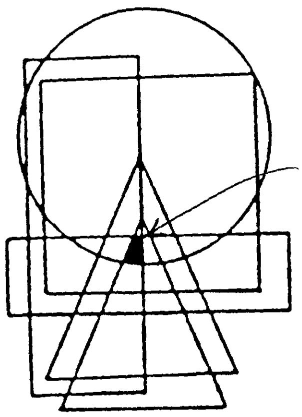
F.I.T. SCORING KEY

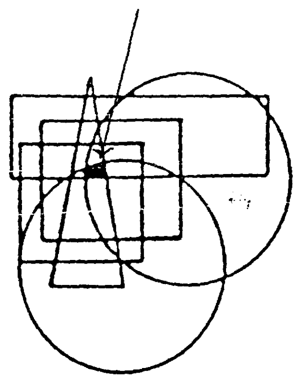


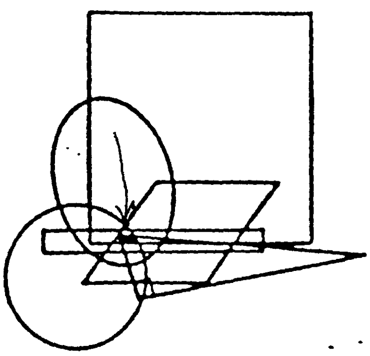


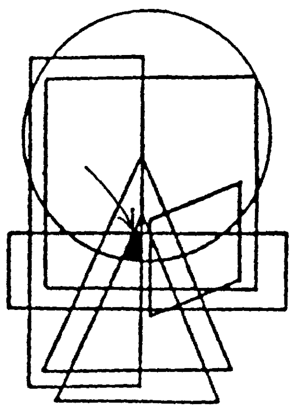


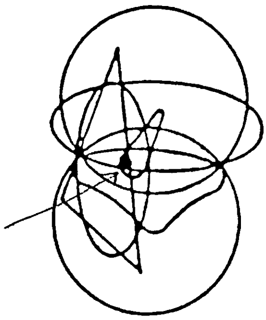
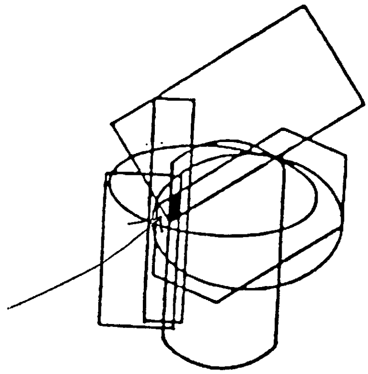
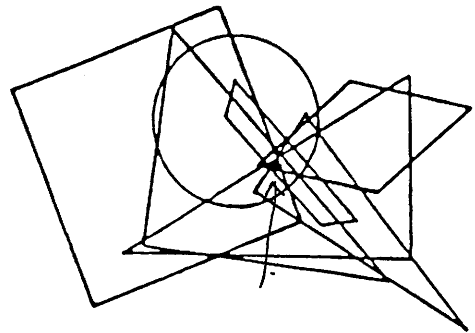
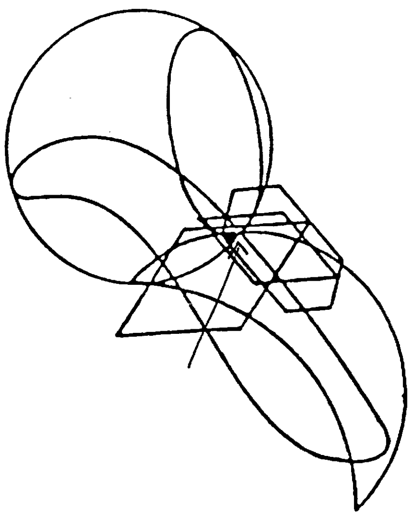
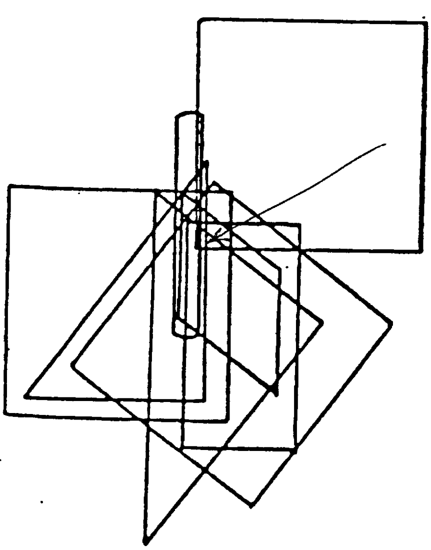
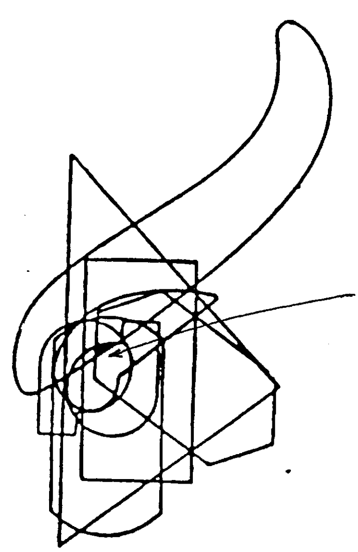


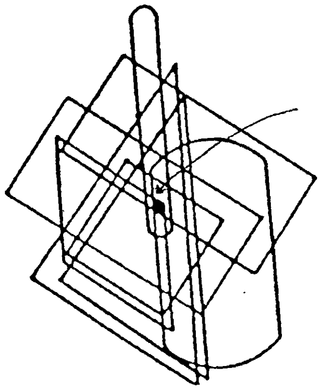
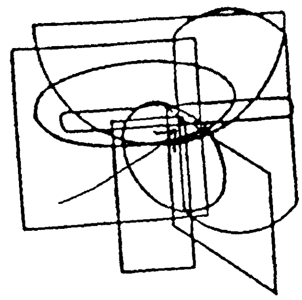
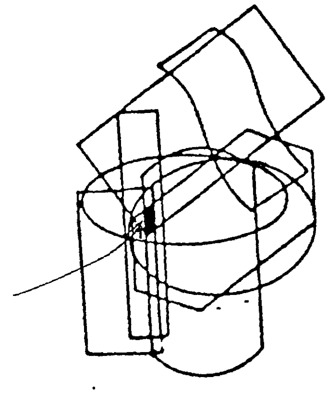
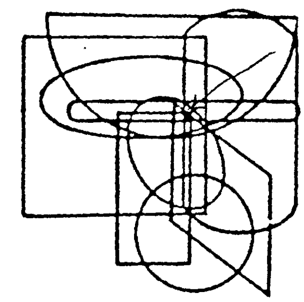
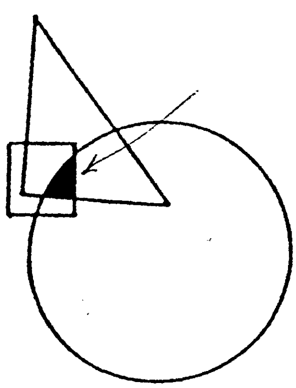
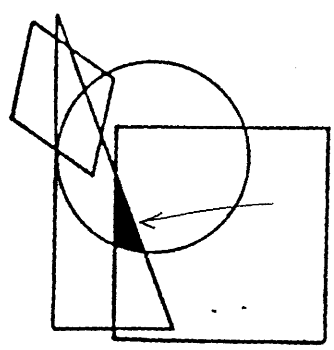
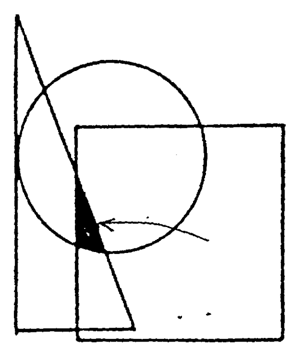
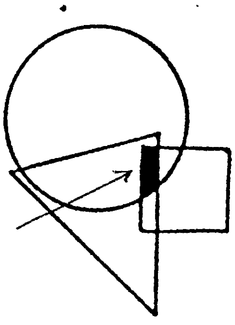
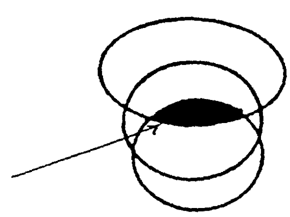








APPENDIX 5

THE MOLE QUESTIONS OF DIFFERENT Z-DEMAND

Question 1

How many moles of hydrogen ions (H^+) are there in 200 mL of 2M sulphuric acid (H_2SO_4)?

Steps involved	Items to be activated at a time
(1) No.of moles of H^+ = $v_{(L)}$ x M x No. of H^+ in formula	a. No. of H^+ in H_2SO_4
	b. 200 ml → 0.2 L
	c. Calculation
	0.2 x 2 x 2 = 0.8 moles

Z = 3

Question 2

What weight of potassium hydroxide is contained in 0.2 L of 4 M potassium hydroxide solution?

(At. masses: K = 39, O = 16, H = 1)

Steps involved	Items to be activated at a time
(1) No. of moles = $v_{(L)} \times M$	a. v $\xrightarrow{in}$ litre b. work out n = 0.2 x 4 = 0.8
(2) G.F.W. of KOH	a. formula of KOH
(3) G.F.W. = 1 mole	
(4) Weight of KOH actually dissolved = n x G.F.W.	

Z = 4

APPENDIX 5 (cont'd)

Question 3

How many grams of magnesium would react exactly with 0.4 L of 1 M sulphuric acid solution?

(At. mass: Mg = 24)

Steps involved		Items to be activated at a time	
(1)	Writing equation	a.	formula of reactants
		b.	kind of reaction
		c.	formula of products
(2)	Find moles ratio		
(3)	No. of moles of acid react = v x M	a.	v $\xrightarrow{\text{in}}$ litre
		b.	work out n = 0.4 x 1 = 0.4
(4)	At. mass of Mg = 1 mole		
(5)	Convert moles of Mg → grams	a.	work out 24 x 0.4 = 9.6 g

Z = 5

Question 4

What is the molarity of lithium hydroxide solution if 2 L of 0.4 M nitric acid will neutralise 0.3 L of it?

Steps involved	Items to be activated at a time
(1) Writing equation	a. formula of reactants
	b. kind of reaction
	c. formula of products
(2) Find moles ratio 1 : 1	
(3) No. of moles of acid react. = 2 x 0.4 = 0.8	
(4) Relate moles of acid into moles of base = 0.8	
(5) Molarity is the number of moles in 1 L.	
(6) Work out the calculation. $M = \frac{n}{v(L)}$	

Z = 6

Question 5

What is the molarity of a hydrochloric acid solution, if 400 mL of 1 M potassium hydroxide solution neutralises 250 mL of it?

Steps involved	Items to be activated at a time
(1) Writing equation	a. formula of reactants b. kind of reaction c. formula of products
(2) Find moles ratio 1 : 1	
(3) No. of moles of base react. = 1 x 0.4 = 0.4	
(4) Relate moles of base into moles of acid = 0.4	
(5) Molarity is the number of moles in 1 L.	
(6) Change 250 mL $\rightarrow$ 0.25 L	
(7) Work out the calculation	

Z = 7

Question 6

How many grams of potassium carbonate should be dissolved in 1 L solution, if 0.2 L of the same potassium carbonate solution exactly neutralised 1 mole hydrochloric acid?

(At. masses: K = 39, C = 12, O = 16)

Steps involved	Items to be activated at a time
(1) Write equation	a. formula of reactants b. kind of reaction c. formula of products
(2) Balance the equation	
(3) Find moles ratio	
(4) Relate moles of acid moles of carbonate	
(5) Work out G.F.W. of K_2CO_3	
(6) G.F.W. = 1 mole	
(7) Weight of K_2CO_3 actually reacting	
(8) Work out the calculation 69 g in 0.2 L ? g in 1 L	

Z = 8

APPENDIX 6

* DERIVATION OF A FORMULA FOR THE MAXIMUM WIDTH OF A CONFIDENCE INTERVAL

The 95% Confidence Interval about the difference between two proportions is approximately

$$(p_1 - p_2) \pm 1.96 \sqrt{p(1 - p)(1/N_1 + 1/N_2)},$$

(where p_1, p_2, are the proportions in the samples of size N_1, N_2),

and $$p = \frac{N_1 p_1 + N_2 p_2}{N_1 + N_2}$$ is the mean proportion.

The width of the Confidence Interval, W, is given by the second term in the above expression;

$$W = 1.96 \sqrt{p(1 - p)(1/N_1 + 1/N_2)}.$$

The Confidence Interval will not capture 0 if

$$|p_1 - p_2| > W.$$

Although W depends on the values of p_1 and p_2, as well as on the sample sizes, it has a maximum value for any fixed N_1 and N_2, that depends only on the sample sizes.

For fixed N_1 and N_2,

$$W = C \sqrt{p(1 - p)} \qquad C = 1.96 \sqrt{1/N_1 + 1/N_2}$$

$$\frac{dW}{dp} = \frac{\frac{1}{2}C(1 - 2p)}{\sqrt{p(1 - p)}}$$

$$= 0 \text{ when } p = \tfrac{1}{2}.$$

When $p = \frac{1}{2}$, W takes on its maximum value,

$$W_{max} = \frac{1.96}{2} \sqrt{1/N_1 + 1/N_2}.$$

Let $x = \frac{N_1}{N_2}$

then $W_{max} = \frac{1.96}{2\sqrt{N_2}} \sqrt{1 + 1/x}.$

In the general case, it is convenient to define a new variable,

$$w = \frac{1.96}{2} \sqrt{1 + 1/x}.$$

Values of w may be recorded (by tabulation or graphically) for

$.01 > x > 1.$

If $|p_1 - p_2| > W_{max}$,

i.e. $> \frac{w}{\sqrt{N_2}}$

then the Confidence Interval about $(p_1 - p_2)$ will not capture 0, whatever the values of p_1 and p_2.

If percentages rather than proportions are used, the required difference is

$$\frac{100w}{\sqrt{N_2}}$$

If you have two samples:

1. Designate the smaller N_1 and the larger N_2

2. Calculate $\frac{N_1}{N_2}$ = value on x axis

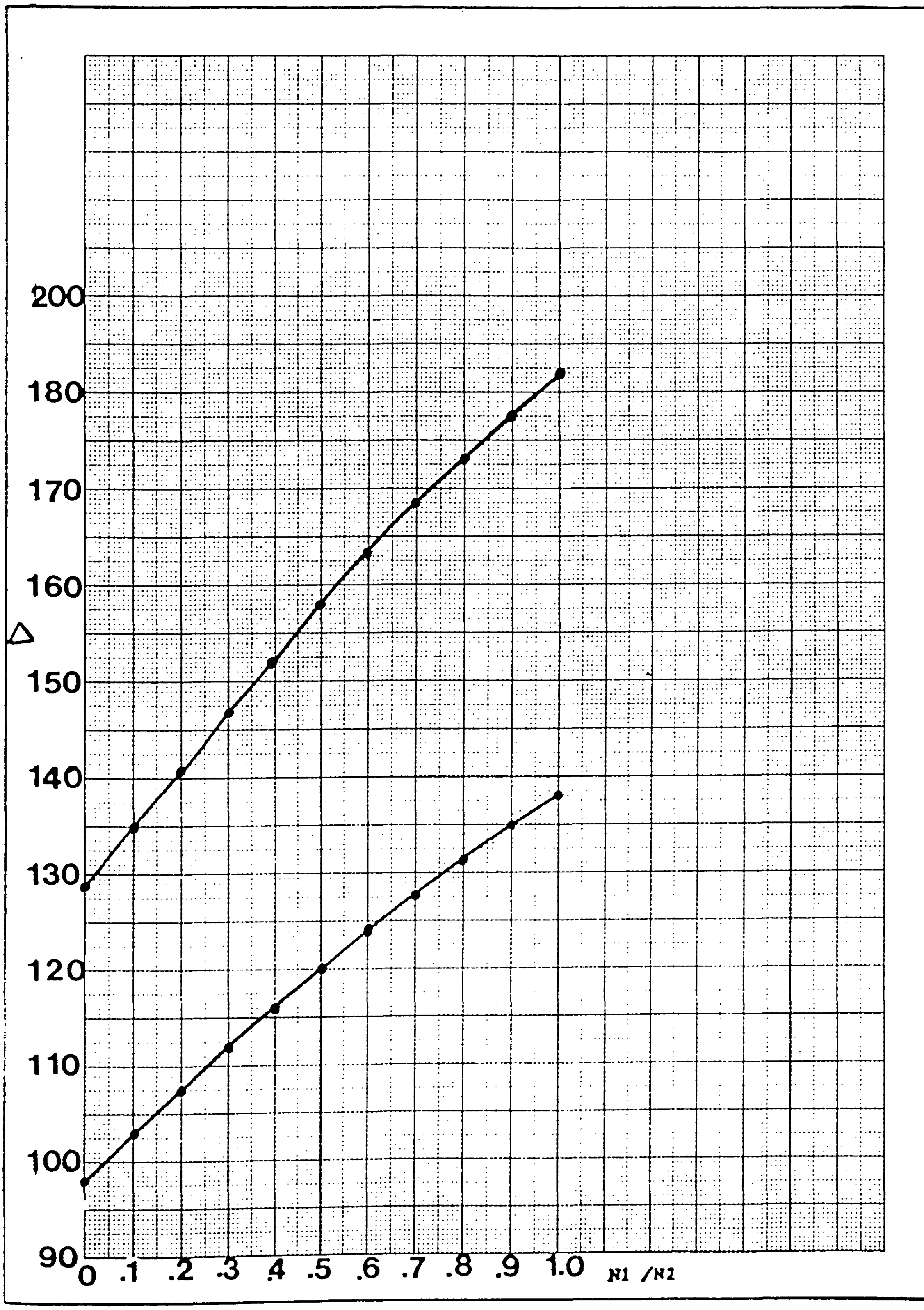
3. From graph read off Δ

4. The $\frac{\Delta}{\sqrt{N_1}}$ gives the difference in % $(P_1 - P_2)$ which must be significant independent of P_1 & P_2.

5. If ratio x $\sim$ .1 or .9 then $0.6 \times \frac{\Delta}{\sqrt{N_2}}$ will still be significant.

6. If ratio x $\sim$ .2 or .8 then $0.8 \times \frac{\Delta}{\sqrt{N_1}}$ will still be significant.

7. If x $\sim$ .3 or .7 then 0.9 x will still be sig.
x $\sim$ .4 or .6 then 0.98 x will still be sig.
x $\sim$ .05 or .95 then 0.43 x will still be sig.



* Extracted from Reference No. (42)

APPENDIX 7

Glasgow University,
Chemistry Department,
Science Education Research.

THE MOLE TEST

(With Grids)

School: ....

Name: ....

Sex: ....

Class: ....

Question	Score
1	
2	
3	
4	
5	
6	
T	

In the following pages are a set of questions. For each question construct your answer from the answer grids. The grids contain more than enough steps for you to answer the question. Pick out the relevant steps, and arrange these in the way you would use them to answer the question.

What you have to do is:-

(1) Read the question carefully.

(2) Think of the way you would go about answering the question.

(3) Look in the boxes on answer grid to select the steps you would take to answer the question.

(4) Write down the numbers sequence you have chosen to answer the question (i.e. in the order you would use them).

(5) Then having done this, work out a numerical answer according to the order of the boxes which you selected.

Note:

The numbers and sequences are important.

It is not necessary to use all of the steps shown in the grid.

Example:

Suppose you were asked to do this calculation:-

* What is the formula mass of sulphuric acid?

Convert moles of reactants moles of products. (1)	Work out the correct formula for the compound. (2)	Write a correct balanced equation (3)
Find the atomic masses for all elements. (4)	Calculate number of moles which actually react. (5)	The molarity is number of moles per litre. (6)
Change unit from mL to litre (7)	Find number of moles in the solution. (8)	Using the atomic masses, calculate the formula mass of the compound. (9)

* The answer:

* from the grid you would need:

Box (2) Work out the correct formula for the compound, then

" (4) Find the atomic masses for all elements, then

" (9) Using the atomic masses, calculate the formula mass of the compound.

So, your order would be:-

2	4	9				

* and, then your numerical answer would be:

Step (2) H_2SO_4

" (4) H = 1, O = 16, S = 32

" (9) (1 x 2) + (1 x 32) + (4 x 16) = 98

Now: Do the following examples in the same way. Remember, it is not necessary to use all of the steps shown in the grids.

How many moles of hydrogen ions (H^+) are there in 200 mL of 2 M sulphuric acid (H_2SO_4)?

find number of (H^+) in the formula. (1)	The G.F.M. of a compound is equal to 1 mole of the compound. (2)	work out number of (OH^-) in the formula. (3)
the molarity is equal to number of moles per litre. (4)	change mL. litre. (5)	write a correct balanced equation. (6)
convert moles of reactant grams of reactant. (7)	relate moles of one reactant moles of another reactant (8)	Number of moles of the ion is equal to M x V x No. of ion in formula. (9)

* The order

* Numerical Answer:

How many grams of magnesium would react exactly with 0.4 L of 1 M sulphuric acid solution?
(At. mass of Mg = 24)

write the formula of reactant(s) (1)	find number of moles of sulphuric acid actually reacting. (2)	relate moles of one reactant moles of another reactant. (3)
write a correct balanced equation. (4)	the molarity is equal to number of moles per litre. (5)	write the formula of product(s). (6)
convert moles of magnesium grams of magnesium. (7)	from balanced equation write down number of moles involved. (8)	find number of (H^+) in the solution. (9)

* The order

* Numerical Answer:

What is the molarity of lithium hydroxide solution if 2 L of 0.4 M nitric acid will neutralise 0.3 L of it?

write the formula of reactant(s). (1)	find volume in litres (2)	find number of moles of nitric acid actually reacting. (3)
write a correct balanced equation. (4)	number of moles is equal to molarity X volume (L) (5)	write the formula of product(s). (6)
relate moles of one reactant into moles of another reactant. (6)	from balanced equation write down number of moles involved. (8)	convert moles of reactant grams of reactant (9)

* The order

* Numerical Answer:

What weight of potassium hydroxide is contained in 0.2 L of 4 M potassium hydroxide solution?

(At. masses: K = 39, O - 16, H = 1)

write the formula of potassium hydroxide. (1)	find number of $(OH)^-$ in the formula. (2)	convert moles of potassium hydroxide grams. (3)
find number of moles in solution. (4)	The molarity is equal to number of moles per litre. (5)	find G.F.M. of potassium hydroxide. (6)
convert grams of potassium hydroxide moles. (7)	Change unit: Litre mL. (8)	find number of (H^+) in the solution. (9)

* The order

* Numerical Answer:

What is the molarity of a hydrochloric acid solution, if 400 mL of 1 M calcium hydroxide solution neutralises 250 mL of it?

write the formula of reactant(s). (1)	find volume in litres. (2)	find number of moles of calcium hydroxide actually reacting. (3)
write a correct balanced equation. (4)	the molarity is the number of moles per litre. (5)	write the formula of product(s). (6)
relate moles of one reactant into moles of another reactant. (7)	from balanced equation, write down number of moles involved. (8)	convert moles of reactant grams of reactant. (9)

* The order

* Numerical Answer:

How many grams of potassium carbonate should be dissolved in 1 L solution, if 0.2 L of the same potassium carbonate solution exactly neutralised 1 mole hydrochloric acid solution?

(At. masses: K = 39, C = 12, O = 16)

write the formula of reactant(s). (1)	find the molarity of potassium carbonate. (2)	find number of moles of potassium carbonate actually reacting. (3)
write a correct balanced equation. (4)	find G.F.M. of potassium carbonate. (5)	write the formula of product(s). (6)
find the weight of potassium carbonate which must be dissolved in 1 L solution. (7)	from balanced equation write down number of moles involved. (8)	convert moles of potassium carbonate actually reacting into grams. (9)

* The order

* Numerical Answer:

APPENDIX 8

Glasgow University,
Chemistry Department,
Science Education Research.

THE MOLE TEST

(With Sub-divided Questions)

School: ....

Name: ....

Sex: ....

Class: ....

Question	Score
1	
2	
3	
4	
5	
6	
Total	

How many moles of hydrogen ions (H^+) are there in 200 mL of 2 M sulphuric acid (H_2SO_4) solution?

What weight of potassium hydroxide is contained in 0.2 L of 4 M potassium hydroxide solution?

(At. masses: K = 39, O = 16, H = 1)

How many grams of magnesium would react exactly with 0.4 L of 1 M sulphuric acid solution?

(At. mass of Mg = 24)

What is the molarity of lithium hydroxide solution if 2L of 0.4 M nitric acid will neutralise 0.3 L of it?

How many moles of hydroxide ions (OH^-) are there in 400 mL of 1 M calcium hydroxide solution?

How many moles of hydrochloric acid solution are required to neutralise 0.4 moles calcium hydroxide solution?

What is the molarity of hydrochloric acid solution if 0.8 moles hydrochloric acid are dissolved in 250 mL solution?

How many moles of potassium carbonate solution are required to neutralise 1 mole hydrochloric acid solution?

What is the molarity of potassium carbonate solution if 0.5 moles of potassium carbonate are dissolved in 0.2 L solution?

What weight of potassium carbonate is contained in 1L of 2.5 M potassium carbonate solution?

(At. masses: K = 39, O = 16, C = 12)

APPENDIX 9

THE FINAL FORM OF THE NEW TEACHING MATERIAL FOR MOLE CALCULATIONS (STOICHIOMETRY AND NEUTRALIZATION CALCULATIONS) FOR O-GRADE STUDENTS

UNIT 1

WHAT IS THE MOLE?

We often use collective words for things rather than an actual number. For example, we talk about:-

- A dozen eggs (12 eggs)
- A score of oranges (20 oranges) and
- A gross of pencils (144 pencils)

In Chemistry, we are dealing with very small particles, and so with very large numbers of them. For example, in a teaspoonful of air, there are more than one hundred million, million, million particles (molecules)! To handle these big numbers we use a collective word, the "Mole" (equal to about 6×10^{23} particles) that is about six hundred thousand million, million, million! To avoid such a big mouthful each time, we call this number a "Mole".

> The mole is seen to be a counting unit as in a dozen, a score and a gross. But it differs from the other units, because the number is very, very large and the particles cannot be handled one by one (very, very small).
>
> Remember: 1 mole = 6×10^{23} particles

HOW DID WE COME UP WITH SUCH AN AWKWARD NUMBER AS 6×10^{23}?

If you go to the bank to pay in some coins, you will find the bankers do not count the coins but weigh them. This is because they know the weight of a single coin. To understand what they do let us suppose someone gives you 140 g of 50p. pieces. How many coins are in the 140 g if you know that one coin weighs 14 g? To count the coins, you would have to divide total weight of coins (140 g) by the weight of single coin (14 g), i.e.

$$\text{Number of Coins} = \frac{140}{14} = 10 \text{ coins.}$$

Now, if you were given 140 grams of ½p. pieces, how many coins would you have this time? (one ½. coin weighs 2 grams).

$$\text{Number of Coins} = \frac{140}{2} = 70 \text{ coins.}$$

* similarly:-

> We can calculate the number of particles in any weight of any element, if we know the weight of one atom of this element.

Examples:-

(1) To calculate how many hydrogen atoms are in 1 gram of hydrogen, you would have to divide 1 gram by the weight of one hydrogen atom. If you know that the weight of a hydrogen atom is 1.67×10^{-24} grams, then:-

Number of hydrogen atoms in 1 gram hydrogen (its Atomic Mass in grams) $= \dfrac{1 \text{ gram}}{1.67 \times 10^{-24} \text{g}} = 6 \times 10^{23}$ atoms

= 1 Mole atoms

(2) Consider another element:-

An atom of sodium weighs 3.8×10^{23}g. How many sodium atoms are in 23 g sodium (its Atomic Mass in grams)? Again, to calculate this, you would have to divide 23 g (total weight) by the weight of one sodium atom:-

$$\text{i.e. Number of sodium atoms in 23 g sodium} = \frac{23\ g}{3.8 \times 20^{-23} g.}$$

$$= 6 \times 10^{23} \text{ atoms}$$

$$= 1 \text{ mole atoms}$$

In General:-

> If we weigh out a number of grams of any element equal to the number of its atomic weight (Mass), we would have a mole of atoms of this element.

Examples:-

Atomic weight of Lithium is	7
Atomic weight of Aluminium is	27
Atomic weight of Calcium is	40

7 grams Lithium

contain 1 mole of Lithium atoms

27 grams Aluminium

contain 1 mole of Aluminium atoms

40 grams of Calcium

contain 1 mole of Calcium atoms

* More than one Element:-

Chemical Compound:-

A chemical compound is a substance which contains more than one element chemically bonded together. The term mole applies not only to elements but also to chemical compounds.

So,

> To weigh one mole of any chemical compound, we would have to calculate the Gram Formula Weight (G.F.W.) of that compound, by adding the atomic weights of all the atoms in the formula expressed in grams.
> i.e. 1 mole of any compound = G.F.W. of that compound.

Example:-

(1) Sodium Chloride:- NaCl

To weigh one mole of NaCl, you would have to calculate G.F.W. of NaCl, i.e.

Na	Cl
At.wt. = 23	At.wt. = 35.5

$$23 + 35.5 = 58.5 \text{ g}$$

Therefore, 1 mole of NaCl weighs 58.5 g.

Therefore, 58.5 g of sodium chloride will contain one mole of sodium ions and one mole of chloride ions. In other words = 58.5 g NaCl contain 2 moles ions (1 mole Na^+ + 1 mole Cl^-).

Now, you might have been asked to calculate how many moles of sodium chloride are in 117 grams sodium chloride.

Simply, you have to divide 117 grams of G.F.W. of sodium chloride, i.e.

$$\text{number of moles} = \frac{117}{58.5} = 2 \text{ moles NaCl.}$$

(2) Aluminium Oxide:- Al_2O_3

Similarly, to weigh one mole of Al_2O_3 you would have to calculate G.F.W. of Al_2O_3.

$$\boxed{Al_2 \mid O_3}$$

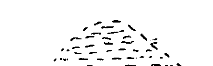
$$2 \times 27 \quad + \quad 3 \times 16 \quad = \quad 102 \text{ g.}$$

Therefore, 1 mole of Al_2O_3 weighs 102 grams.

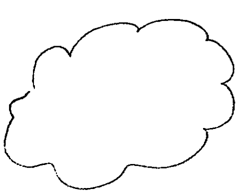
This means that 102 g of Al_2O_3 will contain 2 moles Al^{3+} (Aluminium ion) and 3 moles O^{2-} (oxygen ion).

Summing up so far:

1 Mole Al. — Contains 1 mole Al. atoms or 6×10^{23} Al. atoms and weighs 27 grams (At.wt.)



1 Mole Na_2SO_4 —
contains 2 moles Na^+
contains 1 mole SO_4^{2-}
contains 3 moles ions
weighs 142 grams (G.F.W.)



1 mole Cl_2 —
contains 2 moles Cl atoms
contains 1 mole Cl_2 molecules
weighs 71 grams.

* Molar Mass:-

Molar Mass means: mass per mole. It is another way of saying G.F.W. of a compound and the atomic weight of an element.

(1) At. Mass of Al. = 27

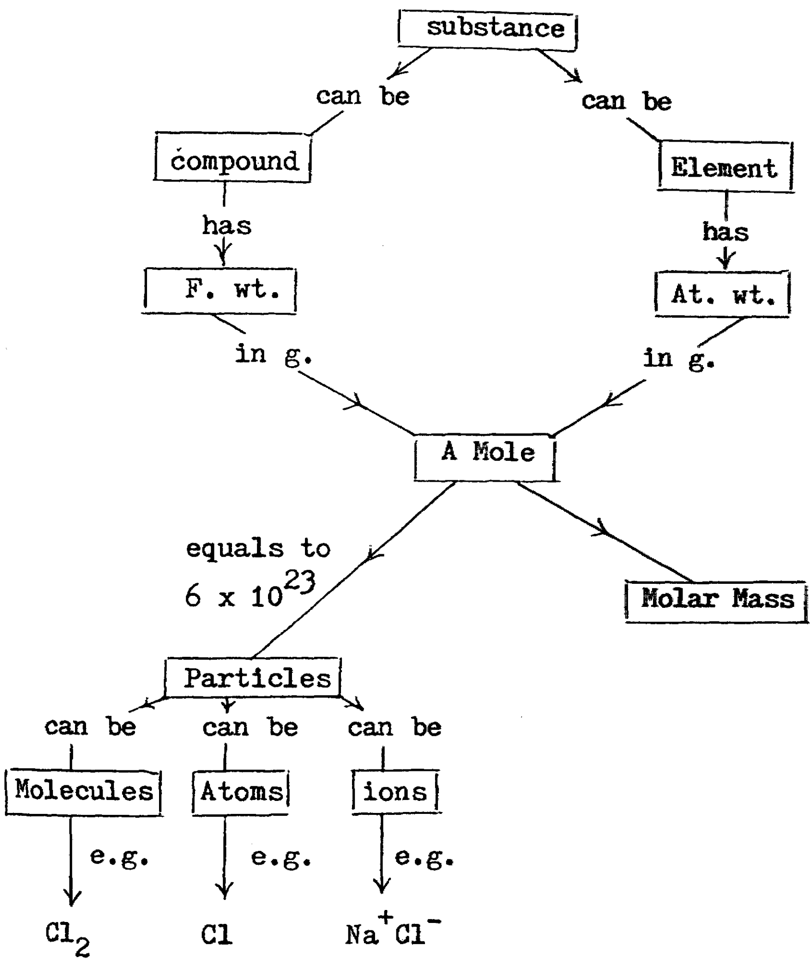
Molar mass of Al. = 27 g/mole.

(2) Formula wt. of Na_2SO_4 = 142

Molar Mass of Na_2SO_4 = 142 g/mole.

* SUMMARY /

* SUMMARY:-



This is a map connecting all the ideas which you have met in this lesson.

UNIT 2

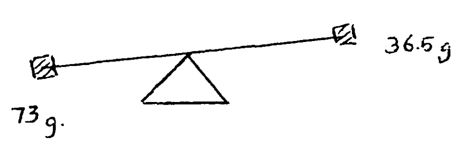
* Chemical Equation and the Mole

You have had some practice in writing chemical equations to summarise a chemical reaction. For example, the equation for the reaction between one mole of hydrogen gas and one mole of chlorine gas to form hydrogen chloride gas is as follows:-

$$H_{2(g)} + Cl_{2(g)} \longrightarrow HCl_{(g)}$$

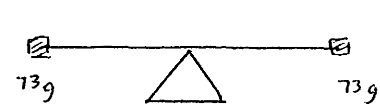
Since material is neither created nor destroyed, the weight of the reactants (H_2 and Cl_2) should equal the weight of the product (HCl). The quantities on the two sides of the above equation are not equal.

$$\underbrace{\underset{(2 \times 1)\ g}{H_2} + \underset{(2 \times 35.5)\ g}{Cl_2}}_{73\ g} \longrightarrow \underbrace{\underset{(1 \times 35.5)\ g}{HCl}}_{36.5\ g}$$



The balanced equation would have to include two moles of hydrogen chloride on the right hand side:-

$$\underbrace{\underset{(2 \times 1)\ g}{H_2} + \underset{(2 \times 35.5)\ g}{Cl_2}}_{73\ g} \longrightarrow \underbrace{\underset{2\ (1 + 35.5)\ g}{2\ HCl}}_{73\ g}$$



A balanced equation: an equation in which the number of the different kinds of atoms in the reactants must be equal to those which appear in the products, and so, the weight of the reactants = the weight of products.

* How can we do a Calculation from an Equation?

(1) Balancing an Equation:

A balanced equation is essential for calculating quantities in a chemical reaction. So, you would have to balance the equation before doing any calculation by the following steps:-

(i) write the word equation,

(ii) write the formulae of reactants,

(iii) write the formulae of products,

(iv) write the symbols equation and balance it.

(2) Getting the Mole Ratios:

Having balanced the equation, the numbers before each formula indicate how many moles of that substance are required to react with a given number of moles of another substance. The next step then is to write these numbers as the mole ratios.

(3) The Calculations:

The third step is to do the calculation required following these steps:-

(i) /

(i) identify the Standard and the Unknown

(ii) plan the calculation sequences, remembering 1 mole = G.F.W.

Examples:-

(Example 1) What mass of magnesium would react completely with 32 g of oxygen?

From (1) Balanced Equation:

(i) the word equation: Magnesium + Oxygen ⟶ Magnesium Oxide

(ii) formula of reactions: Mg , O_2

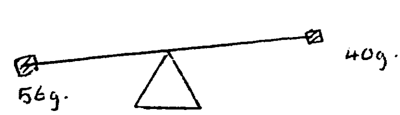
(iii) formula of product: MgO

(iv) the symbols equation: $Mg + O_2 \longrightarrow MgO$

To balance the equation:-

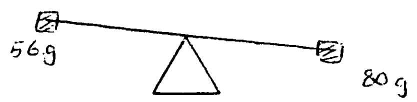
(a)

$$\begin{array}{ccccc} Mg & + & O_2 & & MgO \\ 24\ g & & 2 \times 16g & & (24 + 16)\ g \\ & 56\ g & & & 40\ g \end{array}$$



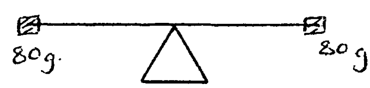
(b) by adding 1 mole of MgO in the right hand side:-

$$\begin{array}{ccccc} Mg & + & O_2 & \longrightarrow & 2\ MgO \\ 24\ g & & 2 \times 16\ g & & 2\ (24 + 16)\ g \\ & 56\ g & & & 80\ g \end{array}$$



(c) another mole of Mg is required in the left hand side:-

2 Mg	+	O_2	$\longrightarrow$	2 MgO
2 x 24 g		2 x 16 g		2 (24 + 16) g
	80 g			80 g



i.e. the balanced equation is:-

$2\ Mg + O_2 \longrightarrow 2\ MgO$

From (2) The Mole ratios:-

2 moles of Mg + 1 mole O_1 $\longrightarrow$ 2 moles of MgO

From (3) The Calculation:-

(i) known is Mass of O_2 = 32: Unknown is: Mass of Mg.

(ii) From (2):-

2 moles Mg react with 1 mole O_2

but 1 mole = 1 G.F.W. or At. wt.

i.e. (2 x 24) g Mg react with 32 g O_2.

(Example 2) How many moles of hydrogen gas are required to react completely with 1 mole nitrogen gas to form ammonia?

From /

From (1) Balanced Equation:-

(i) the word equation: Hydrogen (g)↑ + Nitrogen (g) ↑ ⟶ Ammonia (g) ↑

(ii) formulae of reactants: $H_2 + N_2$

(iii) formula of product: NH_3

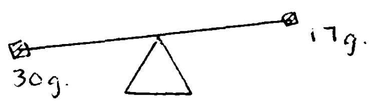
(iv) the symbols equation: $H_2(g)\uparrow + N_2(g)\uparrow \longrightarrow NH_3(g)\uparrow$

To balance the equation:-

(a)

$$H_2 \quad + \quad N_2 \quad \longrightarrow \quad NH_3$$

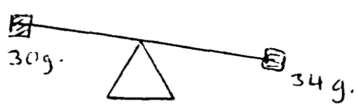
$$\underbrace{(2 \times 1)\ g \quad + \quad (2 \times 14)\ g}_{30\ g} \qquad 14 + \underbrace{(3 \times 1)}_{17\ g}\ g$$



(b) if we add 1 mole NH_3 in the right hand side:-

$$H_2 \quad + \quad N_2 \quad \longrightarrow \quad 2\ NH_3$$

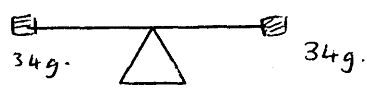
$$\underbrace{(2 \times 1)\ g \qquad (2 \times 14)\ g}_{30\ g} \qquad 2\ \underbrace{(14 + 3)}_{34\ g}\ g$$



Another 2 moles H_2 are required in the left hand side:-

$$3\ H_2 \quad + \quad H_2 \longrightarrow 2\ NH_3$$

$$\underbrace{(6 \times 1)\ g \quad (2 \times 14)\ g}_{34\ g} \qquad 2\underbrace{(14 + 3)}_{34\ g}\ g$$



i.e. the balanced equation is:-

$$3\ H_2 \quad + \quad N_2 \longrightarrow 2\ NH_3$$

From (3) The Calculation:-

(i) known is 1 mole N_2 . Unknown is: Moles of H_2

(ii) from balanced equation:=

3 moles H_2 are required to react with 1 mole N_2.

Now: Try to solve these problems by yourself:-

(1) Calculate the weight of sodium needed to react completely with 106.5 grams of chlorine gas to form sodium chloride solid. (69 g)

(2) What weight of hydrogen gas is produced when 7.8 grams of potassium react completely with water? (0.2 g)

* Summary

* Summary

Three main steps are required to do any calculation from the chemical equations. These steps are:-

(1) Balancing an Equation by:-

(i) writing the word equation,

(ii) writing the formulae of reactants,

(iii) writing the formulae of products,

(iv) writing the symbols equation, and balance this equation.

(2) Getting the Mole Ratios:-

From the balanced equation, the numbers before each formula indicate how many moles of this substance are required to react with another substance.

(3) The Calculation:-

by:- identifying the known and unknown substances and planning the calculation sequences remembering

1 mole = G.F.W. of a compound

or = At. wt. of an element.

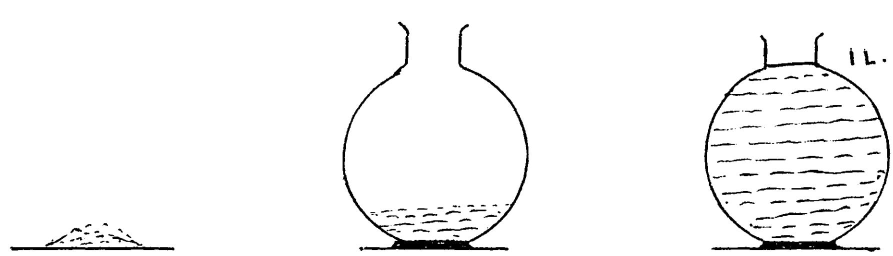
UNIT 3

The Mole in Solution

Suppose you wanted to obtain one hundredth of a mole of sodium chloride NaCl. With a good balance, this could be weighed out accurately, and would weigh 0.585 g.

If, however, we needed a $\frac{1}{1000}$ mole of NaCl, weighing could be more difficult now. How then, can we handle such small quantities accurately? Here is a clever idea:

Suppose we weigh out accurately 58.5 g NaCl, and dissolve it in water, and make it up exactly to 1 litre and mix the solution thoroughly.



58.5 g NaCl — dissolve in some water ⟶ make it up to exactly 1 litre

Each millilitre of this solution will now contain $\frac{1}{1000}$ mole of NaCl. We could do even better if we weigh out $\frac{1}{10}$ mole accurately, dissolve it in some water and make it up to a litre with water; each millilitre will contain $\frac{1}{10000}$ mole or 0.00585 g NaCl.

A /

A drop of this solution has a volume of $\frac{1}{20}$ mL. If each mL contains 0.00585 g NaCl, how much does a drop contain?

Simple:

No. of grams in one drop of the NaCl solution $= 0.00585 \times \frac{1}{20}$

$= 0.000295$ g NaCl

> By using solution we have invented a means of handling very small amounts of material. Since most chemical reactions occur in solution, this is very convenient.

Molar Solution and Molarity

A molar solution is a solution which contains 1 mole of a substance (its G.F.W.) in 1 litre of solution. Such a solution is said to have a Molarity = 1 (written 1M).

For example, a mole of sodium hydroxide (NaOH) weighs 40 g. If you dissolve 40 g sodium hydroxide in some water and make it up exactly to 1 litre, you would get a molar solution. In other words, you would get 1M NaOH solution because there is 40 g. NaOH (i.e. 1 mole) in 1 litre.

Now:- If you have -

1 mole of the substance dissolved in 1 litre of solution	the molarity of this solution = 1
or 2 moles of the substance dissolved in 1 litre of solution	the molarity of this solution = 2
or 8 moles of the substance dissolved in 2 litres of solution	the molarity of this solution = 4

In general:-

	*	the molarity of the solution is the number of moles of didsolved material (solute) per litre of solution
		(per = means divided by)
		$$\text{Molarity} = \frac{\text{No. of moles}}{\text{litre}}$$
or	*	Volume (in litres) x Molarity = number of moles

Examples:-

Example (1) How many moles of potassium hydroxide (KOH) are there in 0.2 L of 2 M potassium hydroxide solution?

n (Number of moles) = Molarity x Volume in Litres
= 2 x 0.2 = 0.4 moles

Example (2) How many moles of sodium chloride (NaCl) are dissolved in 500 mL of 1M NaCl solution?

n (Number of moles) = Molarity x Volume in Litres

$$= 1 \times \frac{500}{1000} = 0.5 \text{ moles}$$

Sometimes you might have been asked to calculate the number of grams of substance dissolved in the solution. What would you have to do in this case is:-

(1) to identify the number of moles dissolved by using the relationship:

$$n = M \times V_{(L)} \longrightarrow \text{(a)}$$

and then:

(2) to identify the number of grams dissolved by using the relationship:

Number of grams = n x G.F.W. (b)

There is another method of substitution from (a) in (b), i.e.

Number of grams = $M \times V_{(L)} \times$ G.F.W.

Example (3) How many grams of sodium sulphate (Na_2SO_4) are there in 0.5 L of 2 M sodium sulphate solution?

(At. masses: Na = 23 S = 32)

First method:

$n = M \times V_{(L)}$

$= 2 \times 0.5 = 1$ mole

G.F.W. of Na_2SO_4 = $(2 \times 23) \times 32 \times (4 \times 16)$

= 142 g.

i.e. number of grams dissolved = n x G.F.W.

= 1 x 142

= 142 g.

Second method:

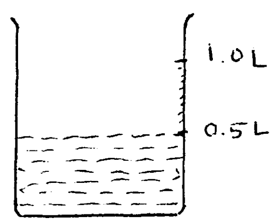
number of grams dissolved = $M \times V_{(L)} \times$ G.F.W.

= 2 x 0.5 x 142

= 142 g.

How to go about counting ions in the Solution

You already have methods for finding the number of moles of materials (or number of grams of it) dissolved in a solution. The question here is about the number of ions in that solution.



Suppose that the above beaker contains 0.5 L hydrochloric acid solution, if you know the molarity of this solution is 4 M, it is possible to find the number of moles of HCl, where:-

$$n = \text{Molarity} \times \text{Volume in Litre}$$
$$= 4 \times 0.5 = 2 \text{ moles HCl}$$

To find the number of moles of (H^+) in this beaker, you would have to know how many (H^+) in the formula of hydrochloric acid (HCl), and then multiply it by the number of moles of HCl.

i.e. Number of (H^+) in the formula HCl = 1

$\therefore$ Number of moles of (H^+) in the solution = 1 x 2
= 2 moles H^+

In general:-

* number of moles of (H^+) in the solution of acid = Molarity x Volume in litres x no. of (H^+) in the formula of the acid.

Similarly:

* number of moles of (OH^-) in the solution of alkali = Molarity x Volume in litres x no. of (OH^-) in the formula of the alkali.

Examples:-

Example (1) How many moles of (H^+) are there in 200 mL 2 M sulphuric acid (H_2SO_4) solution?

- number of H^+ in the acid formula = 2
- number of moles H^+ = M x $V_{(L)}$ x Number of H^+ in the formula.

$$= 2 \times \frac{200}{1000} \times 2 = 0.8 \text{ moles } H^+.$$

Example (2) How many moles of (OH^-) ions are there in 1 litre of 3 M sodium hydroxide solution?

- The formula of sodium hydroxide is NaOH
- number of OH^- in this formula = 1
- number of moles of OH^- = M x $V_{(L)}$ x number of OH^- in the formula

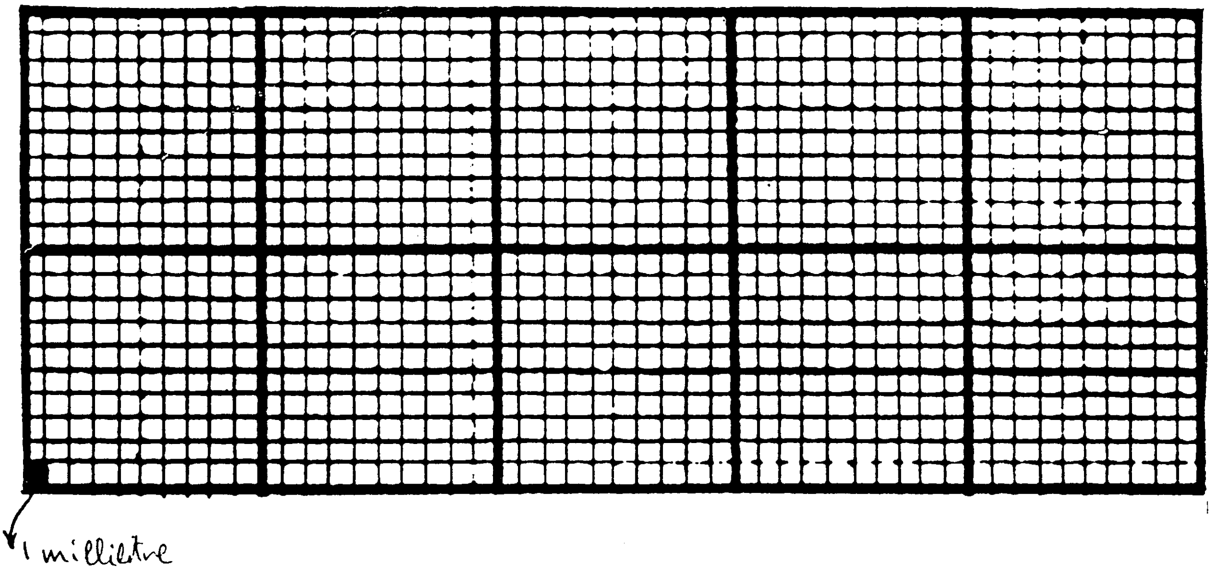
$$= 3 \times 1 \times 1 = 3 \text{ moles } OH^-.$$

The Mole and molarity

You already learned that a mole of any compound is equal to its gram /

gram formula weight (G.F.W.), so, 1 mole sodium hydroxide (NaOH) would weigh 40 g., or 0.001 mole sodium hydroxide (NaOH) would weigh 0.04 g.

Now, look carefully at this diagram:-



Imagine that this diagram represents a beaker in which we have 40 g. of sodium hydroxide (1 mole) in 1 litre of sodium hydroxide solution. The smallest square represents a millilitre. So, each of these squares contain 0.04 g. sodium hydroxide.

If we take all the small squares, i.e. 1000 squares, then we have 1000 millilitre.

1000 mL = 1 litre

1 litre contains 40 g. NaOH (1 mole)

- The molarity of the solution $= \frac{\text{moles}}{\text{Volume}_{(L)}} = \frac{1}{1} = 1$ M

If /

If we take 100 small squares, then we have 100 millilitre.

100 mL = 0.1 Litre

0.1 litre contains 4 g. NaOH (0.1 mole)

- The molarity of this 0.1 L $= \frac{\text{moles}}{\text{Volume}_{(L)}} = \frac{0.1}{0.1} = 1\ M$

If we take one small square we have only one millilitre.

1 mL = 0.001 Litre

This contains 0.04 g. NaOH (0.001 mole)

- The molarity of this 0.001 L $= \frac{\text{moles}}{\text{Volume}_{(L)}} = \frac{0.001}{0.001} = 1\ M$

etc.

Summing up:-

- Every drop of a molar solution : is molar
- Every fraction of a litre of a molar solution, contains the same fraction of a mole of the dissolved substance.

Summary

New words you have met in this lesson:-

1. Molar Solution:-

   is a solution which contains 1 mole of a substance (its G.F.W.) in 1 Litre of solution.

2. Molarity of the Solution:-

   is a number of moles of dissolved material per litre

   i.e. Molarity $= \frac{\text{moles}}{\text{litre}}$

Neutralisation Reactions — Acid-Base Reactions

How can you deal with a titration calculation?

* First: Note these points.

(1) At the end point (Neutralisation
number of moles (H^+) = number of moles (OH^-)

(2) Number of moles H^+ in acid solution = Molarity of acid x Volume of acid in litres x No. of H^+ in acid formula.

(3) Number of moles OH^- in alkaline solution = Molarity of alkali x Volume of alkali in litres x No. of OH^- in alkali formula

(4) Give the symbol X to any unknown quantity.

*Second: What you have to do to find (X) is:-

step (1) To identify the known (the material you know most about) and the unknown (the substance about which you are asked to find something).

step (2) To look at the acid. Ask yourself - how many moles of H^+ does it contain? To answer this you need to know:

- No. of (H^+) in its formula
- its volume in litres
- its molarity, then

Find number of moles H^+ = M x $V_{(L)}$ x number of H^+ in the formula.

step /

step (3) To look at the alkali. Ask yourself - how many moles of OH^- does it contain? You will need to know:

- No. of (OH^-) in its formula
- its volume in litres
- its molarity, then

Find number of moles (OH^-) = $M \times V_{(L)} \times$ No. of (OH^-) in formula.

step (4) At the neutralisation point:

Number of moles (H^+) = Number of moles (OH^-)

$M \times V \times$ No. of H^+ in acid formula = $M \times V_{(L)} \times$ No. of OH^- in alkali formula.

Examples:-

Example (1) What is the molarity of a hydrochloric acid solution if 400 mL of 1 M potassium hydroxide solution neutralized 250 mL of it?

step (1) The known is potassium hydroxide (KOH), because we know its volume and molarity.

The unknown is hydrochloric acid (HCl), because we have to find its molarity.

step (2) The acid:- No. of H^+ in the formula = 1

Volume in litres = $\frac{250}{1000}$ litres

Molarity = X

i.e.

No. of moles H^+ = $X \times \frac{250}{1000} \times 1 = 0.25\ X$

step (3) The alkali:- No. of OH^- in the formula = 1

Volume in litres = $\frac{400}{1000}$

Molarity = 1

i.e.

No. of moles of OH^- = $1 \times \frac{400}{1000} \times 1$

= 0.4 moles OH^-

step (4) At the neutralisation point, = No. of moles of OH^-
No. of moles of H^+

i.e. 0.25 X = 0.4

step (5) X = molarity of acid = $\frac{0.4}{0.25}$ = 1.6M

Example (2) What volume of 2M sodium hydroxide solution is required to neutralize 0.2L of 3M sulphuric acid solution?

step (1) The known is sulphuric acid H_2SO_4 because we know its volume and molarity.

The unknown is sodium hydroxide NaOH, because we have to find its volume.

step (2) The acid:-

No. of H^+ in the formula = 2
Volume in litres = 0.2
Molarity = 3

i.e. No. of moles H^+ = 3 x 0.2 x 2 = 1.2

step (3) The alkali:-

No. of OH^- in the formula = 1
Volume in litres = X
Molarity = 2
i.e. No. of moles OH^- = 2 x X x 1 = 2 X

step (4) At the neutralisation point = No. of moles of OH^-

No. of moles of H^+

i.e.

$$1.2 = 2X$$

step (5) X = volume of NaOH in litres $= \frac{1.2}{2}$

$= 0.6$ L

APPENDIX 10

UNIVERSITY CHEMISTRY QUESTIONS OF DIFFERENT Z-DEMAND

(1st Year of Testing)

QUESTION 1

Consider two half-cells, consisting of nickel metal in contact with a 0.1 M solution of Ni^{2+} and Zinc metal in contact with a 0.1 M solution of Zn^{2+}.

Would a reaction occur if metallic zinc were dipped into a 1.0 M Ni^{2+} solution? Explain your answer.

Answer Scheme

1. State:

   Which reaction is the oxidation and which is the reduction.

2. Write equation:

$$Ni^{2+} + 2e \longrightarrow Ni \qquad (+\ 0.76)$$
$$Zn \longrightarrow Zn^{2+} + 2e \qquad (-\ 0.25)$$
$$Ni^{2+} + Zn \longrightarrow Zn^{2+} + Ni$$

3. Calculate:

$$E^{o} = 0.76 + (-0.25) = +\ 0.51 \text{ volt}$$

4. The reaction occurs because E^{o} drives in direction of the written equation.

(Z = 4)

QUESTION 2

Consider two half-cells, consisting of nickel metal in contact with a 0.1 M solution of Ni^{2+} and zinc metal in contact with a 0.1 M solution of Zn^{2+}.

If the two half-cells were combined to form a cell, determine the e.m.f. of the cell and the polarity of the electrodes.

Answer Scheme

1. State:

   Which reaction is the oxidation reaction and which is the reduction.

2. Write equation:

$$Ni^{2+} + 2e \longrightarrow Ni \qquad \text{Cathode } (+ve)$$

$$Zn \longrightarrow Zn^{2+} + 2e \qquad \text{Anode } (-ve)$$

$$Ni^{2+} + Zn \longrightarrow Ni + Zn^{2+}$$

3. Calculate:

$$E^o = -0.25 - (-0.76) = 0.51 \text{ volt}$$

4. Recall:

   Nernst equation: $E = E^o$ ......etc.

5. Realize that:

$$\left(\frac{0.0592}{2} \log \frac{Zn^{2+}}{Ni^{2+}} = \text{zero}\right)$$

   and hence: $E = E^o = 0.51$ volt

(Z = 5)

QUESTION 3

The density of a gas having the formula XeF_x is $7.80\ g\ L^{-1}$ at 110^oC and 1 atm pressure. Assuming ideal behaviour, calculate its molecular weight and hence its molecular formula.

1. Recall:

$$n = \frac{R\ V}{R\ T}$$

2. Calculate:

$n = 0.03184$ mole
- assume 1L of gas
- change units

3. Realize that:

0.03184 mole occupies 1 litre

4. Use:

$$d = \frac{\text{mass}}{\text{volume}}$$

i.e. $7.8\ gL^{-1}$ means mass per litre of gas

5. Calculate:

0.03184 mole weighs 7.8 g

i.e. a mole weighs 244.97 g

6. Find X:

$$131.3 + X \times 19 = 244.97$$

$$\text{i.e.} \quad X = \frac{244.97 - 131.3}{19} \simeq 6$$

7. Write the formula:

X_eF_6

(Z = 7)

QUESTION 4

Calculate the molar concentrations of N_2H_4, $N_2H_5^+$, and OH^- in a 0.100 M aqueous solution of hydrazine at 25°C. Find also the degree of ionisation of hydrazine and the pH of the solution.

(At 25°C pK_b = 6.02 for hydrazine)

Answer Scheme

1. Write the equation:

$$N_2H_4 + H_2O \rightleftharpoons N_2H_5^+ + OH^-$$

2. Deduce:

$$K_b = \frac{[N_2H_5^+][OH^-]}{(N_2H_4)} = 10^{-6.02} = 9.55 \times 10^{-7}$$

3. Realize that:

$$[N_2H_5^+] = [OH^-]$$

and $(N_2H_4) \simeq 0.100$ M

4. Find:

$$[OH^-] = [N_2H_5^+] = (0.100 \times 9.55 \times 10^{-7})^{\frac{1}{2}}$$
$$= 3.1 \times 10^{-4} M$$

5. Find:

$$[N_2H_4] = 0.1 - 0.00031 = 0.09969 = 0.100 \text{ M}$$

6. Calculate:

$$\alpha = \frac{[OH^-]}{0.100} = 3.1 \times 10^{-3} = 0.31\% \text{ ionised}$$

7. Find: $pOH = -\log[OH] = 3.51$

8. and hence $pH = 14 - pOH = 10.5$

(Z = 8)

QUESTION 5

How many moles of methylamine hydrochloride need be dissolved in one litre of 0.0100 M aqueous methylamine solution in order to obtain a buffer solution of pH 11.0?

What change would you expect in pH when 9 litres of water are added to one litre of the buffer solution? Give reasons to justify your answer.

(At 25°C $K_b = 5.0 \times 10^{-4}$ for methylamine.)

Answer Scheme

1. Write the equation:

$$B + H_2O \rightleftharpoons BH^+ + OH^-$$

2. Deduce:

$$K_b = \frac{[BH^+][OH^-]}{[B]} = 5.0 \times 10^{-4}$$

3. Realize:

$$[B] = [Base] = 0.100\ M$$

4. Find:

$$pH = 11.0$$

i.e. $pOH = 14 - 11 = 3$

5. Deduce:

$$pOH\ , = -\log [OH^-]$$

i.e. $[OH^-] = 1 \times 10^{-3} = 0.001\ M$

6. Find:

$$[BH^+] = \frac{K_b\ [Base]}{[OH^-]}$$

$$= \frac{5.0 \times 10^{-4} \times 0.1}{0.001} = 0.05\ M$$

7. Recognize that:

addition of 0.05 moles salt to 1 litre of base solution gives a buffer of pH 11.0.

8. Recognize that:

pH is controlled by $\frac{[Base]}{[Salt]}$ ratio.

9. Deduce:

dilution does not alter the pH.

(Z = 9)

QUESTIONS OF DIFFERENT Z-DEMAND FOR 2nd YEAR OF TESTING

(GLASGOW UNIVERSITY - 1st YEAR - 1986)

(1) Using the list of bond energies on the cover page, calculate the enthalpy change for the reaction:

$$C_2H_2(g) \ + \ 2H_2(g) \longrightarrow C_2H_6(g)$$

(2) If the enthalpy of formation of ethyne (C_2H_2) is 225 kJ mol^{-1}, calculate the enthalpy of formation of ethane (C_2H_6).

(3) If the enthalpy of formation of ethene (C_2H_4) is 62 kJ mol^{-1}, calculate the bond energy for the C = C bond in ethene.

Answer Scheme

(1) 1. Write the equation:

$$H - C = C - H(g) + 2H\text{-}H(g) \rightarrow H - \begin{array}{c} H \\ | \\ C \\ | \\ H \end{array} - \begin{array}{c} H \\ | \\ C \\ | \\ H \end{array} - H\ (g)$$

2. Bonds broken:

C = C, 2 C - H, 2 H - H

3. Bonds formed:

C - C, 6 C - H

4. $\Delta H^o = \sum$ Bonds broken - $\sum$ Bonds formed

$= -287$ kJ

(Z = 4)

(2) The above steps in addition to:

1. Write the equation:

$2C(s) + H_2(g) \longrightarrow C_2H_2(g) \qquad \Delta H^o = 225$ kJ

2. Add:

$C_2H_2(g) + 2H_2(g) \longrightarrow C_2H_6(g) \qquad \Delta H^o = -287$ kJ

H for the formation of Ethane:

$2C(s) + 3H_2(g) \longrightarrow C_2H_6(g)$ is: -62 kJ

(Z = 6)

(3) The above steps in addition to:

1. Write the equation:

$2C(s) + 2H_2(g) \longrightarrow C_2H_4(g)$; $\Delta H^o = 62$ kJ

2. Add:

$C_2H_6(g) \longrightarrow 2C(s) + 3H_2(g) \qquad \Delta H^o = 62$ kJ

i.e. H for the formation of ethene from ethane:

$C_2H_6 \quad C_2H_4 + H_2$ is 124 kJ

3. Bonds broken : Bonds formed

Bonds broken	Bonds formed
C - C	C = C
2C - H	H - H

4. Calculate bond energy for C = C.

(Z = 10)

(4) A monochloroalkane (A) reacts with hydroxide ion to produce an alcohol (B). The rate of this reaction depends on the concentration of A alone and is independent of the concentration of the hydroxide ion.

Alcohol B, on combustion analysis, gives the following percentage composition figures: Carbon 64.9%, Hydrogen: 13.4%.

Assign structures to A and B, name them systematically and give clear reasons for your assignments.

Answer Scheme

1. B is : $C_4H_{10}O$

   a. C + H = 78.3%

   b. O = 21.7%

   c. C: $\frac{64.9}{12}$ = 5.4

   d. H: $\frac{13.4}{1}$ = 13.4

   e. O: $\frac{21.7}{16}$ = 1.4

   f. C:H:O = 4:10:1

2. Rate independent of $[OH^-]$ $\therefore$ S_N1
   i.e. (A) is tertiary

3. (B) is $CH_3 - \overset{CH_3}{\underset{CH_3}{C}} - OH$

4. Work out the name as 2, hydroxy-2-methyl propane.

5. (A) is $CH_3 - \overset{CH_3}{\underset{CH_3}{C}} - Cl$

6. Work out the name: 2, chloro-2-methyl propane.

(Z = 6)

These questions should be answered by selecting box numbers from the grid on the next page and entering them in your exam book. Deductions will be made for the choice of irrelevant boxes.

Any box may be used several times to answer different questions.

QUESTION NUMBERS

(5) Which box(es) contain the complex trichloro triammine chromium(III) ion in the fac form?

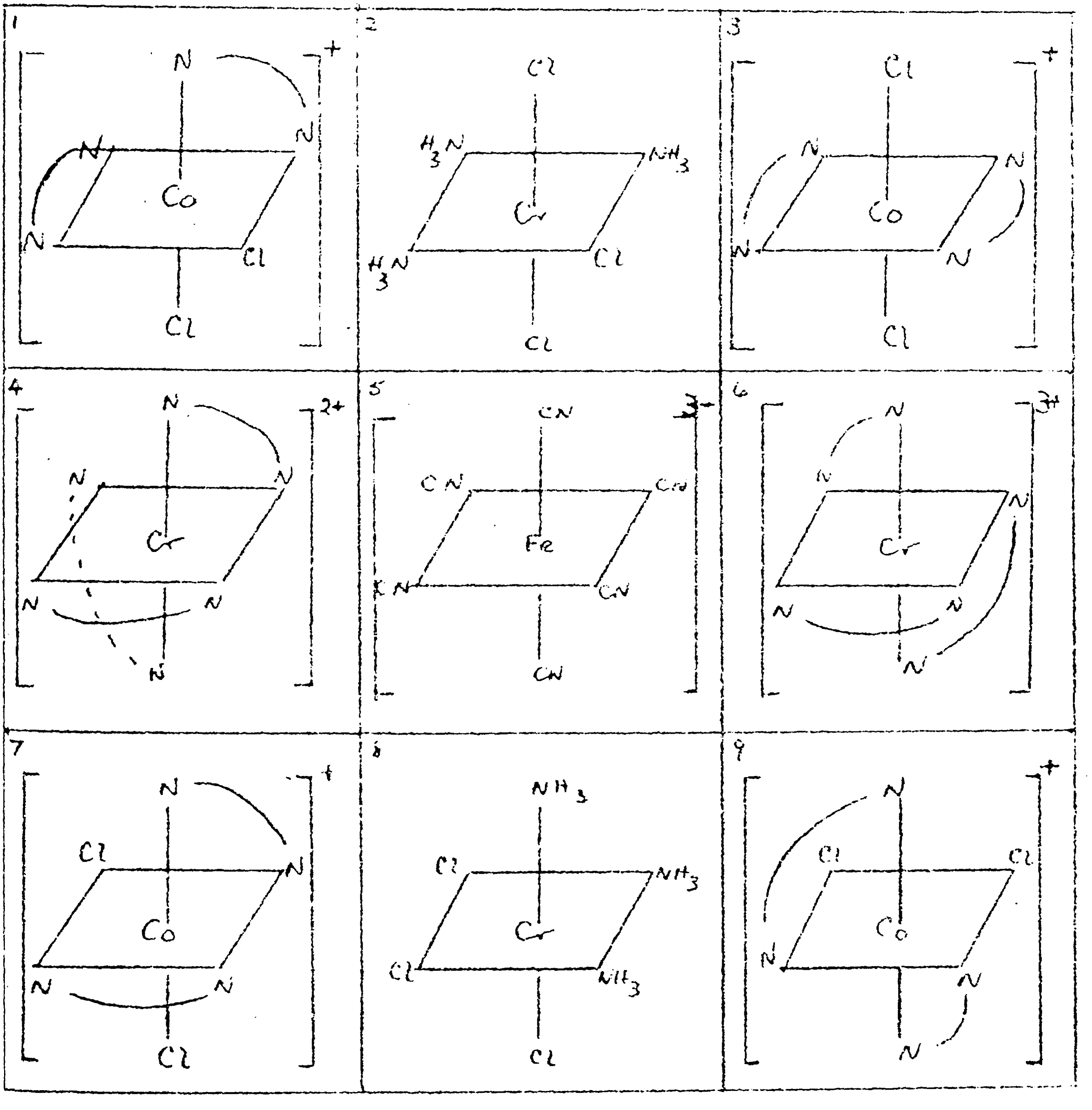
(6) Which box contains the metal ion in the lowest oxidation state of the nine species shown?

(7) Which box(es) contain species which you can be sure will be paramagnetic?

(8) Which two boxes contain a corresponding pair of optical isomers?

(9) Of the chromium (III) species, which box contains the one which is likely to be the most stable relative to the others?

If N⌒N represents 1, 2-diaminoethane, give a written explanation for your choice.



1
N
N
N
N
Co
Cl
Cl
+
2
Cl
H_3N
NH_3
Cr
H_3N
Cl
Cl
3
Cl
N
N
Co
N
N
Cl
+
4
N
N
N
Cr
N
N
N
2+
5
CN
CN
CN
Fe
CN
CN
CN
3-
6
N
N
N
Cr
N
N
N
3+
7
N
Cl
N
Co
N
N
Cl
+
8
NH_3
Cl
NH_3
Cr
Cl
NH_3
Cl
9
N
Cl
Cl
Co
N
N
N
+

Suggested thought steps:

(5) i. Find trichloro
ii. Find triammine
iii. Find Cr^{3+}
iv. Recognize the meaning of "fac" form.

(Z = 4)

(6) i. Oxidation state involves charges on ligands and over-all charge on the ion.
ii. Recognize that = Cl is Cl^-
CN is CN^-
and all other ligands are neutral.
iii. Work out the oxidation state for each metal.

(Z = 3)

(7) i. Recall: Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn.
ii. Recall: the d configuration for each metal.
iii. Find the d electron configuration for each ion.
iv. Recognize the high spin and low spin.
v. Recognize the meaning of paramagnetic.
vi. To be sure means that number of d electrons should be fewer than 6.

(Z = 6)

(8) /

(8) i. Find the boxes which contain the same metal.

ii. Find the boxes which contain the same ligand.

iii. Recognize the meaning of optical isomers.

iv. Problems of mental rotation (possibly maximum demand here)

(Z = 4)

(9) i. Find Cr^{3+} boxes.

ii. Realize that 5 membered ring is most stable.

iii. Realize that Cr^{3+} is a harder acid than Cr^{2+}.

iv. Recognize that $2NH_3$ is more stable than $1NH_3$.

v. Recognize that poly dentate ligands give more stable complex than monodentate.

(Z = 5)

(10) 1.00 g of hydrated calcium chloride ($CaCl_2.6H_2O$) was heated with excess concentrated sulphuric acid and the hydrogen chloride gas produced was collected at 12.5°C in a vessel of volume 485.3 cm^3.

Calculate the pressure the hydrogen chloride would exert if it behaved as an ideal gas.

Answer Scheme

1. $CaCl_2.6H_2O + H_2SO_4 \longrightarrow HCl + CaSO_4 + H_2O$

2. $CaCl_2.6H_2O + H_2SO_4 \longrightarrow 2HCl + CaSO_4 + 6H_2O$

3. 1 mole 2 moles

4. Standard is: $CaCl_2.6H_2O$

   Unknown is: HCl

5. $$1.00\ g \times \frac{1\ \text{moles}\ CaCl_2 6H_2O}{219.1\ g} \times \frac{2\ \text{moles HCl}}{1\ \text{mole}\ CaCl_2.6H_2O}$$

   $= 9.13 \times 10^{-3}$ moles

6. Recall:

   $$P = \frac{nRT}{v}$$

7 Work out:

$$\frac{9.13 \times 10^{-3} \times 0.0821 \times 285.6}{0.4853}\ \text{atm}$$

= result

(Z = 7)

A P P E N D I X 12 (A)

THE FD/FI TEST (HFT)

Name: Sex:

Date of Birth:

School:

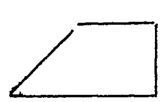
Class:

This is a test of your ability to find a simple shape when it is hidden within a complex pattern.

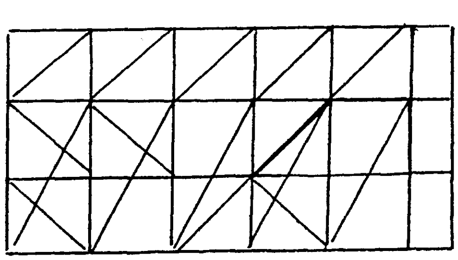
The results will not affect your school work in any way.

Example (1)

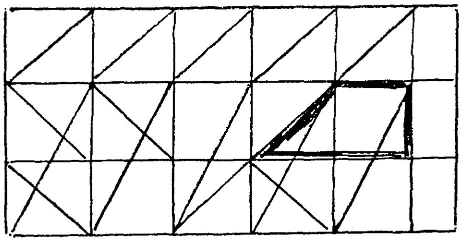
Here is a simple shape which we have labelled (X):

(X) 

This simple shape is hidden within the more complex figure below:

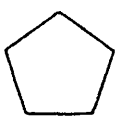


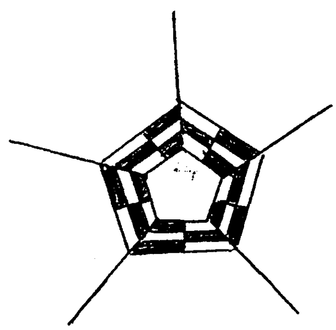
Try to find the simple shape in the complex figure and trace it in pen directly over the lines of the complex figure. It is the same size, in the same proportions, and faces in the same direction within the complex figure as when it appeared alone.
(When you finish, turn the page to check your answer.)

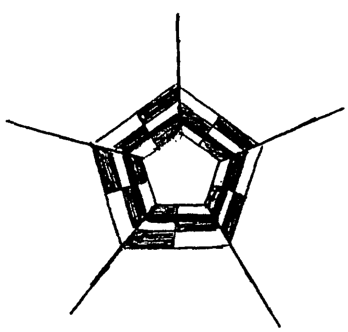


Example (2)

Find and trace the simple shape (Y) in the complex figure beside it.

(Y) 



The answer is : 

In the following pages, problems like the ones above will appear. On each page you will see a complex shape, and beside it will be an indication of the simple shape which is hidden in it. For each problem, try to trace the simple shape in pen over the lines of the complex shape.

Note these points:

(1) Rub out all mistakes.

(2) Do the problems in order. Don't skip a problem unless you are absolutely stuck on it.

(3) Trace only one simple shape in each problem. You may see more than one, but just trace one of them.

(4) The simple shape is always present in the complex figure in the

same size,

same proportions,

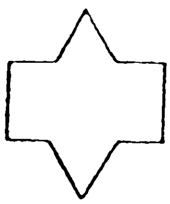
and facing in the same direction;

as it appears alone.

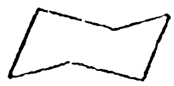
(5) **LOOK BACK AT THE SIMPLE FORMS AS OFTEN AS NECESSARY.**

Now: Attempt each of the items on the following sheets.

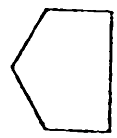
SIMPLE FORMS



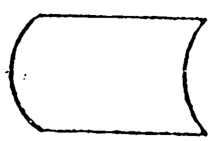
A



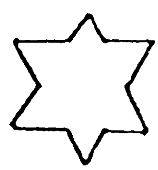
B



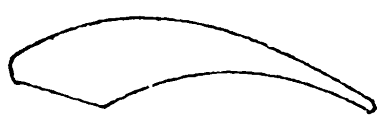
C



D

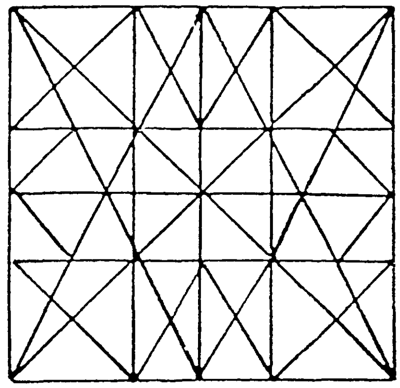


E

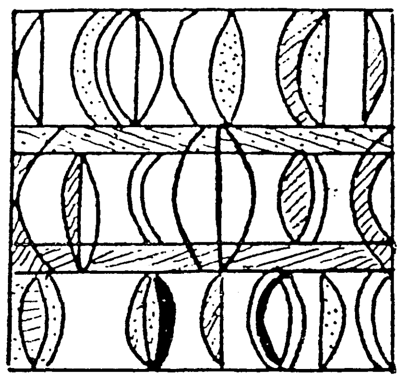


G

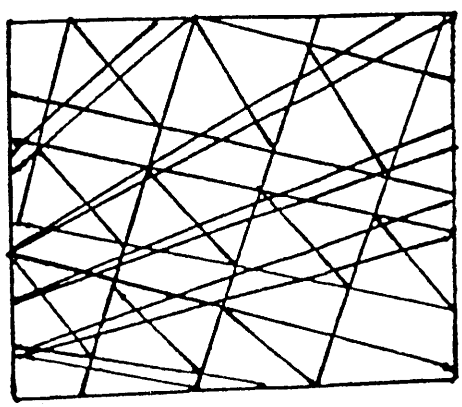
Find Simple Form "C"



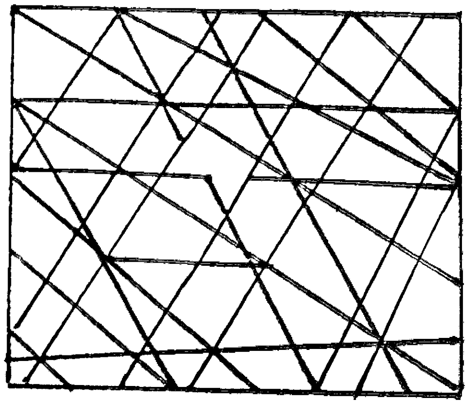
Find Simple Form "D"



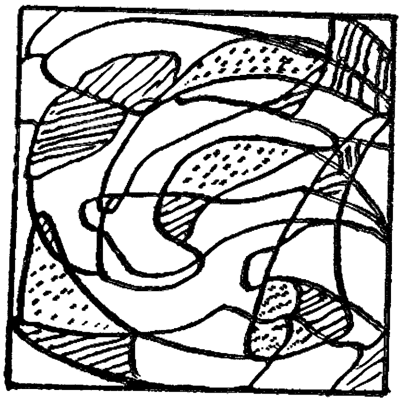
Find Simple Form "B"



Find Simple Form "E"



Find Simple Form "G"



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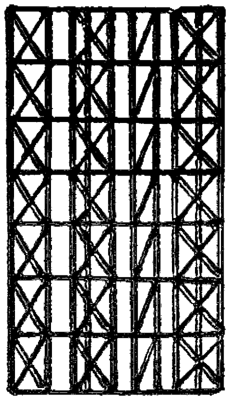

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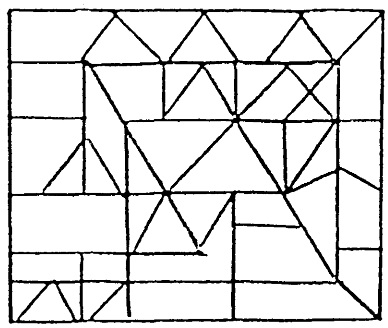

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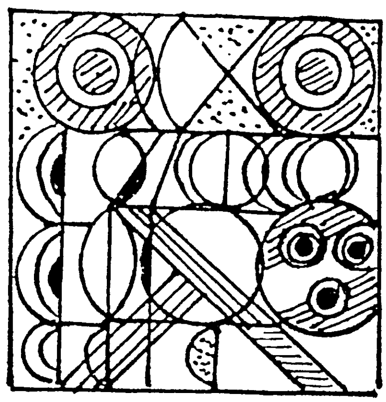

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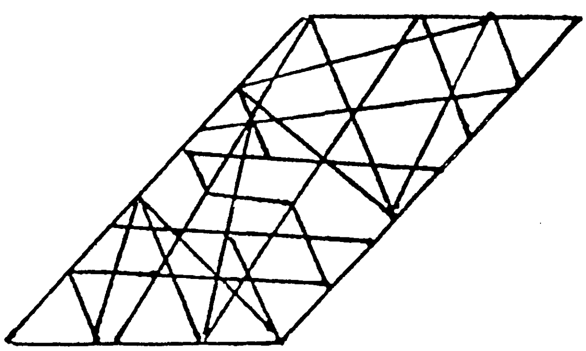

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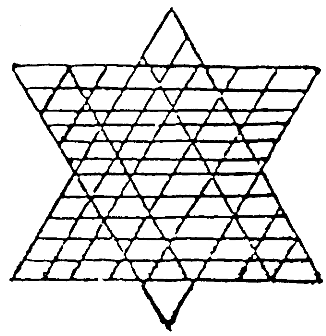

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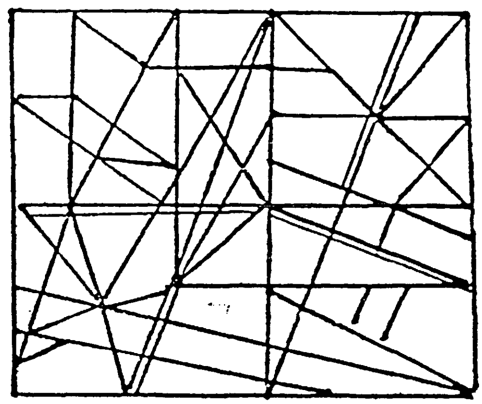

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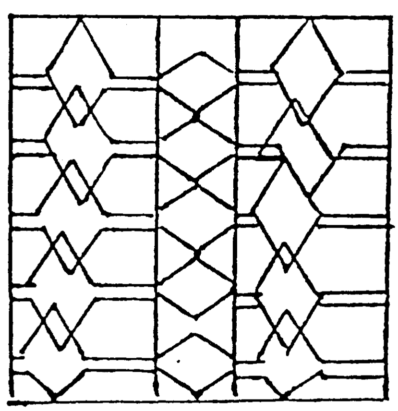

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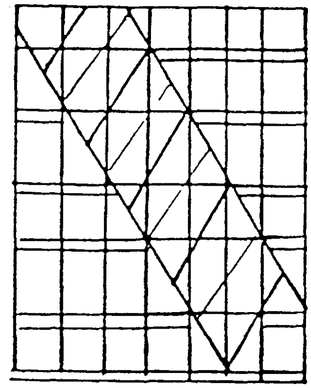

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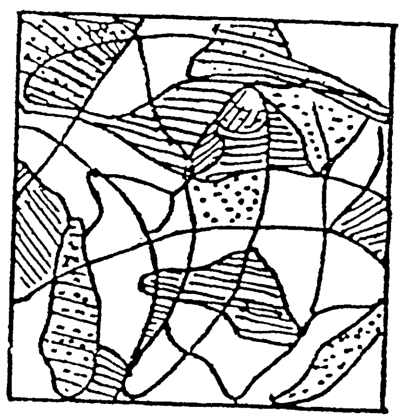

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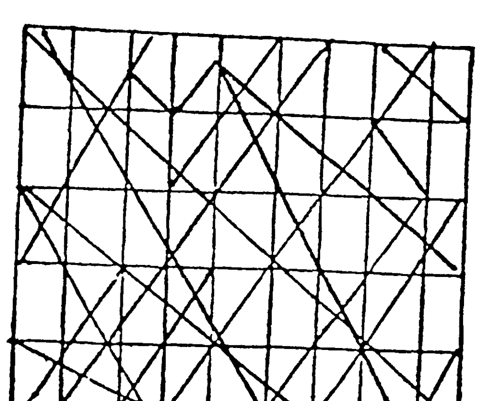

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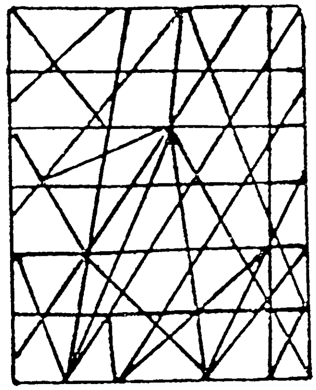

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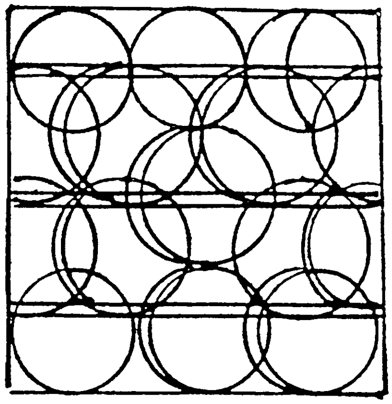

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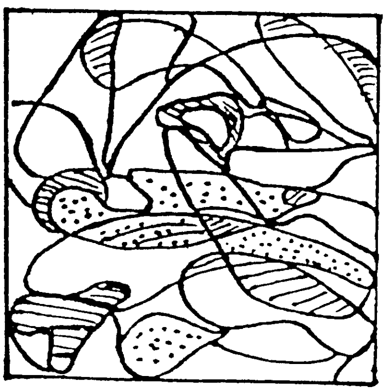

APPENDIX 12(B)

H.F.T. SCORING KEY