A STUDY OF PSYCHOLOGICAL FACTORS AFFECTING STUDENT PERFORMANCE IN BIOLOGY

by

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FADHIL. U. HASSON,

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TO MY PARENTS

AND MY BROTHER HATAF

ALSO MY COUNTRY

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Abstract

This thesis describes a predictive model for Science Education, based upon information processing.

The questions which form the basis of this model deal with relationships between the psychological concepts of working memory and Field Dependence, and students' performance in biology.

The empirical work was done in the Biology Department at Glasgow University in sessions 1986-1987, 1987-1988 and the samples were 272 and 273 undergraduates, respectively.

This study shows how to measure the working memory space of students. It is shown that working memory capacity is directly related to biology performance in conventional exams. The psychological behaviour was measured by standardised tests of working memory capacity, such as Digit Span Backwards, Letter Span Backwards, and Figural Intersection (Pascual-Leone). Field Dependence/Independence was also measured by a test similar to that in Witkin's work.

When comparisons between working memory space (W.M.C.), the degree of Field Dependence/Independence and biology performance were made, it was found that the best biology performance was for students with high working memory space who were also Field Independent.

It was also noticed that low capacity Field Dependent students seemed to do well in fixed response questions.

It is also suggested that the findings in this thesis should affect the way in which biology is presented to students at all levels to avoid working memory overload and to take into account the learning styles of Field Independence/Dependence.

CONTENTS

CHAPTER 1

A LITERATURE SURVEY

During their lifetime, people learn many things. In early childhood, they learn to interact with their environment and with others, to manipulate objects and to respond appropriately to their guardians.

Children learn to speak and to use language, providing an enormously powerful set of skills that will have the most profound effect on all their subsequent learning and this will set them apart from all other animals for the remainder of life.

So human individuals will continue their "Socialization", as well as learning to respond appropriately to symbols which represent the environment in miniaturized fashion. In other words, they have to learn how to deal with the environment and people, not only by direct interaction with objects and people, but by solving problems constructed in the imagination. (1)

As education continues, man learns more and more specialised knowledge and more highly complex skills. (2) However, it is possible to think about learning in all its varieties by focussing on what is learned and how it is learned, rather than upon the conditions which obtain when learning occurs.

It is necessary to distinguish as clearly as possible between the varieties of learned capabilities. These capabilities must be observed as different kinds of human behaviour.

1 - An individual may learn to interact with the environment by using logic symbols. This kind of learned capability is given the name "intellectual skills". (3)

2 - A person may learn to state or retrieve some meaningful information as single entities, or as groups. In this case, an individual must know how to construct at least simple sentences through meaningful learning. In other words, being able to state ideas, rules, and so on, is a learned capability called "verbalisation".

3 - The human has learned skills (cognitive strategies), by which he manages his own learning, remembering, and thinking, which are required to solve any problems.

4 - The person has learned to execute movement in a number of organised motor acts, such as drawing the picture of a cell.

Human beings acquire most of their human qualities through meaningful learning, and the capacity for learning makes possible the remarkable difference in patterns of behaviour of humans, as well as their enormous adaptability to change. Thus "learning is a change in human disposition or capability, which persists over a period of time, and which is not simply ascribable to the process of growth". (4).

1.1 There are four main schools of thought about learning: those of Ausubel, Gagné, Piaget, and the Neo-Piagetian and, of these, the first three have received a great deal of attention in the literature of science education. Each, however, has been criticised in recent literature. The next Chapter will describe a model of memory and information processing, which can be used to guide and inform science education research.

Over the past twelve years, in science education, cognitive science has emerged as a study. "This new view brings together researchers with overlapping interests from the fields of artificial intelligence, psycholinguistics, epistemology, education, and neurophysiology". (5) Even though, the publication of Newell and Simons, "Human problem solving" (6) is often cited as the beginning of the era of cognitive science. Some of the major epistemological issues addressed by cognitive scientists can be found in the writings of Kant, Hume and other seventeenth century philosophers.

By the 1950s and early 1960s, even logical empiricism was being challenged by the writings of philosophers of science, such as Toulmin (7, 8), Hanson (9) and Kuhn (10), whose views on knowledge were more compatible with cognitive psychology. Chomsky's devastating review of Skinner's behaviourist ideas states that "behaviourism was essentially finished as a theory that could adequately explain the more complex aspects of human mental activity". (11)

From that point, psycholinguists began to tackle problems that would help to give focus to research in cognitive science. (12).

There can be no doubt that Ausubel and Piaget, researchers familiar to science education, were also forerunners of cognitive science, sharing a commitment to a cognitive view of human behaviour. Cognitive scientists acknowledge their debt to Piaget even as they challenge his developmental theory, but the similarities between Ausubel's work and that of cognitive scientists have often been overlooked. Anderson (13) and Shallert have recognised similarities. Shallert said, "The similarity between Ausubel's theory of knowledge acquisition and schema theory is obvious", and said, "it is to me a fluke of psychology's history that Ausubel is not more closely associated with current schema theoretic notions". (14) His research has been the centre of controversy, sharply criticised and vehemently defended for years.

Of all the research areas addressed by cognitive scientists, some are more important than others for science education. Problem-solving, cognitive development, and learning are particularly important. In addition, research on general intelligence by Hunt (15) and Sternberg (16), could be of interest to science educators, because of its emphasis on the activities of thinking. Science education in schools today aims to promote the pupils' understanding of basic scientific concepts. Recent studies by Bell and Driver have indicated that "learning science is not a matter of passively absorbing information, but of actively constructing for oneself an understanding of observed events". (17,18) Pupils use their existing ideas, which may or may not be accepted scientific ideas, to interpret or construct a meaning for what they see or hear. This recognises the importance of the learner's "prior knowledge" influencing the understanding of new information. (19)

Cognitive science should be able to help us understand these phenomena.

1.2 A Piagetian View

The work of Piaget is directly concerned with how children learn. It is primarily concerned with describing and explaining in a very systematic way the growth and development of intellectual structure and knowledge. He sees that intellectual and biological activity are both part of the overall process by which an organism adapts to the environment and organises experience. He also thinks that cognitive structures [schema], are continually being modified throughout life. These are controlled by internal changes [maturation and equilibrium], and external changes [social reaction, endowment and experience].

These concepts are used to explain how and why mental development occurs. He also believes the mind has to have structures much in the same way as the body does. (20) Piaget says that knowledge is not transmitted directly, but is constructed. Learning is a process of building up the structure of the human mind little by little. Cognitive acts are seen as "acts of organisation of, and adaptation to the perceived environment". The child develops the ability to solve problems that can be solved through logical operation. (21)

Some researchers like Herron, have used Piaget's theory to describe the generalised logical operation [seriation, correspondence, reversibility, combinational reasoning, proportional reasoning, etc.] that are likely to be available to individuals at various ages, and that are necessary for an individual to make sense out of information that is deliberately "taught" or spontaneously "learned".

Herron also mentioned that, "learning is possible if you base the more complex structure on simple structures, that is, when there is a natural relationship and development of structures and not simply an external reinforcement. (22) But he does not explain how this operation takes place. Other supporters of Piaget, such as Floyd, Case and Lovell, explain thinking, not as representation, but as a descriptive event. Rather, it is an action which at first overtly, and later covertly, transforms one reality state into another, thereby leading to knowledge of the latter stage.

In Piaget's view, to understand state, one must understand the transformation which brought the state about. (23) He does not, however, explain how this comes about.

1.3 Ausubel's View

He has distinguished between reception and discovery learning, on the one hand, and between meaningful and rote learning on the other. So it will be necessary to consider in greater detail, meaningful learning as "a process", and the relationship of the meaningful learning process to the nature of its "product", namely, to the nature of meaning itself.

Once it is clear what he thinks meaning is, and to consider generic meanings or concepts and how they are acquired, then it will also be desirable to consider some of the changes in cognitive development that affect the nature and relative importance of concept formation and concept assimilation at different stages in the life cycle. (24,25)

In reception learning, the principal content of what is to be learned is presented to the learner in more or less its final form. On the other hand, discovery learning means that the principal content of what is to be learned is not given but must be discovered by the learner before he can internalise it. Learning is meaningful if it can be related non-arbitrarily and substantively to the learner's structure of knowledge and that the learner manifests a corresponding set to do so.

Non-arbitrariness implies some plausible or reasonable basis for establishing the relationship between the new material and the relevant ideas in question. Therefore, Ausubel sees "the significance of meaningful learning for acquiring and retaining large bodies of "subject matter". This becomes strikingly evident when we consider that human beings", (26) unlike computers, can incorporate only very limited amounts of discrete verbatim material, and can also retain such material only over very short intervals of time, unless it is greatly overlearned, and frequently reproduced. Hence, the "tremendous efficiency of meaningful learning" as an information-processing and storing mechanism can be largely attributed to the two properties [non-arbitrary (or logically) and substantiveness (non-verbatimness)] that makes learning material potentially meaningful.

Substantiveness implies that a group of symbols could be similarly related to the same relevant ideas without any resulting change in meaning. In other words, "proposition expressed in synonymous language would induce substantially the same meaning". (25,26)

Non-arbitrary incorporation of a learning task into relevant portions of cognitive structure, so that new meanings are acquired, implies that the new meaningful learning material becomes an organic part of an existing, hierarchically organised ideational system. Thus, as a result of this type of anchorage to generic cognitive structure, the newly learned material is no longer dependent for its incorporation and retention on the frail human capacity for assimilating and retaining arbitrary association. "This anchoring process also protects the newly-incorporated information from the interfering effect of previous learning and subsequently encountered similar materials that are so damaging in rote learning".(27,25)

Ausubel sees the rote learning characterisation as not a dichotomy but a continuum, along which reside several degrees of meaningfulness of learning task. The latter property is influenced by the learning set and the relevant cognitive differentiation of the learner. (28) Ausubel also sees that the ability to solve problems calls for such traits as feasibility, resourcefulness, originality, and problem sensitivity, that are not only less generously distributed in the population of learners than is the ability to understand and retain verbally presented ideas, but are also less teachable. (29.30) Therefore "the student's failure to use the particular model to explain some concepts, such as, solids, liquids, and gases, suggests that the idea lacks meaning in the Ausubelian sense and there is no evidence of intellectual development in the Piagetian sense".(22)

So Ausubel's theory is one of learning, while Piaget's theory is one of development.

Briefly, Ausubel's notions help us to understand conditions that affect the acquisition of new information and incorporation of it in our store of previously learned information, so that interrelation among concepts is clear and so that information can be recalled and applied to novel situations. (31)

1.4 A Gagné View

He sees human beings acquiring most of their human qualities through learning. The capacity of learning makes possible the remarkable differences in patterns of behaviour of humans, as well as their enormous adaptability to change. (32) He considers learning as a change in human capacity, which persists over a period of time, and which is not simply ascribable to the processes of growth. So the learner makes sense through stimulation that is constantly being received and organised into various patterns of neural activity, some of which are stored in memory in such a way that they can be recovered. Such memories may then be translated into action that may be observed as the movement of muscles in executing responses of various sorts. This means that learning takes place when the stimulus situation, together with the contents of memory that has already been organised, affect the learner in such a way that performance changes from a time before being in that situation to a time after being in it. (33)

Gagné believes in learning hierarchies in which meaningful learning has cumulative characters in which the acquisition of specific rules establishes the possibility of transfer of learning to a number of more complex, higher-order rules. (34) On the other hand, he sees that meaningful information which is learned occurs in varying degrees of complexity, depending upon its propositional structure. So the main requirement is that the learner be readily able to gain access to the meaningful information he already has.

Hence, some people appear to be better in their performance than others, because the quality of their learning and thinking is better, faster, or more profound. (35) The Gagné learning model has been faulted because of its limited scope. "Behavioural objectives may be suitable for specifying intended learning outcomes in the case of skill learning, but the other types of learning outcomes, such as, propositional and conceptual learning, cannot be specified by "action" verbs." (36) Moreover, Gagné's "bottom-up" view has been labelled "associationist" by Strike and Ponser, who have commented on the difficulty of structuring content using such a model. The limited nature of the content structure presented by Gagné, White and other "bottom-up" researchers, frustrate questions regarding the diversity of purposes for which one might structure content. (37)

Now, how can one organise hierarchically meaningful information and retrieve it when needed? This is not completely answered in Gagné's work.

1.5 A Neo-Piagetian Approach

Pascual-Leone, a one-time student of Piaget, has tried to reconcile a developmental model with the theory of information processing now current in cognitive science. He has attempted to place a quantitative view upon Piaget's observations. This will be discussed in the next Chapter.

CHAPTER 2

INFORMATION PROCESSING MODELS

Because memory plays a key role in most aspects of cognition, the study of memory should provide important insights into cognitive development.

Human cognitive science is the study of the process by which sensory inputs are transformed, reduced, elaborated, stored, and retrieved.

There are many researchers who have worked in this large field, such as Miller, who adapted the paradigm of information processing theory to provide a new approach to the study of speech, judgement and decision. Miller's paper was important for drawing attention to how little the upper limit varies in performance on absolute judgement and memory span tasks and for suggesting recoding the information to form chunks can help one overcome the limited capacity of short term memory. (38)

Simon and Baddeley saw information processing as the predominant approach to the subject of human cognition. Simon and Newell (6) and Baddeley (39,40) developed a highly influential theory of problem-solving based on an anology between human beings and the electronic computer.

Atkinson and Shiff rin developed a theory of human memory based on the notion of information processing analogous with information storage. (41,42)

Gagné and White described a model for memory structures and learning outcomes after hierarchical learning. (35)

Baddeley's view is that the memory is a blanket term that has often been used to describe the activities of acquisition, retaining, and recalling, and at one time was thought to be faculty capable of being exercised, like muscle, in order to improve the quantity of what we learn. (43)

Ausubel's and Cagne's views that we are endowed with capacity for memorisation and, although we can improve on our methods of assimilating information, it is possible that we have limits to our capacities.

2.1 Long Term Memory and Short Term Memory

Memory can be thought of as having a long term memory store and a short term memory or working memory. (44)

The human Long Term Memory (L.T.M.) has vast, unlimited capacity, which is so organised as to permit generally rapid recognition of familiar symbols and retrieval of information associated with recognised symbols. (45)

L.T.M. contains information that is relatively permanent. We can learn new information because L.T.M. is unlimited.

Atkinson and Shiffrin proposed several control processes that could be used in an attempt to learn new information, such as rehearsal, coding, and imaging. (46,41)

In other words, L.T.M. is a faculty that is involved with meaningful information being stored in an organised way and having a search procedure which allows for retrieval of relevant stored information when we need it.

Ausubel hypothesised that retention and forgetting constitute later phases in cognitive function of the same interactional learning process between new learning material and existing relevant ideas in the learner's structure of knowledge. (29,30)

Bruner sees the process of learning as essentially one of transferring information from our environment into our L.T.M. through short term memory/working memory. (47)

In Miller's view, people are limited in the number of items they can keep active in Short Term Memory, and that its limited capacity influences their performance in a variety of tasks. (38)

Miller used the word "chunk" to describe a clustering of pieces of information which are recognised together, and he pointed out that the number of chunks which can be held in S.T.M. is about 7. (48) A "chunk" is what an individual makes it. In some circumstances a chunk may be a single piece of information, such as a letter, a digit, or a symbol. In others, depending upon previous knowledge, a chunk may be a cluster of pieces of information, such as an entire ten digit phone number. He states that the S.T.M. span is a fixed number of chunks, but that the information it contains can be increased by building up larger and larger chunks. (49)

There is increasing evidence that the major determinant of individual differences in memory is how effectively people can group material into familiar chunks. (50) "But S.T.M. should be measured in chunks rather than in individual items". (51)

Johnstone described a chunk as what an observer perceives or recognises as a unit, for instance, a word, a letter or digit, when describing problem-solving ability. "It is associated with a student's ability to organise or "chunk" the information provided in the problem into memorisable patterns". (52)

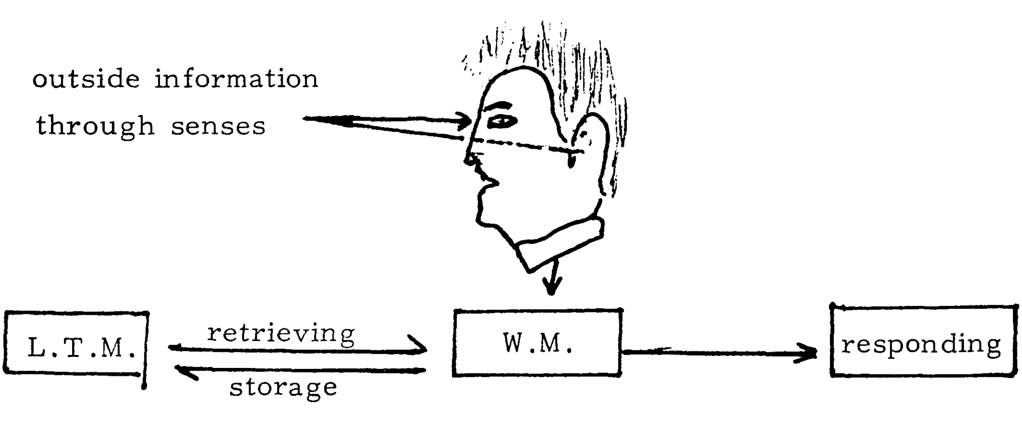
Working Memory (W.M.) is considered to be involved in the work done in transforming, reducing, and elaborating information for the purposes of more economical storage, the combination of information from other sources, and the solving of problems. (53)

Anderson sees W.M., "as a kind of desktop, a work space for holding information needed temporarily for the purposes of some other processing activity and its holding capacity is limited in amount and time." (54)

W.M. can be thought of as a mental space where ideas are held and worked upon.

2.2 Gagné and White offer a model of information processing. In their picture, all information has to be processed through W.M. before storage in L.T.M. When a response is required, information from outside is mixed with information from L.T.M. and processed to make a response. However, this is controlled by the limited size of W.M.

The following figure shows Gagné and White's model: (3,55)



2.3 Pascual-Leone, a former student of Piaget, noted that students seemed to operate at more than one Piagetian level on tasks which seemed to have the same logical structure. Piaget had described this as "horizontal décalage". (56)

Pascual-Leone suggested that "although two tasks had the same logical structure, they would not involve the same amount of information handling". (57) He was able to show this experimentally.

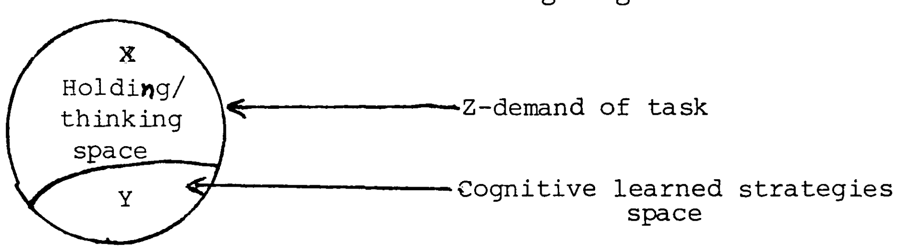
He recognised the importance of the limitations of working memory space, and tried to blend this in with Piagetian work and so he created the Neo-Piagetian movement.

He described the Working Memory as having M-space and related this to the M-demand of a task. In line with his Piagetian training, he tried to relate M-space to age, showing that it increased by roughly one unit for every two years of age and levelled off at about age 16. He recognised that, in practice, different individuals had different measurable M-spaces. The suggestion was that this was made up of two parts, which he called (a) and (k); 'a' was a constant for an individual and 'k' grew with age (a + 1, a + 2, a + 3,....a + k). (57) Other psychological factors were seen to play a part in a student's ability to use his M-space to tackle a problem of a given M-demand. In particular, Field Dependence was seen as a limitation. If a student was Field Dependent, he would not use his M-space to the full extent and so would tend to handle tasks of lower than expected demand. (58)

2.4 Johnstone has developed a model for capacity derived from White and related to Pascual-Leone and Ausubel.

The idea of holding-thinking space emerges as a view of the Working Memory in which we have a shared space for holding information and working on it. If too much has to be held, there is no space left for the operations of chunking, coding, ordering, and sending for storing in the L.T.M. On the other hand, if the working operations are complex, the amount of information which can be handled must be small.

The model is summarised in the following diagram:



So his hypotheses are, that the demand of a task (Z) must not exceed (X) (W.M.S.). If it is to be done $Z \leqslant X$ for success. This is a necessary, but not sufficient condition for success.

If $Z > X$, the task can only be done if cognitive learned strategies (Y) are available for chunking Z to make it less or equal to X. (59)

The nature of the task (Z) will determine how (X) is to be deployed in holding and processing. This will be modified by the action of Y which is made up of strategies recalled from L.T.M. (60)

They may enable the information load of Z to be reduced by chunking and they will also contribute to the coding and shaping activities being brought to bear upon the information. (61)

All of this must operate within the limited confines of the holding-thinking space (X). The efficiency of X in holding and processing must be related to Y. Y links in with Ausubel's idea of meaningful learning in that what we already have as knowledge of facts and some recall as strategies, will in turn operate through Y to make the efficient use of X possible.

The Z-demand of the task may be perceived by the student as high

(i) when irrelevant material is present and interacting with previous experience,

(ii) when some necessary element is absent,

(iii) when the number of chunks still exceeds X-space,

(iv) when there is no strategy of chunking devices,

(v) when unfamiliar vocabulary is used,

(vi) when the whole Gestalt of the Task makes the task look insurmountable,

(vii) when misleading figures (pictures) are present,

(viii) when students have not been trained to formulate and test theories,

(ix) when the content of the question is associated with difficulty in previous experience.

2.5 Testable Hypotheses Arising

All of this theory leads to a number of hypotheses which will be tested experimentally in this piece of research in biological education.

1 - Provided a student has the necessary biological knowledge, he should be able to be successful in tasks which have a demand less than or equal to his W.M. capacity.

2 - When the demand of the tasks exceeds the W.M. capacity, a drop in performance is expected unless the student has some strategy for coping with this.

3 - In a paper with a set of questions of varying demands, the student of lower capacity will have access to less of the paper than the student of higher capacity. This will appear as a lower all-over score for low capacity students when compared to those of higher capacity. In a pass/fail situation, more students of high capacity should pass.

4 - It should be possible to construct exams in which the information demand of all the questions is within the capacity of all students. Any discrimination would then be due to biological factors.

2.6 Other Psychological Factors

Another psychological factor is implicit in the list of factors affecting demand, particularly (i), (v), (vi) and (vii) (page 17). This is the idea of Field Dependence or Independence - the ability to attend to relevant and to ignore irrelevant information. This has been studied by Witkin and several others.

Field Dependent (FD) subjects are assumed to be low capacity processors who assign higher weight to perceptual cues than to cues provided by the task instruction. In situations where these two sets of cues exist, there is a suggestion of conflicting executive schemes. (58)

Field Independent (FI) subjects are assumed to be high X-processors who assign a higher weight to the task instructions than to perceptual cues in such conflicting situations. These will be discussed in more detail in the next Chapter.

We might add to our testable hypotheses that students of high capacity who are Field Independent will tend to give higher performances and that students of low capacity who are Field Dependent/Independent will give the lowest performances. This will be investigated in Chapter 6.

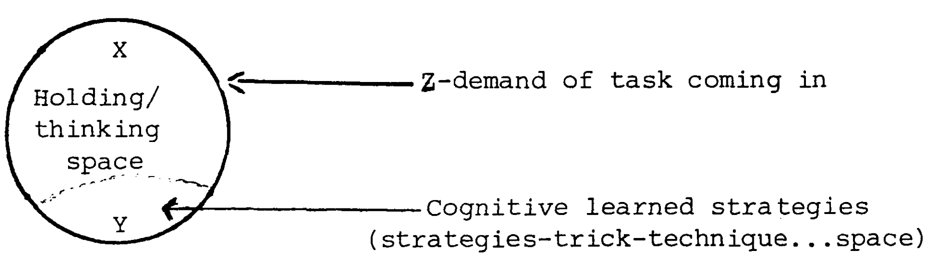
How capacity (X) of working memory, the demand of question (Z) and the degree of Field Dependence are measured will be the subject of later Chapters.

CHAPTER 3

PLANNING THIS STUDY

Johnstone and El-Banna have proposed a model concerning student S.T.M., which has later been modified and elaborated by Johnstone, his students and his colleagues.

The model attempts to explain success and failure in the learning and problem-solving processes in light of the students' limitations associated with their working memory capacities. The simplified model is given below. (59)



The model suggests that, for an individual, the constant X-space is the total holding/thinking space which is capable of holding information and operating it. The Y component represents any functional strategy required to organise information to make it more processable. So it should be noted that, if a student has to hold a great deal of information, including recalled material, there will be little or even no space left for processing.

There are at least three other factors occurring together in an interactive situation; the demand of the problem (task), the student's limited working memory space and any strategy he may use.

This study set out to investigate the model as it applies to Biology undergraduate students.

1 - First of all, this Chapter describes how capacity (X) is measured.

2 - Some hypotheses for testing are set out.

3 - How the estimate of the demand of a task is made.

Measurement of Capacity

There are several standardised psychological tests which claim to do this, such as digits span backwords test (DBT), letter span backwords test (LBT), and the figural intersection test (FIT). These were used in this study to divide the students into three groups, those of high capacity (7,8), those of low capacity (4,5) and those of medium capacity (6).

3.1 The Tests to Measure X-space

I. Digits Span Backwards Test (DBT)

As long ago as 1883 Galton, and in 1885 Ebinghaus proposed that humans had limited working mental space. In 1887 Jacobs furnished an answer to the question of how a large quantity of a given sort of material can be reproduced perfectly after one presentation. (62) This was further elaborated by Miller in 1956, when he pointed out that the number of chunks which can be held in S.T.M. is about 7. (38) The number 7 ± 2 for conscious working memory space occurs over and over again in experimental psychology. What constitutes a chunk in this space is controlled by one's previous knowledge, experience, interest, inclination, and acquired skills. (59)

However, to obtain a value for X we need to control the chunking devices which students may have, and so we give them a task of a kind which they are unlikely to have done before, so that they cannot bring any previous chunking devices into operation. In other words, we are trying to paralyse "Y" so that each digit becomes a unit of information to be processed.

By giving them the task of turning the digits around in their minds, part of the working memory is devoted to holding information and part is given over to operating on the information.

The instructions were standardised on a tape recording, and the rate of delivery of the digits was controlled to one per second. The time given for the response was also controlled to one digit per second.

Before describing the procedures of each test, it is worth mentioning some important points.

In order to qualify as a measure of W.M.S., the measurement must meet the following requirements:

1 - The task must be unfamiliar to the students, to ensure that the individual differences in working memory space (W.M.S.) are not due to strategies or operations used before. If strategies (Y) are unable to operate, the task should measure W.M.S. only.

2 - The task used must require some transformation of the input data to ensure that it truly measures both holding and thinking processes.

3 - In order to reduce measurement errors, it is useful to use more than one task with different stimuli to be sure that whatever the stimuli, the capacity for holding and using these stimuli is substantially the same.

4 - In the letter test, the series of letters should not make "sense".

A - A transcript of the tape is given below

We are trying to improve the quality of our teaching and your learning by trying to understand better how people handle information. We would like you to undergo a simple psychological test to help us in our understanding. In no way will the results of this test be held against you, but we would like to have your name, matriculation number, your sex, and your birthday.

The idea is to give you a set of pairs of tasks to do. Each successive pair will be harder than those before and, eventually, your "brain will hurt".

We would like to know at what level you can operate before it does "hurt".

Try as hard as you can to succeed.

As an easy warm-up, we are going to give you two pairs of preliminary tasks. On the tape recording you will be asked to commit a set of numbers to memory and, when the speaker stops, write down the numbers from left to right in the boxes provided, but in reverse order.

For example, if I say 7, 1, 9, you would write down 9, 1, 7.

Now, no cheating, no writing from right to left. Listen carefully, turn the numbers over in your mind, and write them down from left to right.

Have you got that? let's begin.

(2) 2, 4.

5, 8.

(3) 6, 2, 9.

4, 1, 5.

(4) 3, 2, 6, 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.

B - Determination of the value of W.M.S.

The working memory span is taken to be the level achieved before a student made mistakes in "both" series of the same complexity.

For example, if the student made mistakes in "both" six digit sequences, he was deemed to have a maximum span of "5 pieces" of information.

The result

By this method, the students were divided into (5) groups of capacities (4, 5, 6, 7, 8) (see appendix 1).

II. Letter Span Backwards Test (LBT)

This test was similar to the DBT, except that letters were used instead of digits, and they were given visually instead of by ear (see appendix 2). However, each item of information which is coming through, either an audio or a visual path, will represent one chunk.

III. Figural Intersection Test (FIT) (Pascual-Leone)

This is best described by looking at the instructions at the beginning of the test.

A - Description and demonstration

This is testing your ability to find the overlap of numbers of simple shapes. There are two sets of simple geometric shapes, one on the right and the other on the left of the page. 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.

Notes:

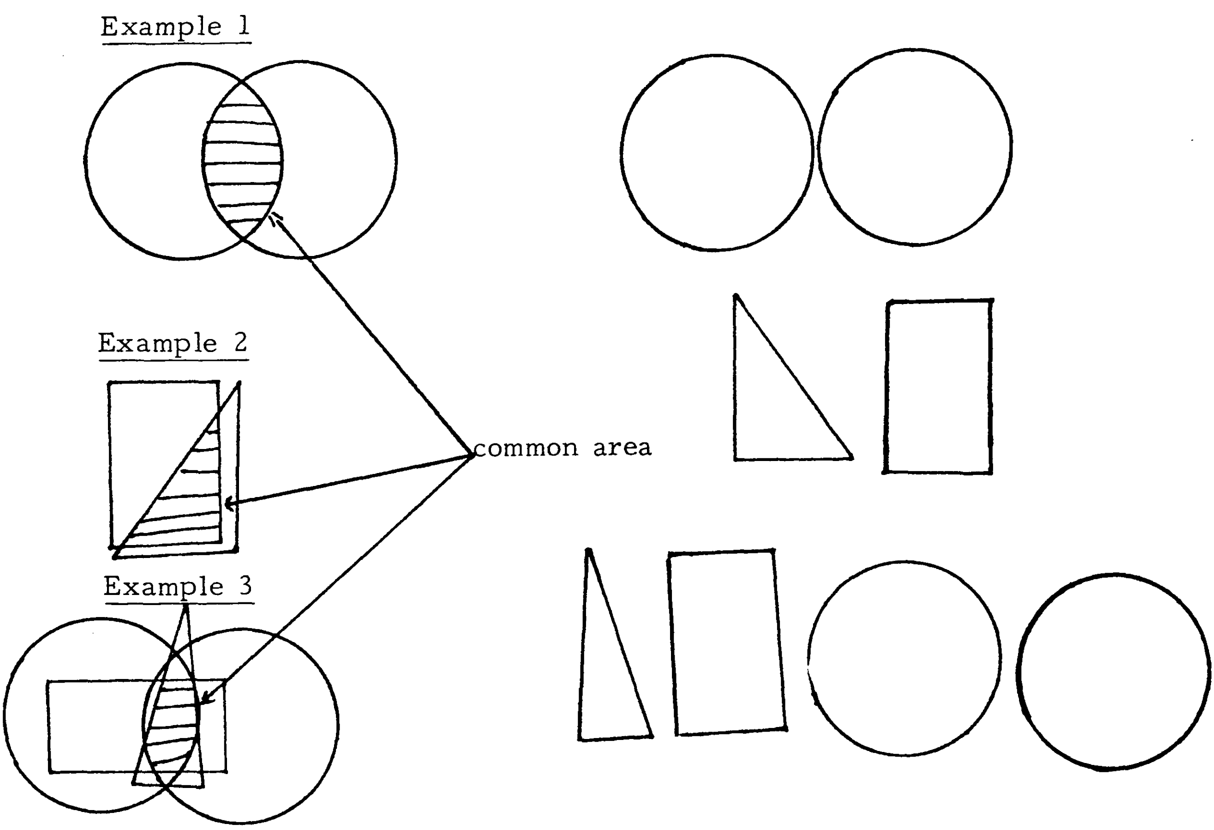
1 - The shapes on the left may differ in size or position from those on the right, but not in shape or proportion.

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 to mislead you, but try to ignore them.

3 - The overlap should be shaded clearly by using a pen.

4 - Please write down your name, your sex, and your birthday.

An important point: your results will not affect your university work in any way. Here are some examples to get you started.



For more detail, see appendix 3.

As the number of shapes increased, the task became more complex.

B - Now how to estimate the value of X-space by this method (scoring system)

The scoring of the Figural Intersection Test (FIT) can be done in a number of ways. The simplest suggested by Pascual-Leone, is to use the conversion table shown below.

This is a simple table for converting the total number of items correct into a capacity, as given below. (63)

Table 3.1 shows the total of correct shades which is converted into a capacity value for each individual.

Number of items correct	Capacity score
5 → 9	2
10 → 15	3
16 → 20	4
21 → 25	5
26 → 30	7
⩾ 30	

Notice. Pascual-Leone suggests several scoring methods for his test, but the simplest to operate is this one. In this, the total number of correct shadings for any individual is found and then converted into a capacity value as shown in Table 1. (See appendix 4)

The score for an individual student was taken to be the lower of the two values obtained for any pair of tests he attempted.

3.2 Comparison of Scores on the Three Tests

All (272) students in the sample took the DBT and took also either the LBT or the FIT. The totals do not match exactly, due to absences occurring between the test sessions, as shown in the table below.

Table 3.2 shows the number in each group of First Year Biology students involved in session 1986-87

Groups	DBT	LBT	FIT
1 - The number of students involved	272	115	146
2 - The number of students who misunderstood instruction	7	5	4
3 - The number of the students not completing test	9	3	2

Table 3.3 shows the comparison of the students' score in each pair of tests in First Year Biology students in session 1986-1987

Groups	Performance in DBT	Performance in FIT	Performance in DBT	Performance in LBT
Identical score	63	63	30	30
	45% (of 146)		29% (of 115)	
Differences ± 1	46	46	48	48
	33% (of 146)		47% (of 115)	
Total	109	109	78	78
	77.8% (of 146)		76.5% (of 115)	

If agreement is taken to be the same score or the same score ± 1, then the degree of agreement between DBT and FIT is 77.8%.

W.M. capacity for individual students was taken to be the lower of the two values obtained, if they were not identical.

The DBT was checked on a subset of (50) students a year later, and the agreement is shown below.

Table 3.4 shows the performance of students of the same group used previously, but now in Second Year Biology - session 1987-88.

Groups	The performance of the same students in DBT in 1986-87 and in 1987-88	
The total number	50	
Identical score	20	40%
Difference ± 1	21	42%
Total	41	82%

This indicates that the measurement of W.M. capacity was fairly reliable.

3.3 Estimating the Demand of Tasks (Z)

The problem's Z-demand is defined as the maximum number of thought steps which would be employed by the weakest successful student. (64)

Students solving the problem using fewer steps would give evidence of some chunking or organisational strategies, while students attempting to use more steps would be unsuccessful.

The estimate of Z was obtained by examining the exam scripts of successful students and looking for the maximum number of steps used.

There are three sources of information for determing the values of Z, as follows: 1) by taking about 60-70 of the sample from successful students who got full scores; 2) by examining the marking scheme; 3) by discussion with staff examiners.

Generally the value obtained from 1) was higher than that from 2) and 3). However, for multiple choice questions, (3) was our only source of information.

One example of the analysis is shown below.

The question which was put was: The table shows the sources from which the kangaroo, rat and man gain water and how they lose it.

Gains water by	Kangaroo rat	Man
Drinking	0%	40%
Free water in food	10%	40%
Metabolic water in food	90%	12%
Loses water by		
Urine	25%	80%
Evaporation (lungs and skin)	70%	34%
Faeces	5%	6%

Given:

a. Metabolic water means water released in the oxidation of food $CO_2 + H_2O$.

b. 1 ml of water weighs 1 gram.

Q.1 a. Where do you think kangaroo rat lives?

Give a reason for your answer.

Q.2 a. From the data, what do you think constitutes a large part of the kangaroo rat's diet?

b. Why do you think this?

Q.3 a. If the rat produces 1.24 ml of urine/day and eats 10g of food/day, what is the average water content of the food?

b. Show calculation (use the other side of this page).

Q.4 Suggest two reasons why a kangaroo rat should lose 70% of water by evaporation and man only 34%.

The analysis is:

Q.1 i. In deserts...(recall-recognition)
ii. It drinks no free water (recall)
} 2 thought steps

Q.2 i. Dried seeds...(recall)
ii. There is very little moisture in its food (reason)
} 2 thought steps

Q.3 Rat produces 1.24 ml of urine/day → eats 10g food/day...(recall)

production	percentage
2.5	100
1.24	x

$$x = \frac{1.24 \times 100}{25} = 4.96 \text{ ml}$$ (calculation)

but in 10g, how much?

production	percentage
4.96	100
x	10

$$x = \frac{10 \times 4.96}{100} = 0.496 \text{g/day}$$

∴ 4.96% (calculation)

∴ 5 thought steps

Q.4 The air it breathes is very dry $\therefore$ water will evaporate. It loses 70% through evaporation, mainly due to the fact that it loses so little in any other way

$\therefore$ 4 thought steps

In general, each section of the question is independent and not inter-related, but the maximum demand is taken to be the section in which the demand was highest. So we will use the maximum number of thought steps required for that one of them. Therefore 5 thought steps are required. (For more details, see appendix 5).

3.4 Now, after having measured the working memory space (X) for our sample, and the demand (Z) of the questions that the students had to attempt in their biology exams, it was now possible to raise and test several hypotheses from the Johnstone and El-Banna model.

These hypotheses are :

1 - There is a negative relationship between performance in biology and the amount of information to be processed.

2 - The amount of information to be processed (Z-demand of task) will be related to success through the working memory space (X) available. (Belong to hypothesis No. 1 on page 18).

3 - In an examination with questions of various Z-demands, the total score on the paper will be related positively to (X). (belonging to hypothesis No. 3 on page 18).

4 - In a paper where there are no questions of high demand, there will be little or no discrimination between the different capacity groups. (Belonging to hypothesis No. 4 on page 18).

5 - If students are not using chunking strategies, they will not succeed in tasks where $Z > X$. (Belonging to hypothesis No. 4 on page 18). When $Z \leqslant X$, we have a necessary, but not sufficient condition for success, because other factors will enter into the results.

Testing the Hypotheses

The writer examined how well biology students handled multi-choice items that were supplied by the Department of Biology.

A choice of (32) items was made so that about equal numbers of items were in the Bloom categories (65) of knowledge, comprehension, and application (Table 3.5).

Before going into detail and plotting a graph of Facility value (FV) (proportion of class getting it right) against question complexity, I would summarise the data in Table 3.5 below.

Summarising Table 3.5 (Facility value versus item complexity)

No.	Z-demand	Number of questions given Z	Mean Score	Maximum Score	Minimum Score
1	2	12	80.9	92.0	70.7
2	3	5	64.5	77.8	63.6
3	4	7	62.9	76.2	39.9
4	5	4	49.5	56.0	46.4
5	6	1	45.0	-	-
6	7	1	41.3	-	-
7	8	1	40.3	-	-
8	9	1	19.3	-	-

Table 3.5 shows a facility value versus item complexity. It also shows the facility values and Z-demands of the question (First Year Biology students)

No.	Real number of the question	Facility value (F.V.)	Z-demand question complexity	Level of Bloom categories
1	1	70.7	2	k
2	4	47.1	5	app
3	5	45	6	co
4	6	76.4	2	k
5	7	76.2	4	k
6	9	63.4	4	co
7	10	69.8	4	k
8	12	48.5	5	app
9	14	76.2	2	k
10	15	85.4	2	k
11	18	64.3	3	co
12	21	38.9	4	app
13	22	80.2	2	k
14	24	73	2	k
15	25	53.6	3	k
16	27	77.6	2	k
17	28	91.97	2	k
18	5	41.4	7	co
19	3	40.3	8	app
20	39	90.4	2	k
21	4	19.3	9	co
22	31	46.4	5	app
23	32	75.1	2	k
24	34	61.4	3	k
25	35	56	5	app
26	36	87.8	2	k
27	37	77.8	3	k
28	38	68.3	4	co
29	40	72.9	4	co
30	41	49.6	4	co
31	42	86.4	2	k
32	45	65.1	3	k

The level of Bloom categories:

k = knowledge

co = comprehension

app = application

Now: a graph of F.V. against Z-demand, as shown below

Figure 3.1

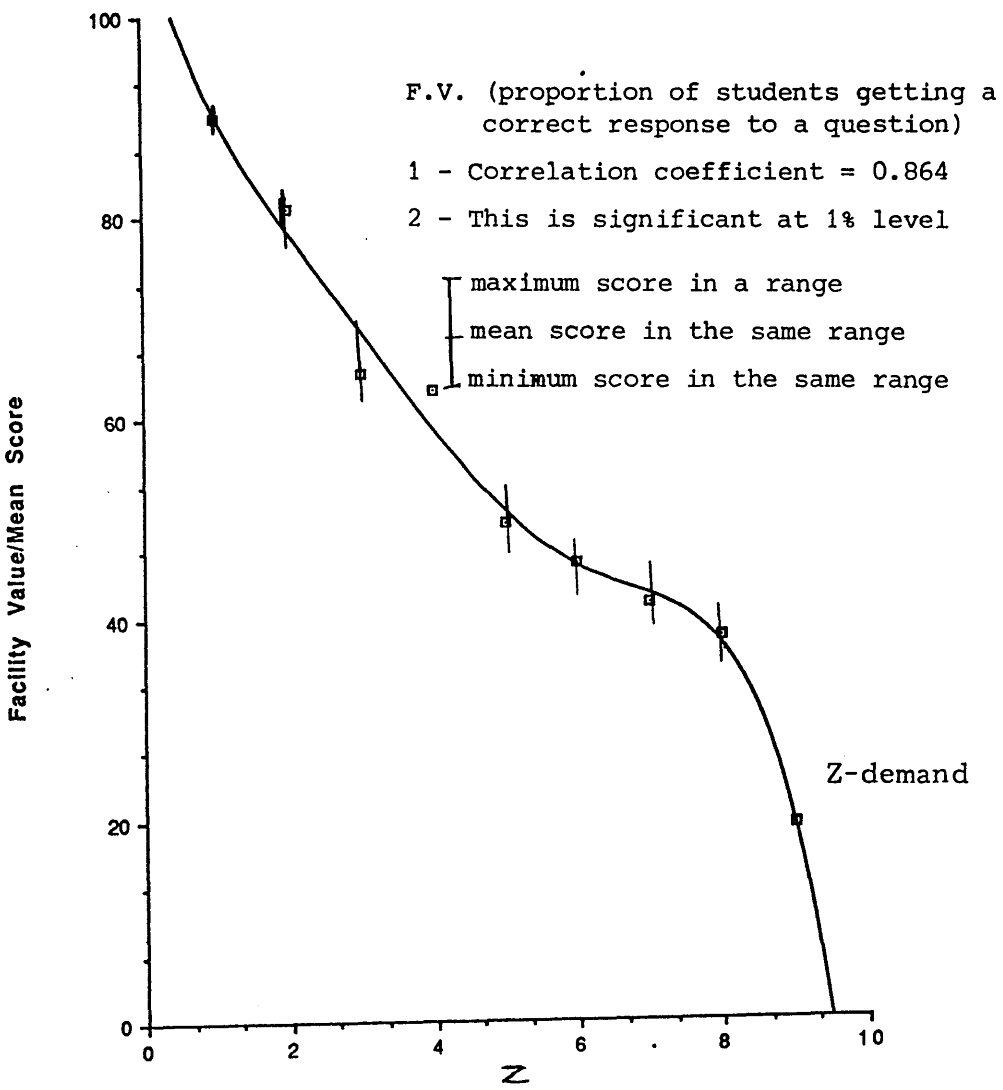


Figure 3.1 above, which shows a plot of F.V. in objective biology versus the number of thought steps required to solve the question. This issue was confirmed by Johnstone with students' performance in chemistry. (59) This does not fit a good straight line. However, as expected, we obtained a strong negative correlation (r = -0.864) from the graph, as shown in Figure 3.1. (This supports the hypothesis number one on page 18).

On further inspection, it was seen that the points fitted on an S-shaped curve, rather than a straight line. Then the curve did not fit the hypothetical one (Figure 3.2); it neither reached as good as 100%, nor dropped to zero, as one might expect in a catastrophic phenomenon, that is, holding up to a certain level followed by sudden drop to a lower level.

From this general finding, several extensions can grow.

Is it possible to obtain a series of these S-shaped curves for sub-groups of students, in biology, with different values of W.M.S. for different question complexity?

Hypotheses

1 - Students should be capable of scoring well on tasks in which $Z < X$. (hypothesis 2 on page 18).

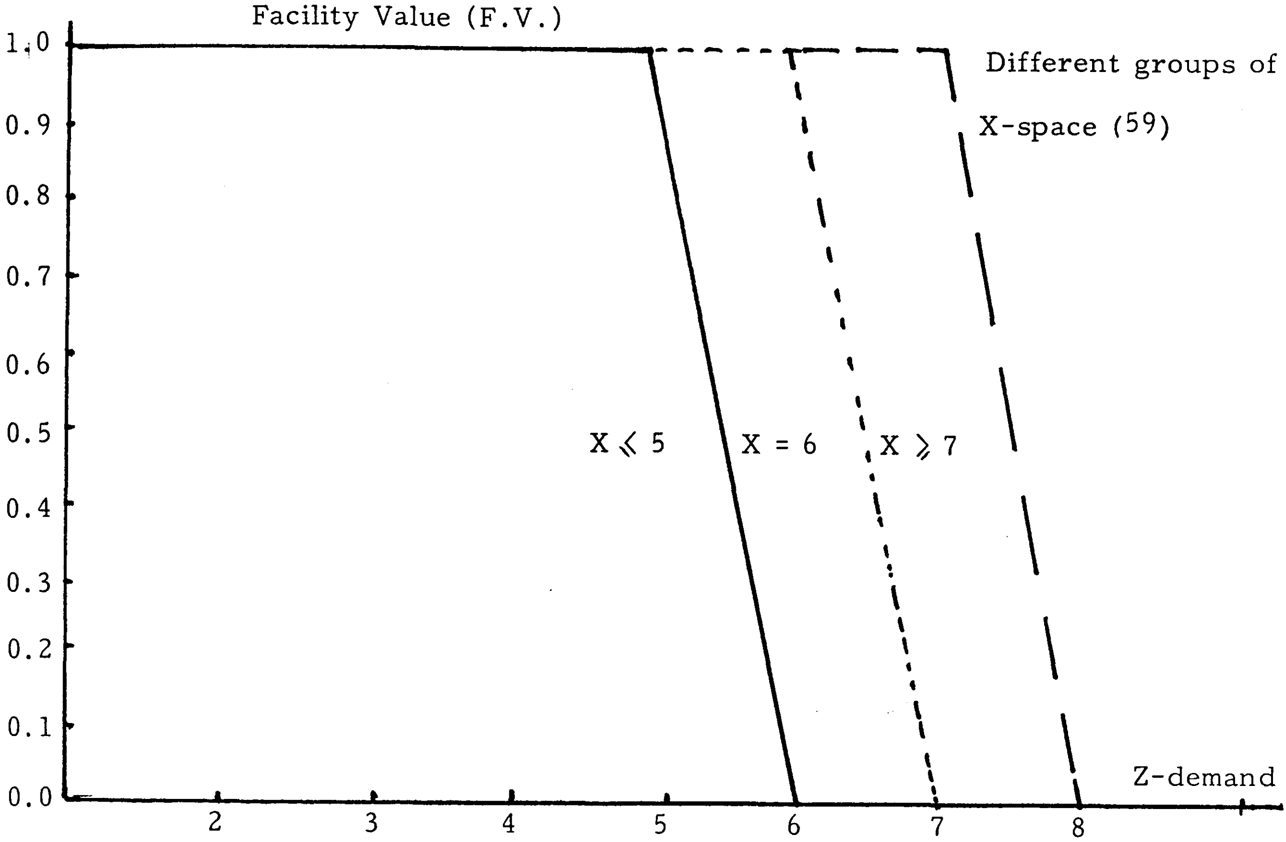
2 - When $Z > X$, a fall in peformance is expected. (hypothesis on page 18).

3 - A consequence of these hypotheses would be that the total score on a conventional test in biology, in which questions of varying Z-values were present, should be related to (X) capacity of the students. (hypothesis No. 3 on page 18).

The idealised situation would be as shown in Figure 3.2.

So if we return to the discussion of the S-shaped curve, we noted that the curve was probably a composite of a set of S-shaped curves, generated by students with a variety of capacities (X). On the basis of the working model we might predict performance, as in Figure 3.2.

Figure 3.2 - The idealised situation



Performance in biology of students of differing X-space capacity in questions of different Z-demand.

Students with capacity X = 5 should do well with problems of Z = 5 or less, but would do badly in problems where Z ⩾ 6.

Similarly, X = 6 students could do well with Z ⩽ 7, and so on.

All of this would assume that (Y), their strategies, were not operating well. This is investigated in the next Chapter.

CHAPTER 4

EXPERIMENTAL RESULTS - SESSION 1986-1987

We now attempt to investigate our hypotheses mentioned at the end of the previous Chapter.

We are going to examine two class (term) examinations for biology students who enrolled in 1986-1987 at Glasgow University.

To address the question at the end of the last Chapter, we have the following information:

(i) The working Memory Capacity (X) for each individual student.

(ii) The demand (Z) for each question.

(iii) The Facility Value for each question for each group of students of varying X-value.

Each question's score might be related directly to its Z-value.

We can now test the hypothesis that there is a relationship between the X-value of a group of students and the point at which performance diminishes with increasing question complexity (Z).

4.1 December 1986 - Class Examination

1.A Hypotheses

When there is no questions with demand greater than 4, there is no discrimination between sub-groups of different capacity.

The December Class Exam consisted of two papers:

(a) Multiple-choice question paper in which no question exceeds Z = 4.

(b) Second paper containing questions of varying demand.

The following table shows the facility value against different questions for different sub-groups in the December class examination. (Multiple-choice - paper one only)

Table 4.1

Groups	Mean Score (F.V.)	S.D.
X $\leqslant$ 5	28.9	6.8
X = 6	28.7	7.2
X $\geqslant$ 7	29.9	7.6
Maximum possible marks is 45		

As expected in this paper with no question with value of Z > 5, there was no discrimination between X = 5, 6, 7 because the higher capacity students had no questions of high Z-demand to show their superiority. This is supported by the hypothesis No. 4 on page 32).

However, the score on the exam gave a normal distribution, as in Figure 4.1.

Therefore, the exam has discriminated on the basis of biology subject matter only, and not on capacity.

It is therefore possible to set an exam of low Z questions and still get satisfactory discriminating results.

In the second paper, the table 4.2 shows the F.V. against different Z demand in different sub-groups (X = 5, 6, 7) of students.

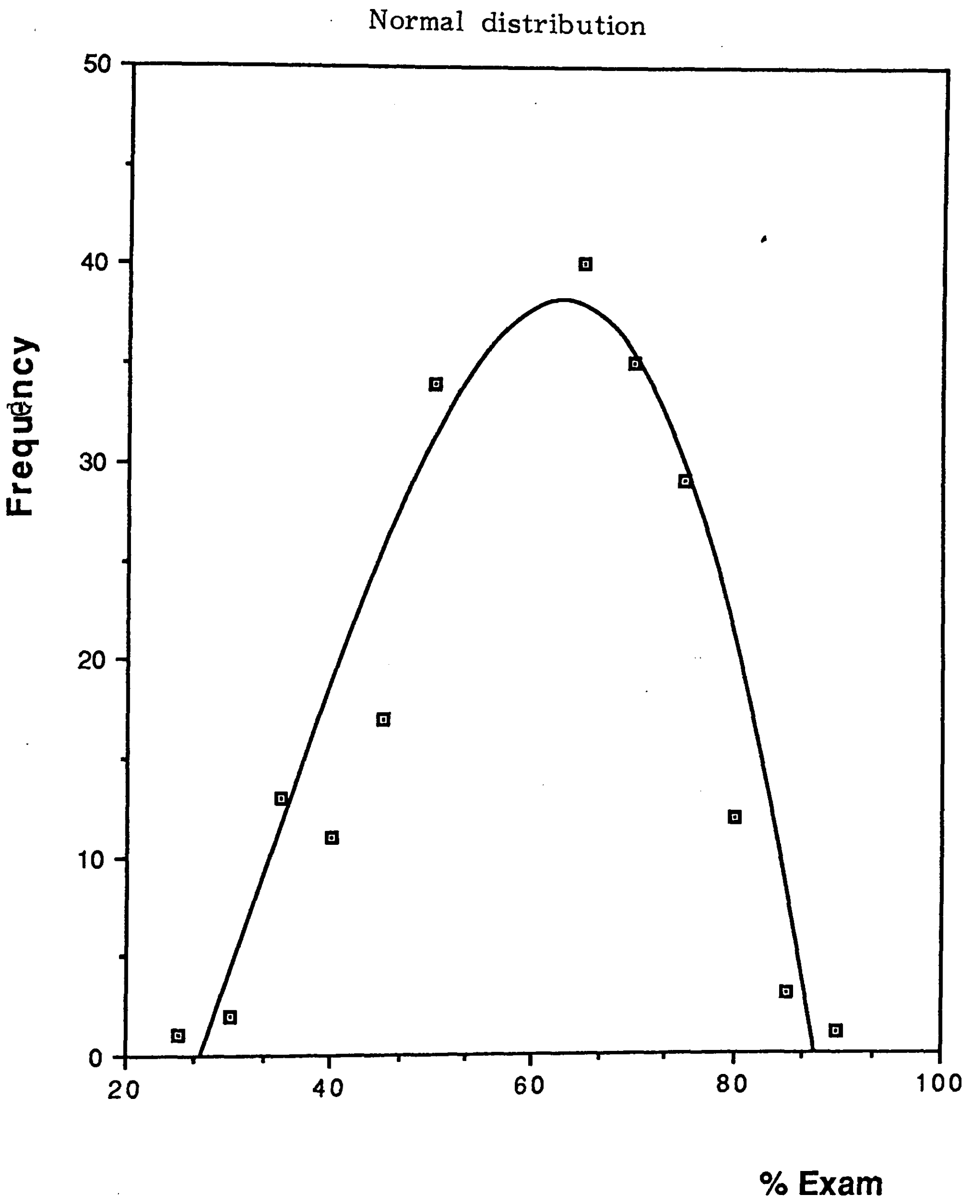


Figure 4.1. Shows normal distribution of exam score for student test when there is no question with Z-demand greater than 4.

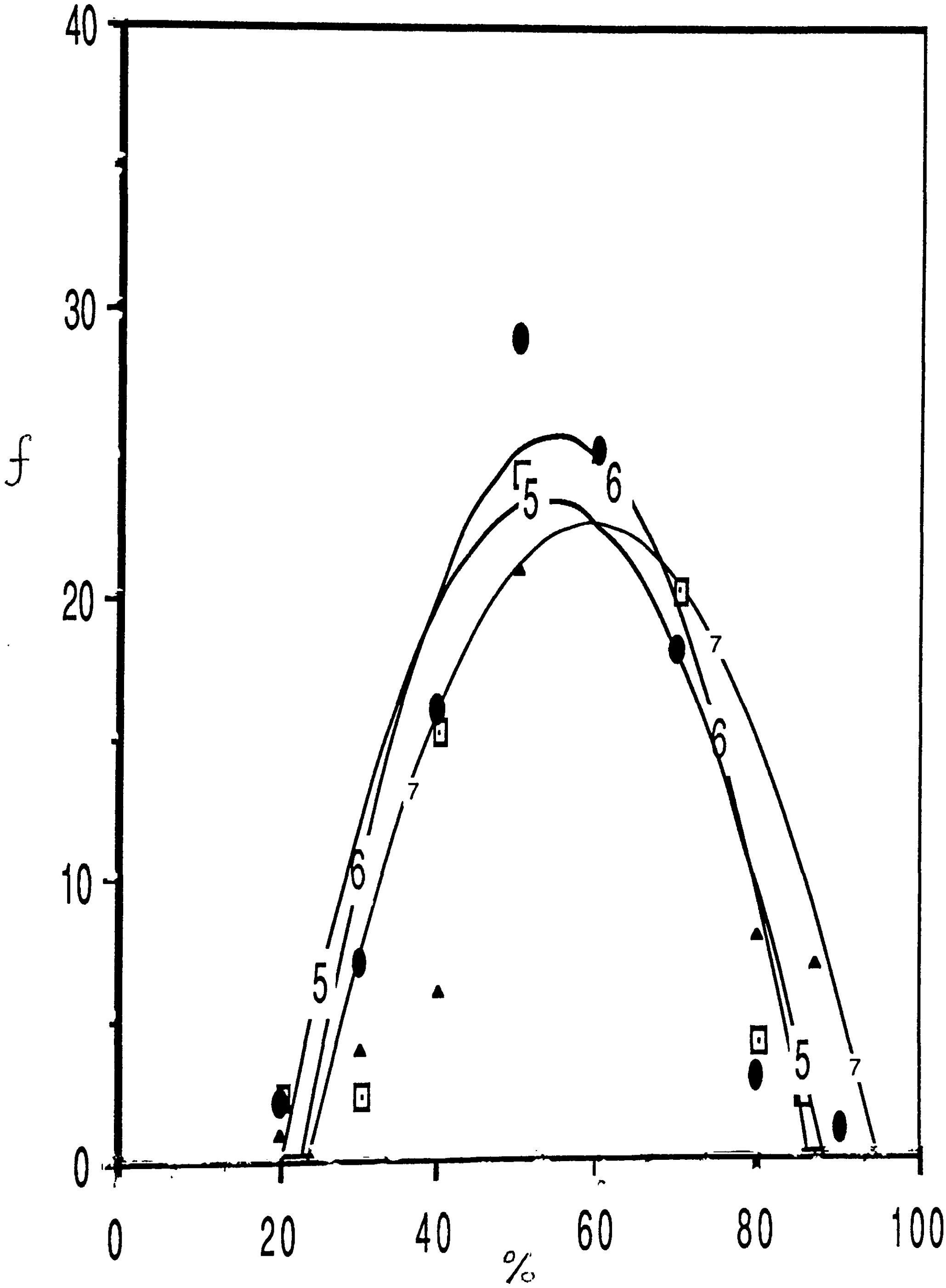


Figure 4.2. Shows normal distribution of exam score for sub-groups capacity (X=7,6,5), when there is no question with Z-demand greater than 4.

Table 4.2 shows the mean score against different question Z in sub-groups X = 5, 6, 7.

Question / Group	Multiple-choice	Q.2 (essay question)	Q.5 (graph question)	Q.3 Z = 7	Q.4 Z = 4
X = 5	28.9	11.4	7.1	2.7	4.4
X = 6	28.7	11.4	8.1	2.7	4.3
X = 7	29.9	11.4	7.9	2.7	4.6
Max.possible marks	45	20	11	6	8

1. Data analysis

The F.V. for all groups on all questions was similar.

There was no significant discrimination between X = 5, 6, 7.

4.2 March 1987 - Class Examination

In this class exam, there are different question complexities, so there is discrimination between the performance of sub-groups of different capacities.

One of the main aims of testing hypothesis No. 2 on page 32). was to find out whether there was a relationship between the students' holding/thinking space (X-space) and their ability to solve individual biology questions of different Z-demand.

Table 4.3. Shows the F.V. for questions of varying complexity against students group capacity

	Question / Group	Q.3 Z=2	Q.20 Z=3	Q.22 Z=4	Q.28 Z=5	Q.32 Z=6	Q.5 Z=7	Q.3 Z=9
1	X ⩽ 5 (N=115)	77.2	78.2	60	50	22	14	1
2	X = 6 (N=85)	77.5	70.8	64	54	29	24	4
3	X ⩾ 7 (N=45)	81.6	75.4	70	60	50	47	9.5

These results do not conform exactly to the theoretical curves mentioned on page 37 , but have strong similarities to Figure 4.3 of X = 5. So students who have X ⩽ 5, maintain a good score for all questions of complexity Z ⩽ 5, but their largest fall is for the question which has Z > 5. Although the X ⩽ 5 students continued to fall, they did not reach 0%. So some students have strategies which help them to survive. It can be seen that only 22% from the X ⩽ 5 groups are able to solve the question which has Z = 6, and only 1% with Z = 9.

From Figure 4.4 students who have a capacity X = 6, do maintain a high F.V. for question Z ⩽ 5. So X = 6 students do well on the problem of Z ⩽ 5, but only 24% survive at Z = 7 and 4% at Z = 9. The break point is not as expected at Z > 6, but performance falls rapidly at Z = 6.

From Figure 4.5, students who have X ⩾ 7, maintain a high F.V. for all questions of Z ⩽ 6, but they fall sharply at question Z = 9.

Only 9% of students were still able to solve the question of Z = 9. Figure 4.6 shows three curves together. Again, this indicates

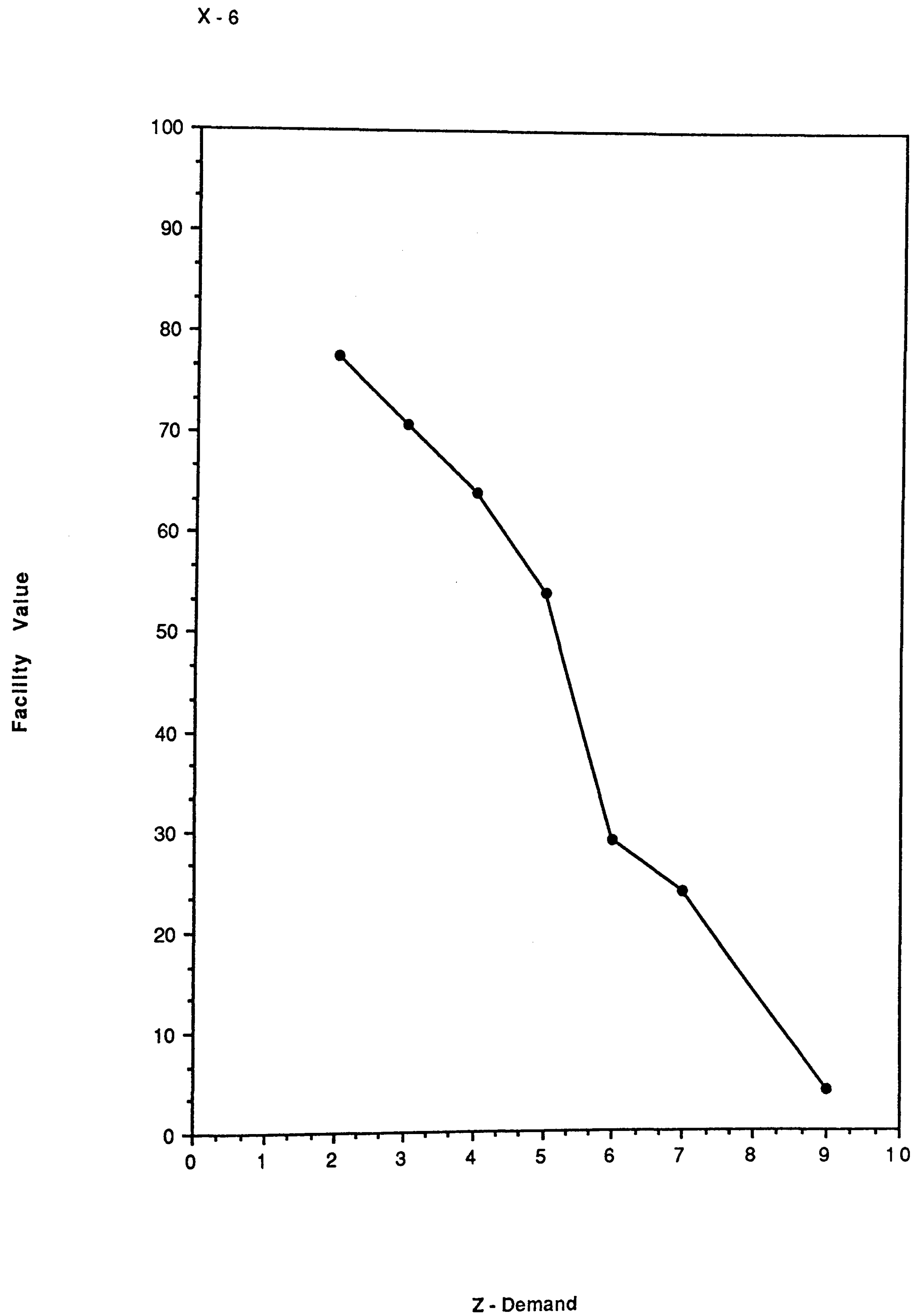


Figure 4.4. Shows the relationship between F.V. and different Z-demand in questions of different complexity for sub-group capacity = 6.
1st Year Biology - University of Glasgow.

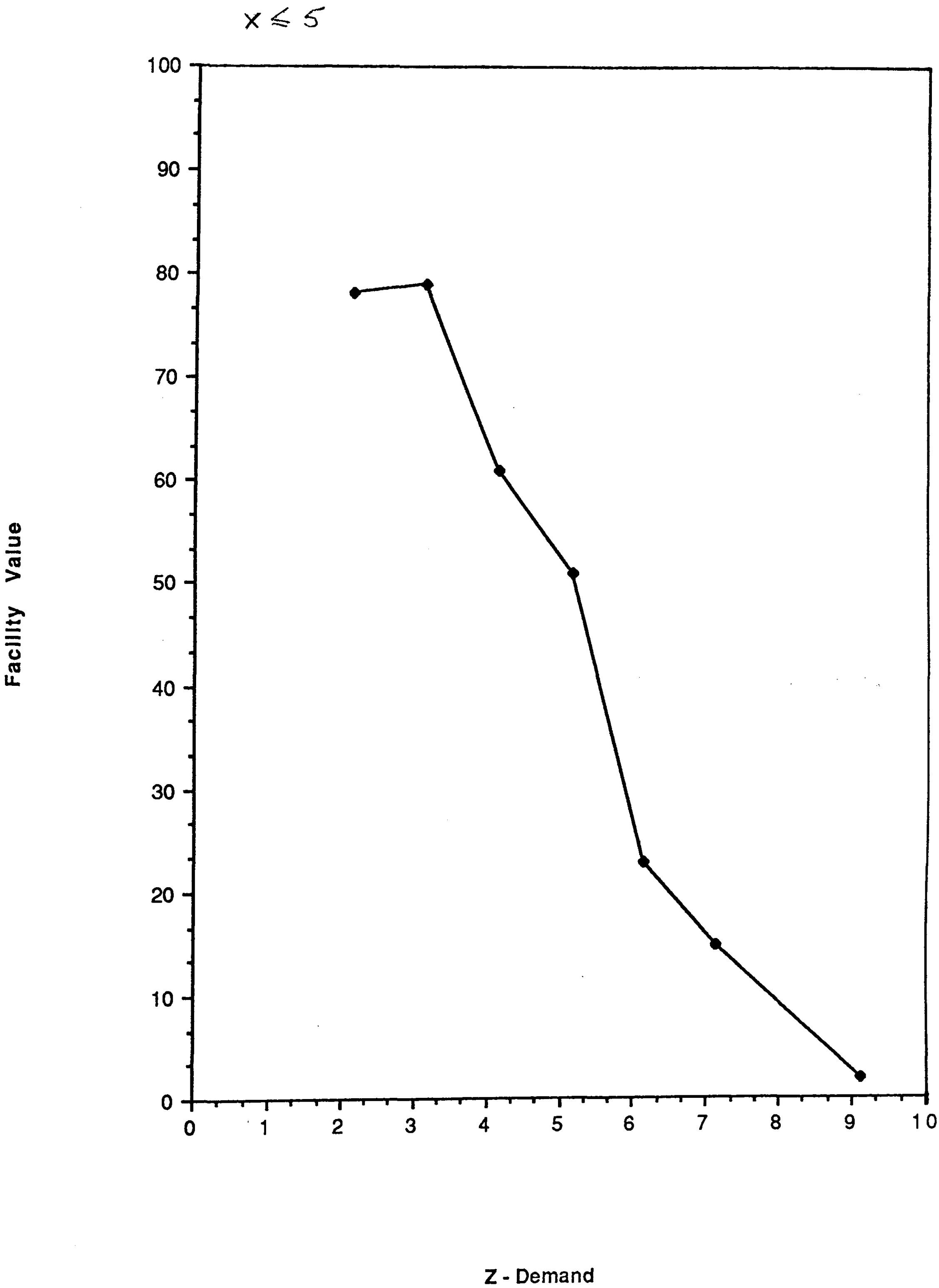


Figure 4.3. Shows the relationship between F.V. and different Z-demand in questions of different complexity for sub-group capacity ≤ 5.
1st Year Biology - University of Glasgow.

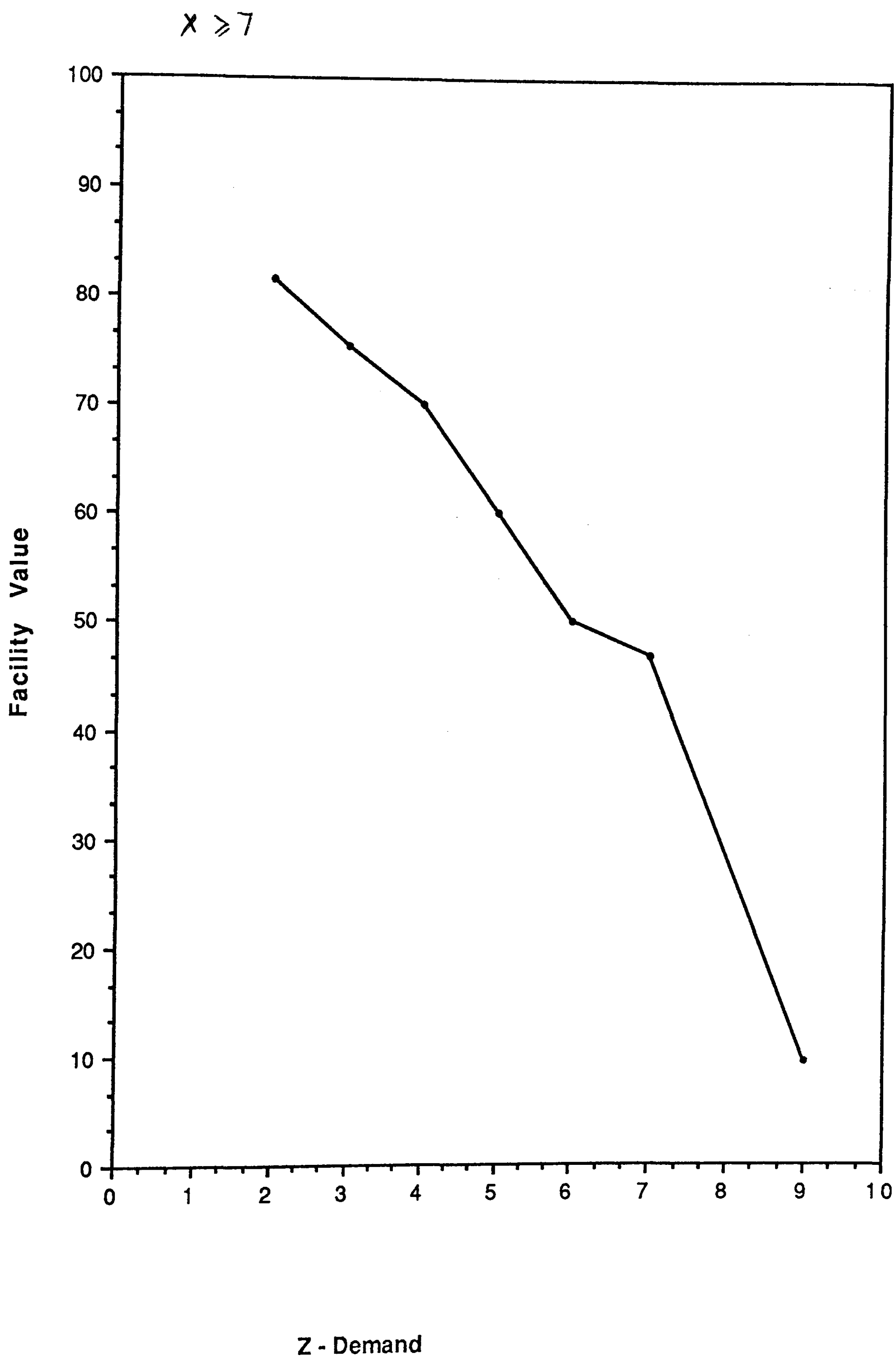
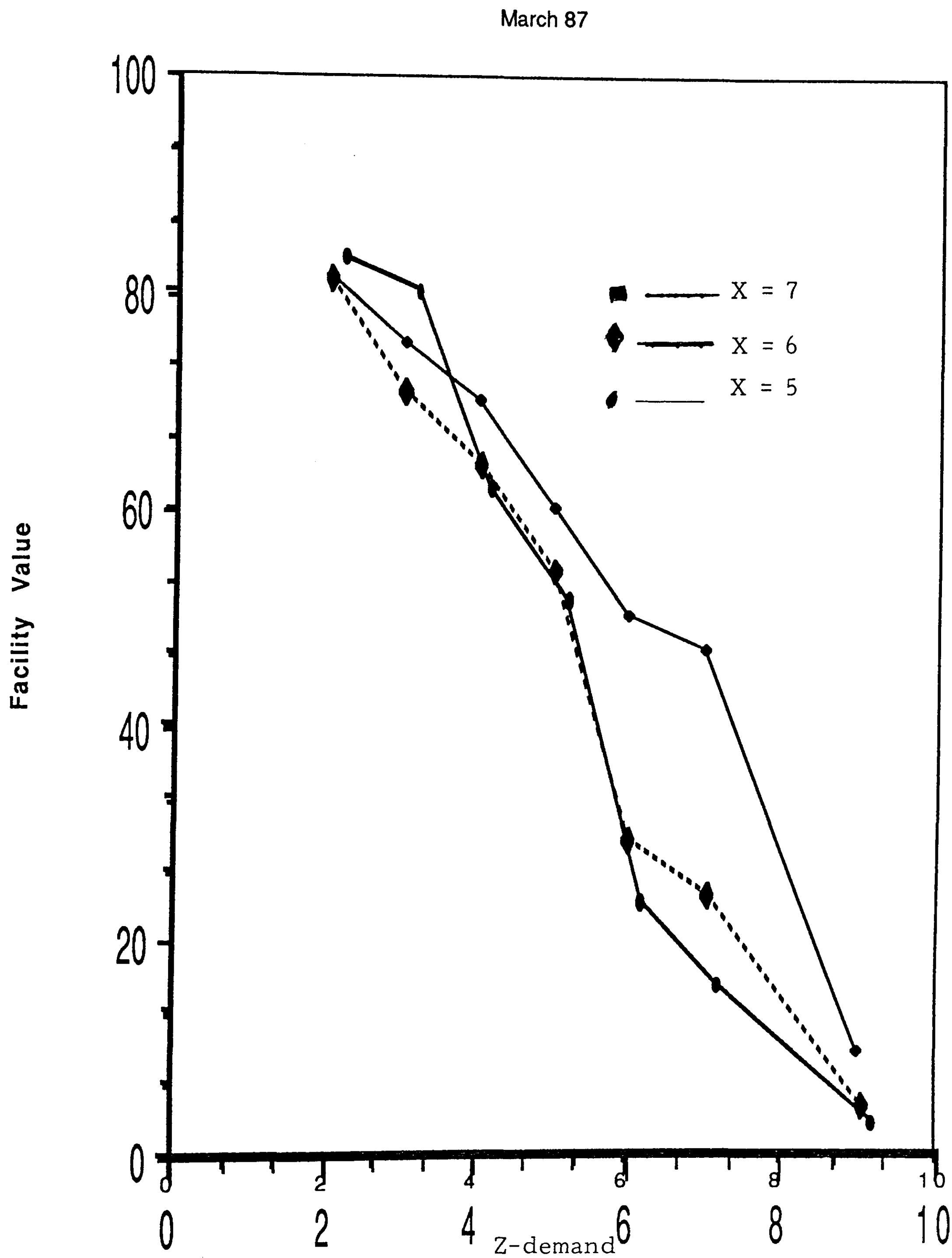


Figure 4.5. Shows the relationship between F.V. and different Z-demand in questions of different complexity - sub-group capacity ≥ 7.
1st Year Biology - University of Glasgow.



<u>Notice</u> When Z > X in X ⩽ 5 largest single drop of 28% in X = 6 is 34%; in X ⩾ 7 is 37%

Figure 4.6. Shows the relationship between different Z-demand of question and F.V. for sub-group (X=7,6,5) (comparison of results from students attempting to answer biology question.
First Year Biology - March Class Examination 1987

that other factors must be involved in all-over performance, which will be dealt with later. In all cases, when $Z > X$, they would not fall to zero, and when $Z \leqslant X$, there is a good performance, but not as good as 100%. Individuals were able to solve questions of Z-demand greater than their measured X-space. However, the above mentioned was similar to hypothesis 2 on page 32 and hypotheses 2 and 3 on page 18.

Our prediction, therefore, that there are other factors also sharing X-space which affect individual performance, is correct.

4.3 General Observations

1 - When Z exceeds X, there is generally a sharp fall in the performance of each sub-group ($X = 5, 6, 7$).

2 - In all cases, the fall did not reach zero percent.

3 - When $Z \leqslant X$, there is good performance for all, but not as good as 100%.

4 - A few of each sub-group's capacity continue to survive (are able to solve questions which have Z-demand greater than their measured X-space). This means that there are other factors involved. So $Z \leqslant X$ is a necessary, but not sufficient condition for success, and $Z > X$ is not disastrous if they have some strategies.

5 - There is a relationship between students' working memory space and their performance.

6 - There is a relationship between F.V. and question complexity.

7 - The performance of high capacity students is better in general than low capacity students in any question. This means that X-space is an important factor affecting a student's biology performance.

8 - In general, considering the question of Z-demand equal or less than lowest X-space ($X \leqslant 5$), all the groups performances ($X = 5, 6, 7$) are similar since these questions were well within the capacity of all groups, as previously expected.

Data has been collected over a two year period from four class examinations and two degree examinations in biology. These will be used to test the hypothesis further.

4.4 Overall Examination Results for the Year

4.A. Students who do well in term (class) exams are rewarded by being exempt from the final degree exams. Since high capacity students potentially have access to more of the paper than low capacity students, we would expect high capacity students to be exempt and to find most of the final exam failures in the low capacity group.

The following table will investigate this prediction.

Table 4.4 shows the results of the exemption, the percentage of success and failure in different capacity sub-groups.

Groups	Exemption		Pass		Fail	
$X \geqslant 7$	38	62%	21	34%	2	3%
$X = 6$	30	35%	45	53%	10	12%
$X \leqslant 5$	30	26%	63	55%	22	19%

Chi-squared value for this Table is 25.587 (observed value) which is significant at 0.001 level. (66).

All the results confirm what we predicted previously, that high X-space students get a significantly higher number of exemptions than low X-space students. Also, there are more failures among the low capacity students than among the high capacity students.

4.B. Discussion

As we predicted in our hypotheses:

1 - There is a relationship between students' W.M.S. and their ability to solve problems of varying complexity. (This means that students of high capacity will get better performances).

2 - There is a relationship between Z-demand of the questions and students' biology performances.

Final Results for

Session 1986-87 (First Year Biology Students)

Chi-square = 25.587
Degrees of freedom = 4
Tail probability = 0.0000

Data Display (3 rows x 3 cols)

Row	col 1	col 2	col 3
1	38.0000	21.0000	2.0000
2	30.0000	45.0000	10.0000
3	30.0000	63.0000	22.0000

Chi-square table (3x3)

Row	col 1	col 2	col 3	Row sum
1	38.000	21.000	2.000	61.000
	22.904	30.149	7.946	
	(9.95)	(2.78)	(4.45)	
2	30.000	45.000	10.000	85.000
	31.916	42.011	11.073	
	(0.11)	(0.21)	(0.10)	
3	30.000	63.000	22.000	115.000
	43.180	56.839	14.981	
	(4.02)	(0.67)	(3.29)	
Col sum	98.000	129.000	34.000	261.000

For 4 degrees of freedom X^2 = 25.587
Critical value of X^2 for 0.1% significance level = 18.46
Therefore results are significant at more than 0.1% level

4.5 Summary

The following patterns emerge from results of testing hypotheses stated as:

1 - In all cases, the $X < 7$ curves represent better all-over performance than $X = 6$, and both have better all-over performance than the $X < 5$.

2 - In general, the performance of high X-space students is better than low X-space students (Hypotheses Nos. 2 and 3 on page 18)

3 - When $Z \leqslant X$, there is a good performance, but not as good as 100%.

4 - When the Z-demand of the question increases, the mean score or facility value decreases gradually.

5 - When Z-demand exceeds the value of the X-space of any sub-group, there is a sharp fall in performance, but some of them are able to solve the question which has Z-demand greater than their X-space. Hence, there are other factors such as strategies which help the student to pass.

Other factors will be investigated later in this thesis.

CHAPTER 5

SECOND EXPERIMENTAL RESULTS - SESSION 1987-88

We attempted to re-examine and re-investigate our hypotheses with another group of biology students who enrolled in session 1987-88. The students were measured for their capacity (X-space) as had been done with biology students in session 1986-87, but this time only by DBT. The following are the results of each class examination and also the final results.

5.1 December 1987 Class Examination

After dividing the students into three measured sub-groups of capacity and analysis of each question, we obtained the following results (Table 5.1).

Group \ Question	Q.13 Z=2	Q.23 Z=3	Q.36 Z=4	Q.33 Z=5	Q.4 Z=6
X = 5 (N=103)	FV = 91	77	49.5	40	34
X = 6 (N=88)	FV = 81	76	60	42	40
X = 7 (N=106)	FV = 92	85	70	60	45

There was no question with $Z > 6$.

<u>Data analysis</u>:

Figure 5.1 shows the curve for students of X $\leqslant$ 5. There is a drop after questions Z = 4.

Figure 5.2 shows the students of X = 6; their curve drops with questions Z $\geqslant$ 5.

Figure 5.3 shows the students of X $\geqslant$ 7 fall with questions Z $\geqslant$ 6.

Figure 5.4 shows the students of X = 5 has fallen before students of X = 6 and both before students of X $\geqslant$ 7. So X $\geqslant$ Z is a necessary but not sufficient condition for success. The results do not confirm exactly the hypothesis that there is a significant difference in the students' performance in the questions of complexity, Z $\geqslant$ X, but, in general, there is a trend with our hypothesis.

When the comparisons were made in both the first and the second years of testing, the results confirm, in general, the hypothesis that there is a relationship between the students' holding-thinking working memory space and their ability to solve questions of different Z-demand.

Now, what about the second class examination?

Figure 5.1

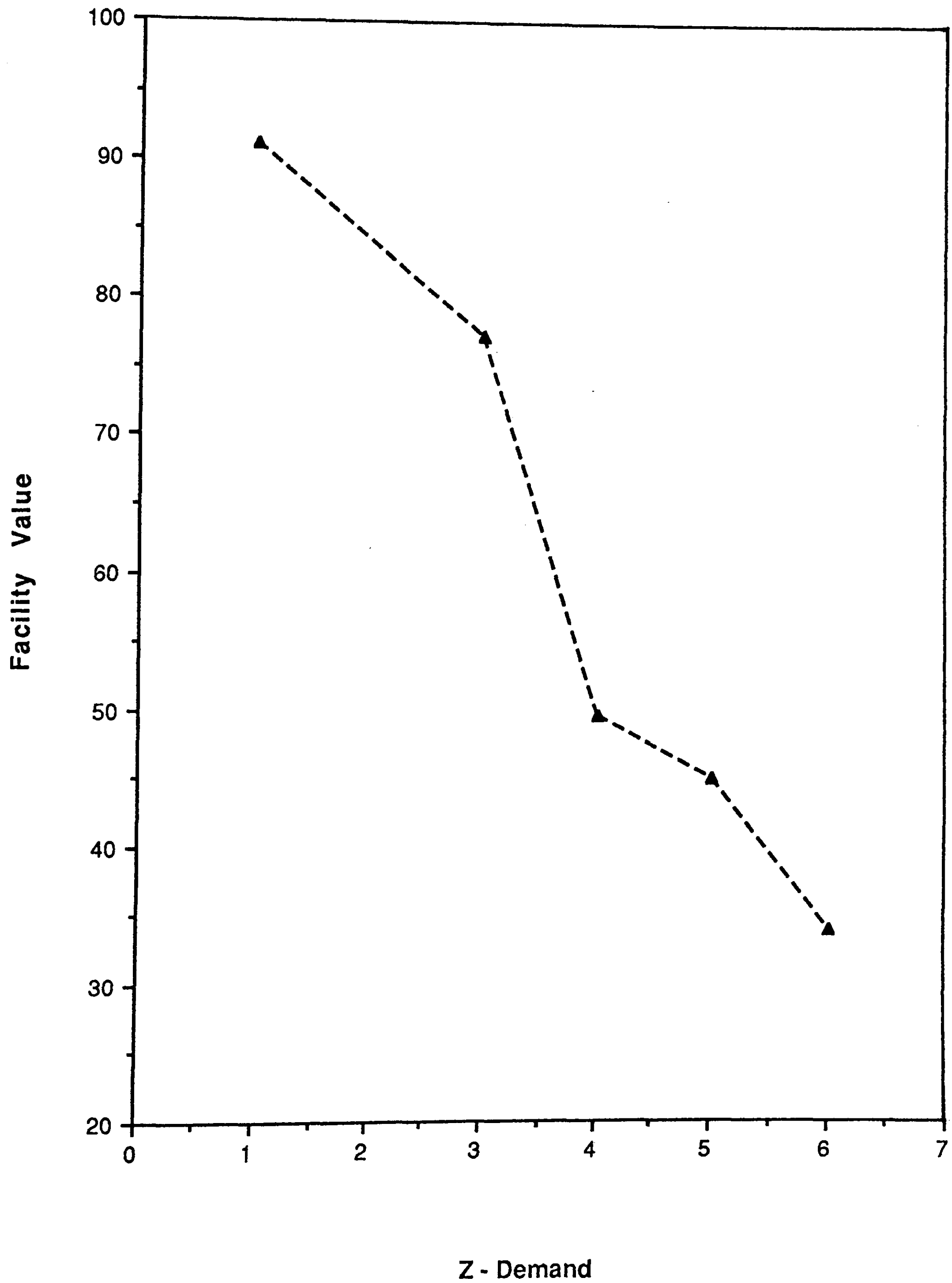


Figure 5.1. Shows the relationship between F.V. and Z-demand of questions of different complexity.
1st Year Biology - University of Glasgow.

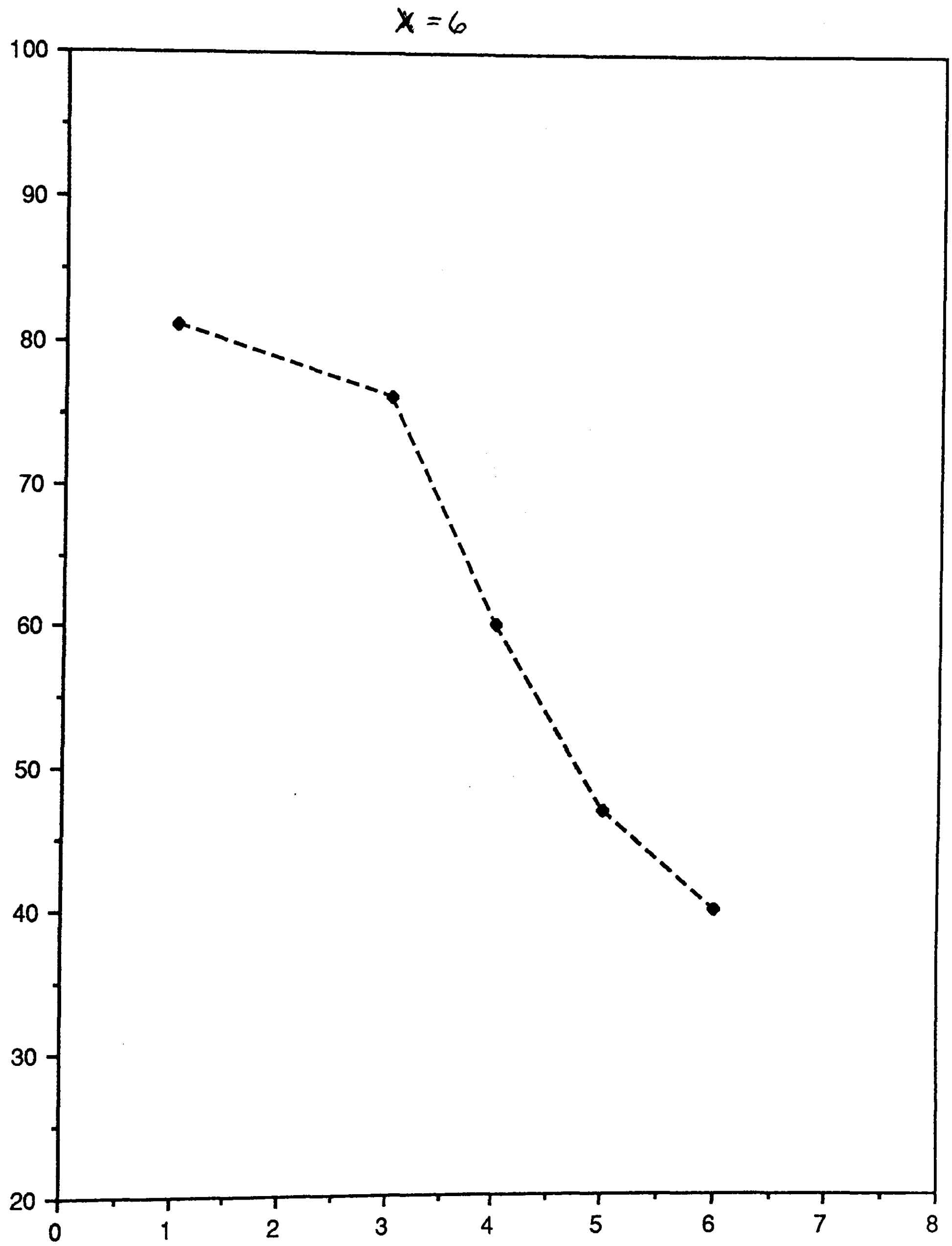


Figure 5.2. Shows the relationship between F.V. and Z-demand of questions of different complexity.
1st Year Biology Exam - University of Glasgow

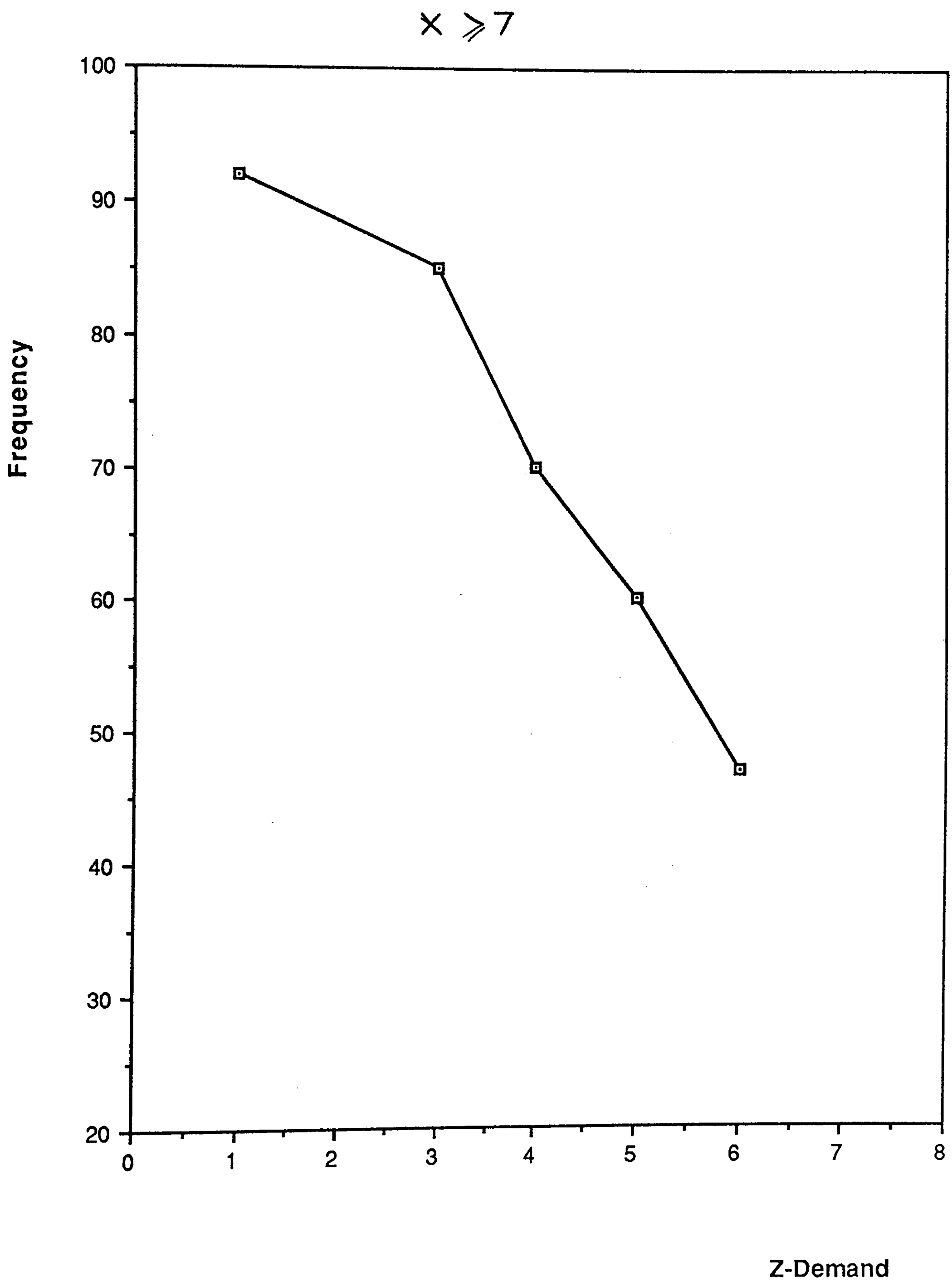


Figure 5.3. Shows the relationship between F.V. and Z-demand of questions of different complexity.
1st Year Biology Exam - University of Glasgow

Figure 5.4

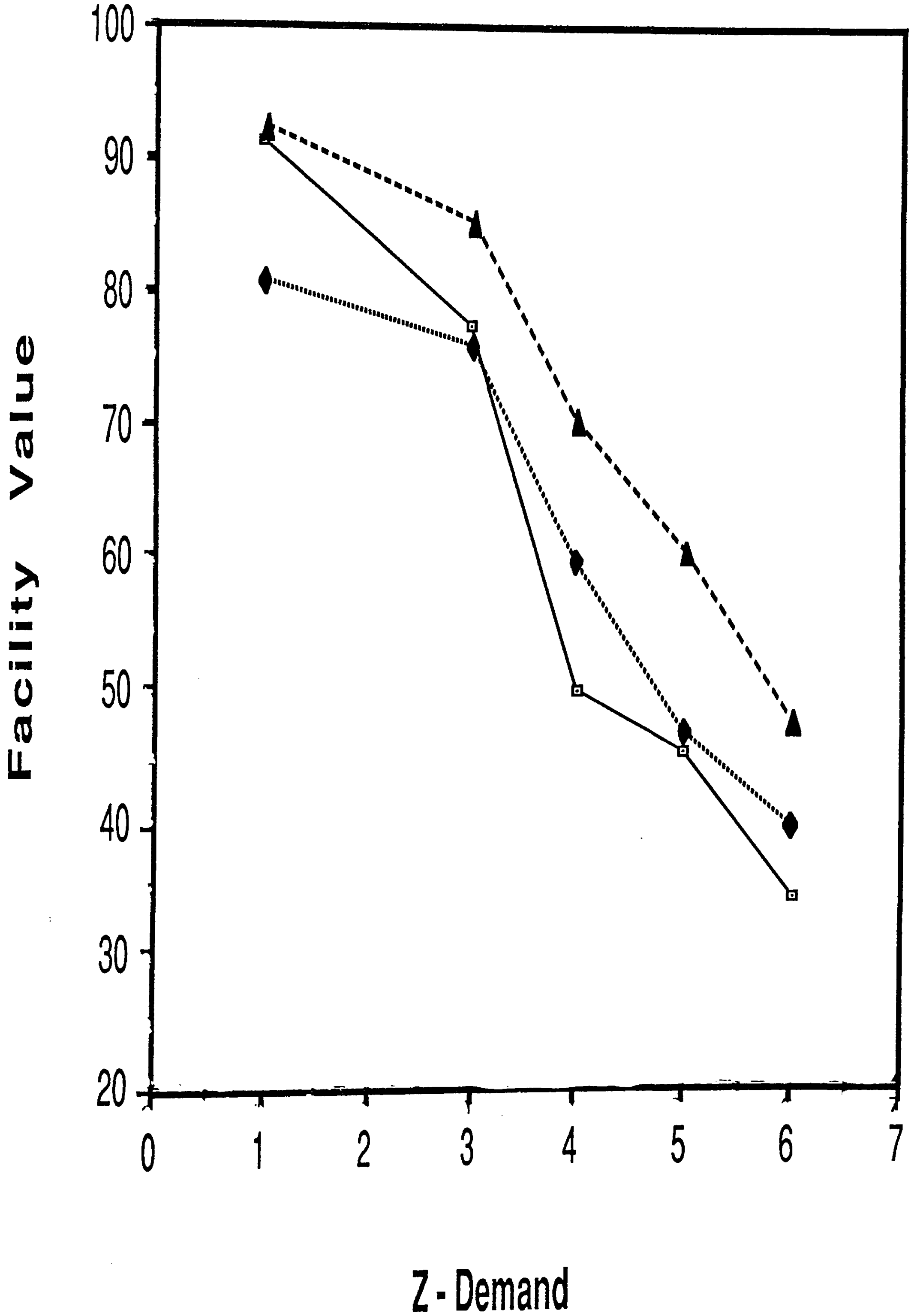


Figure 5.4. Shows the relationship between F.V. and different sub-groups of capacity (X=7,6,5).
December Class Examination - 1st Year Biology

5.2 March Class Examination 1988

Table 5.2 shows the Facility Value against Z-demand for sub-groups of capacity - 1st Year Biology Students

Question / Group	Q.42 Z=2	Q.24 Z=3	Q.7 Z=4	Q.6 Z=5	Q.5 Z=7	Q.4 Z=8	Q.3 Z=9
X = 5 (N=103)	FV=83	68	70	71	11	8	3
X = 6 (N=88)	FV=87	81	81	74	14	14	0
X = 7 (N=105)	FV=86	77	81	77	54	14	5

From Table 5.2, the F.V. of high X-space students is better than students of low capacity. This indicates that the students of high capacity are able to perform better than low capacity students, but the performance in each group decreases with high question complexity. We conclude therefore that there is a relationship between students' X-space and their ability to solve the question. This supports hypothesis No. 2 on page 32.

Now a plot diagram as in Figure 5.5.

Data analysis and discussion

There is no question with Z = 6, so there is a gap.

Figure 5.5 indicates that students of capacity 5 and 6 fall with question $Z > 5$ and that students of capacity equals 7 drop in performance with questions of $Z > 7$. So X = 5, 6 curves before X = 7. This supports hypotheses 2 and 4 on page 18 .

But in all cases, some students survive to solve, even Z-demand of questions greater than their X-space. This means that they should use strategies for getting success. This supports hypothesis 5 on page 32.

Figure 5.5

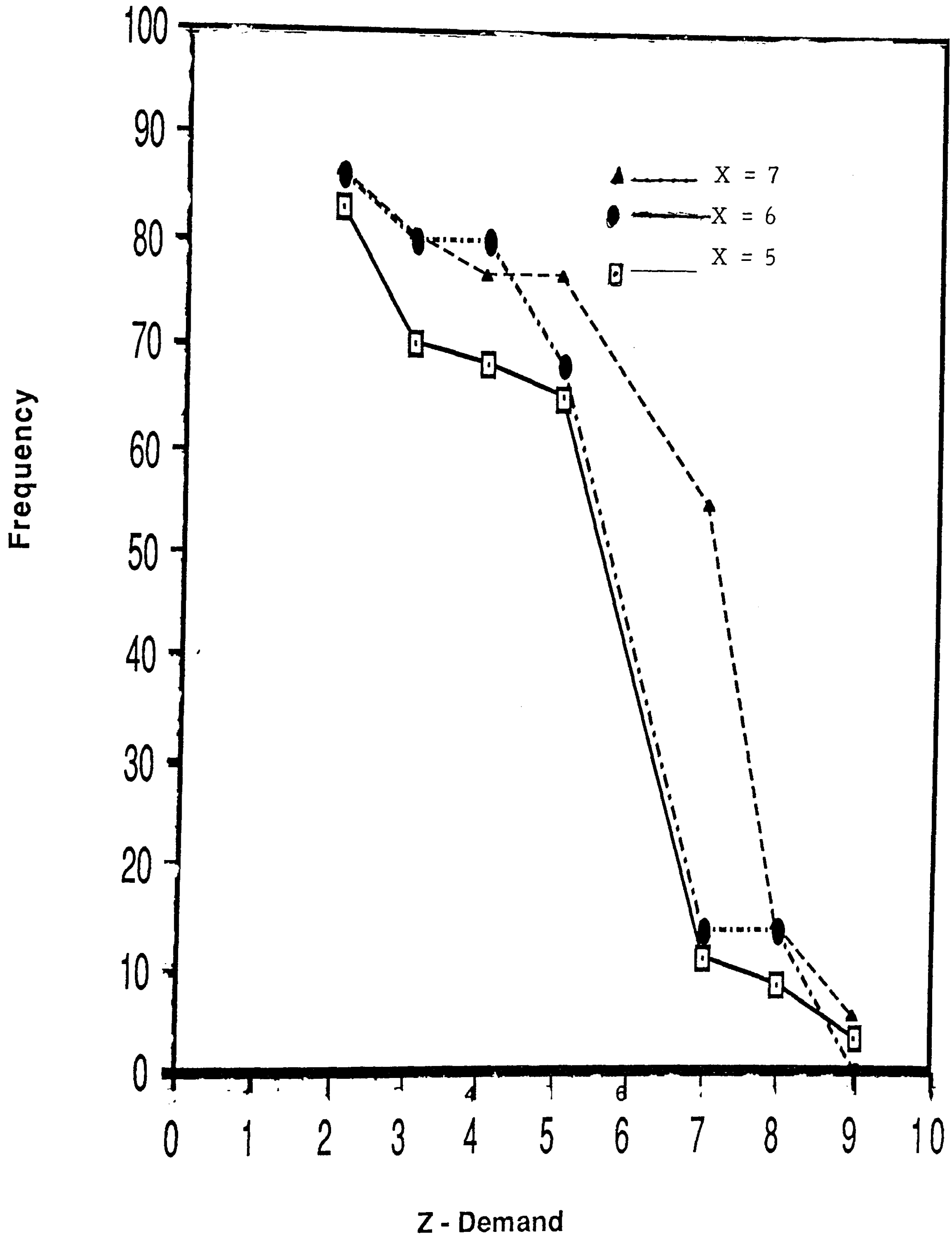


Figure 5.5. Shows the relationship between F.V. and different sub-groups of capacity (X=7,6,5).
March Class Examination - 1st Year Biology.

5.3 Final Results

As shown in a previous section, there was for this group of students, a positive relationship between capacity and their examination (students of high capacity got better performances in biology than students of low X-space) record over the entire year. The highest proportion of exemption came from the high capacity students, and the highest failure rate was among the low capacity students.

The following table investigates what we predicted:

Table 5.3 shows the results of the exemption, the percentage of success and failure in different sub-groups capacity.

	Exemption		Pass			Fail	
	No. of students	%	No. June	No. Sept	%	N	%
X > 7 (N=99)	41	40%	40 39%	11 10%	49%	10	10%
X = 6 (N=83)	39	47%	26 31%	4 5%	36%	14	17%
X < 5 (N=102)	31	31%	42 42%	8 8%	50%	18	18%

The significance of the figures in the above table was at greater than 10% level on the Chi-square Test (see next page).

Final Results for

Session 1987-88 (First Year Biology Students)

Chi-square = 8.1517
Degrees of freedom = 4
Tail probability = 0.0862

Data Display (3 rows x 3 cols)

Row	col 1	col 2	col 3
1	31.0000	50.0000	18.0000
2	39.0000	30.0000	14.0000
3	41.0000	51.0000	10.0000

Chi-square table (3x3)

Row	col 1	col 2	col 3	Row sum
1	31.000	50.000	18.000	99.000
	38.694	45.665	14.641	
	(1.53)	(0.41)	(0.77)	
2	39.000	30.000	14.000	83.000
	32.440	38.285	12.275	
	(1.33)	(1.79)	(0.24)	
3	41.000	51.000	10.000	102.000
	39.866	47.049	15.085	
	(0.03)	(0.33)	(1.71)	
Col sum	111.000	131.000	42.000	284.000

For 4 degrees of freedom X^2 = 8.2

Critical value of X^2 for 10% significance level = 7.78

Results are significant at level more than 10%

5.4 General Discussion

Problem-solving ability is associated with students' ability to organise or chunk the information provided in a given situation into memorisable patterns (67) and, if the X-space is overloaded with too many pieces of information, as shown previously, the processing of information cannot take place unless such information can be effectively chunked.

The size of X-space for an individual student limits his ability to carry out learning and problem-solving tasks in biology. In addition, the nature of biology, as it is taught, may be in conflict with the size of the student's X-space. To overcome this, it is thought that students could learn strategies which would ease the burden on their X-space and so leave space for thought and problem-solving. Such strategies are called "chunking devices".

However, a task's Z-demand ultimately depends upon the strategy used by the subject. It differs from individual to individual, according to the effect of their past experiences.

With this in mind, it is a very difficult matter to determine the task's Z-demand without knowing the strategy employed.

However, what results have emerged during the work?

5.5 Summary

1 - The following findings emerge from the results of testing the Hypothesis stated in Chapters 2 and 3.

a) In general, the $X \geqslant 7$ curves represent better all-over performance than the $X = 6$ and both show better all-over performance than the

X = 5 (hypothesis No. 1 on page 18 and No. 3 on page 32).

b) There is evidence within all groups of different X-space, when Z exceeds their measured X-space, there will be a fall in performance, but not a fall to 0%, except for students of X = 6 in the March Class Examination (hypotheses Nos. 2 and 4 on page 18).

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 groups, i.e. the graphs are usually parallel (hypothesis 2 on page 32 and hypothesis 2 on page 18).

d) The $X \leqslant 5$ students have a lower potential maximum score on a whole test than those for X = 6, 7 students (hypothesis No. 3 on page 32).

e) Despite the fact that the $X \leqslant 5$ students' performance is low, some of them, as well as some of X = 6 students, were performing as well as $X \geqslant 7$ (hypothesis No. 3 on page 18). This may have been achieved by using strategies and having practiced to minimise the load on their working memory space.

2 - There is strong evidence that the questions' Z-demand affects the students' performance as soon as Z exceeds their measured X-space. The students working memory space limits their ability to carry out the problem-solving tasks. This evidence indicated that the relationship between the task's 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 to the theoretical curves shown on page 37 (hypotheses, 2, 3 and 5 on page 32).

Therefore, it is worth emphasising that when $Z < X$, we have a necessary but not sufficient condition for success.

3 - The degree of 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 to handle, they may have difficulty in selecting the relevant information from the irrelevant within their limited X-space, and this could lead to overload.

4 - Failure to recall and apply the required information are some of the reasons which cause the failure to solve some of the biology questions. According to Ausubel, if the learning materials are meaningfully acquired and stored alongside relevant exciting concepts or propositions in the learner's cognitive structure, the learner will find it easy to retrieve or to remember. (68)

5 - The failure to solve biology 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 organising the thinking and working processes before doing any calculations. 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 decided to concentrate on further investigation into student performance, namely Field Dependence/Independence.

CHAPTER 6

THE EFFECT OF FIELD DEPENDENCE/INDEPENDENCE UPON STUDENTS' PERFORMANCE

Much of the research on problem-solving has been concerned with individual differences, conceived in terms of such constructs as availability of function, strategy, cognitive style, and formal reasoning.

Now we need to segregate self/non-self (FD/FI) which affects individual performance.

A Field Dependent individual is more likely to respond to the dominant properties of the field as given and is more likely to use a spectator approach in which properties of the stimulus array play a dominant role.

"Field Independence is more related to competence in cognitive restructuring than Field Dependence". (69) Field Dependent students also tend to use an hypothesis testing approach in which active restructuring is required. However, successful performance on any problem has been related to FI with high capacity. (70,57)

6.1 The Reason for Involving Field Dependence-Field Independence

It is being considered, because one of the conclusions in Chapters 3, 4, and 5, was that some students did not solve questions, for which the demand was less than or equal to their measured X-space (W.M.S.), and so the facility value of these questions did not reach 100%.

Studies by Saarni and Witkin, (71) Moor, Goodenough, and Cox, (72) have indicated that Field Independence, the ability to disembed relevant information from an irrelevant background, contributes significantly to achievement in science.

Kiewra and Frank (73) showed that Field Independent learners generally achieved higher scores on factual and higher order tests than Field-Dependent learners did.

Pascual-Leone called Field Dependence/Independence a cognitive style which may be acting as "moderator" in the use of the full mental space. (74) Karp and Konstadt, Eccles, Pascual-Leone and Parkinson, (75) suggested that there is a relationship between Field Dependence/ Independence and compound-stimuli section of the task (Z-demand). These workers also said that Field Independent people would perform better than Field Dependent ones. They expected FD subjects to function with an X-size inferior to their structural capacity. (75) It could be that the FD students are not capable of choosing relevant from irrelevant information (signal from noise) when both have to share the student's limited holding and thinking space. Also, the FD students will not be able to analyse the data of the question in a complex situation. Likewise they would not synthesise simultaneously the thought steps which would be required to solve questions of high complexity.

An attempt was made by Pascual-Leone to test the first assumption by controlling the sample for one individual difference variable, Witkin's FD/FI. "The variable was expected to insure that only high M-operating subjects (i.e. FI) were accepted in the experimental group". (57)

In general, FD subjects are assumed to be habitually low capacity processors who assign higher weight to perceptual cues than to cues provided by the task instruction, in a situation where these two sets of cues suggest conflicting executive schemes. (74)

FI subjects are assumed to be habitually high X-processors who assign a higher weight to the task instructions than to perceptual cues in such a conflicting situation. (56)

Many researchers, such as Kempa (76) and El-Banna, (64) support the importance of FD/FI cognitive style as a factor influencing a student's learning. For our experimental work we set out to test for any relationship existing between FI/FD and biology performance.

6.2 We attempted to Investigate the Following New Hypotheses

1 - There ought to be a relationship between FD/FI and the student's working memory space (holding-thinking space).

2 - There ought to be a relationship between FD/FI and biology performance (student's attainment).

3 - FI subjects should perform better in biology than FD subjects.

The sample under investigation is drawn from first year biology students who enrolled in 1987-1988 at Glasgow University.

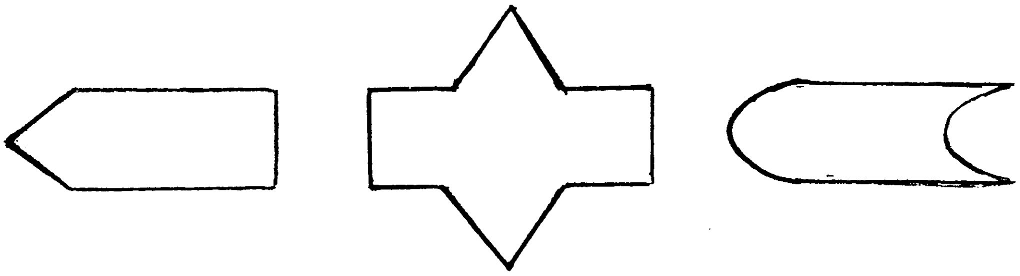
6.3 How to Measure the Degree of Field Dependence and Independence

The test, which was designed to measure the student's degree of FD/FI, was designed and standardised by El-Banna. (64)

The Hidden Figures Test (HFT), is a group administered, paper and pencil test using materials similar to those of Witkin et al.(77.78) The design of the test is based on the definition of FD/FI cognitive style which suggests that subjects who find difficulty in overcoming the influence of a surrounding field, or in separating an item from its context, have perception which is called Field Dependent. On the other hand, subjects who easily break up an organised perceptual field, have a perception which is called Field Independence.

Description of the test:

A. There is a set of six simple geometric and non-geometric shapes which are singly embedded in complex figures. There is more than one complex figure in which each of these simple shapes is hidden. Three examples of these simple shapes are given below.



B. The HFT consists of (18) items (complex figures) plus two 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 trace the outline of the simple shape in the complex figures.

The simple shape:

The shape has to be of the same size and proportion and in the same orientation within the complex figures as when it appears alone in the specimen example.

Administration, materials and instructions:

The HFT is group administered. The instructions of the test are both oral and written. Each student must have a pencil and a test booklet. The booklet page should be thick enough to prevent "show-through" from the next page. Pages one and two of the booklet are occupied by two introductory items and used for instructional purposes (see appendix 6).

Testing and timing:

The testers must be on the look-out for any kind of cheating, such as using a ruler to test the figure. The time required is about 15 minutes. Tests, however, should be collected after 20 minutes.

Scoring:

Each item is scored as "pass" or "fail", and then the overall test score is computed. The total score equals the number of items passed, 18 being the maximum score.

The answer accepted as correct if:

(1) the simple shape of the same size, proportion, and orientation within the complex figure has been located

(2) no other wrong shape in the complex figure has been traced, as in the following example:

Example

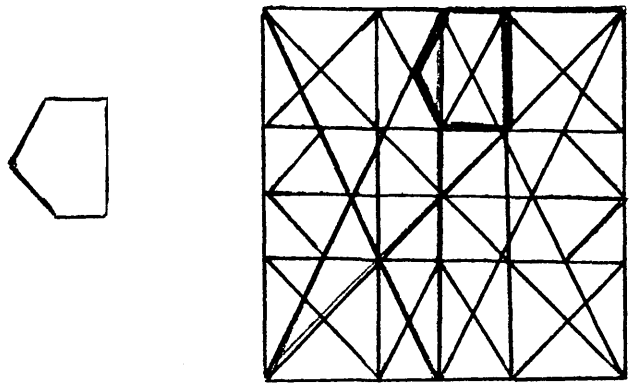


Figure (6.1) shows the distribution of HFT total scores for a sample (273) of first year university students. The mean score is 9.4 and the standard deviation is 2.5. (See next page).

Having constructed a tool for measuring the students' perceptual field, it is necessary to find the relationship (if any) between the students' perceptual field and their attainment scores in biology examinations.

Testing the hypotheses:

To find out, on the basis of the working model, whether there is a relationship between the students' score of Field Dependence/ Independence and their biology performance, we would consider and investigate the following questions, which are based on the hypothesis on page 68

1 - Is there any relationship between the students' measured working memory space and their score in the Field Dependence/Independence test?

2 - Is there any relationship between the students' score in the FD/FI test and their attainment in biology examinations?

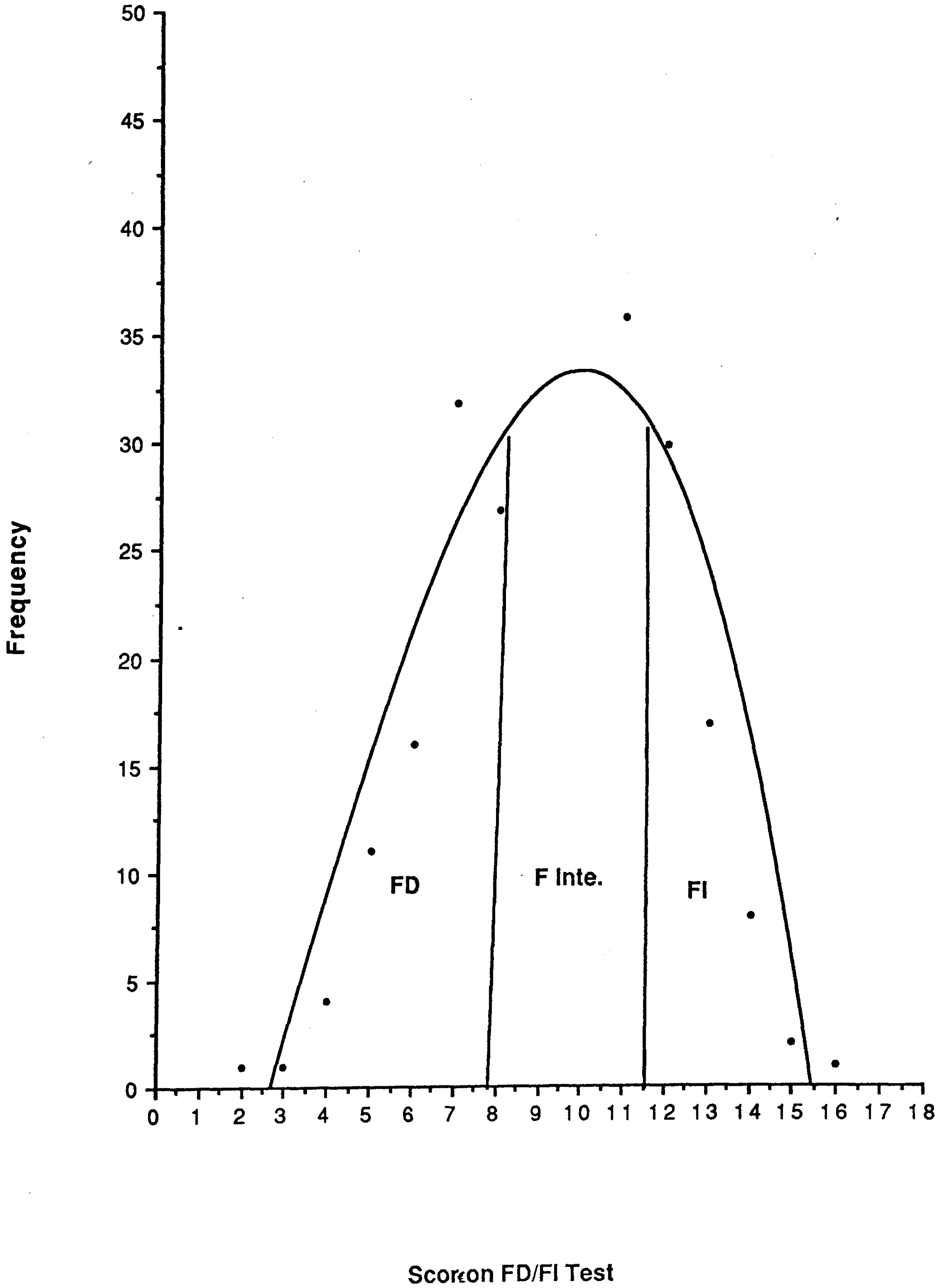


Figure 6.1. Shows the distribution of the H.F.T. total score for sample 273 first year university students in Biology Department.

3 - If the answer to question number 2 is "yes", to what extent does this relationship influence the success of the students (with different X-space) in biology examinations.

6.4 Method

The sample was divided into three groups according to their score of FD/FI measured by the HFT.

Field-Dependent (FD) students were taken to be those who scored less than the half SD below the mean.

Field-Independent (FI) students were those with scores greater than half SD above the mean.

The remainder were classified as Field Intermediate (F.Inter). This is not the criterion used by Scardamalia (56), Case (80,79), Case and Globerson (81) who used a full SD on each side of the mean.

Table (6.1) shows the number of students in these three groups.

Groups	Number of Students	Percentage
FD	93	34%
F.Inter	87	32%
FI	93	34%
Total	273	

Table (6.1)

From this sample, the holding-thinking space of 273 students has been measured putting together the two factors of FD/FI and X-space. Results are as shown in Table (6.2)

Table (6.2). Classification of FD/FI students in each group of different X-space (N = 273)

Groups	FD		F.Inter		FI	
	N°	%	N°	%	N°	%
$X \leqslant 5$	42	45%	31	33%	21	22%
$X = 6$	26	32%	27	34%	27	34%
$X \geqslant 7$	24	24%	30	30%	45	45%

6.5 Data Analysis

1 - Most students of high capacity are Field Independent. On the other hand, most students of low X-space show Field Dependence. These results seem to support Pascual-Leone's idea that those of higher capacity tend to be more Field Independent.

A chi-squared test was administered and showed the distribution to be significant at better than the 1% level. (See next page). Therefore, this shows that there is a relationship between the students' score of FD/FI and their degree of X-space.

Table (6.2) shows that student $X \geqslant 7$ tended to be FI or F.Inter. On the other hand, most of the students $X \leqslant 5$, tended to be FD or F.Inter.

So these results confirm hypothesis number one (on page 68) that there is a relationship between the students' score FD/FI and their measured degree of X-space.

We now explore the relationship of these psychological measurements and biology performances:-

Are all the figures of students with FD, FI, F.Int. for each sub-group significant?

Session 1987-88 (First Year Biology Students)

Chi-square = 13.778
Degrees of freedom = 4
Tail probability = 0.0080

Data Display (3 rows x 3 cols)

	$X \geq 7$	$X = 6$	$X \leq 5$	
Row	col 1	col 2	col 3	
1	45.0000	27.0000	21.0000	= FI
2	30.0000	27.0000	31.0000	= F.Inter
3	24.0000	26.0000	42.0000	= FD

Chi-square table (3x3)

Row	col 1	col 2	col 3	Row sum
1	45.000	27.000	21.000	93.000
	33.725	27.253	32.022	
	(3.77)	(0.00)	(3.79)	
2	30.000	27.000	31.000	88.000
	31.912	25.788	30.300	
	(0.11)	(0.06)	(0.02)	
3	24.000	26.000	42.000	92.000
	33.363	26.960	31.678	
	(2.63)	(0.03)	(3.36)	
Col sum	99.000	80.000	94.000	273.000

For 4 degrees of freedom X^2 = 13.8
Critical value of X^2 for 1% significance level = 13.28
Results are significant at 1% level

1 - The variable of the students' scores of FD/FI was determined by using the HFT, as explained previously. It is the students' ability to separate and distinguish an item from its context in terms of biology; it is the students' ability to analyze the data and pick up the relevant while discarding the irrelevant data.

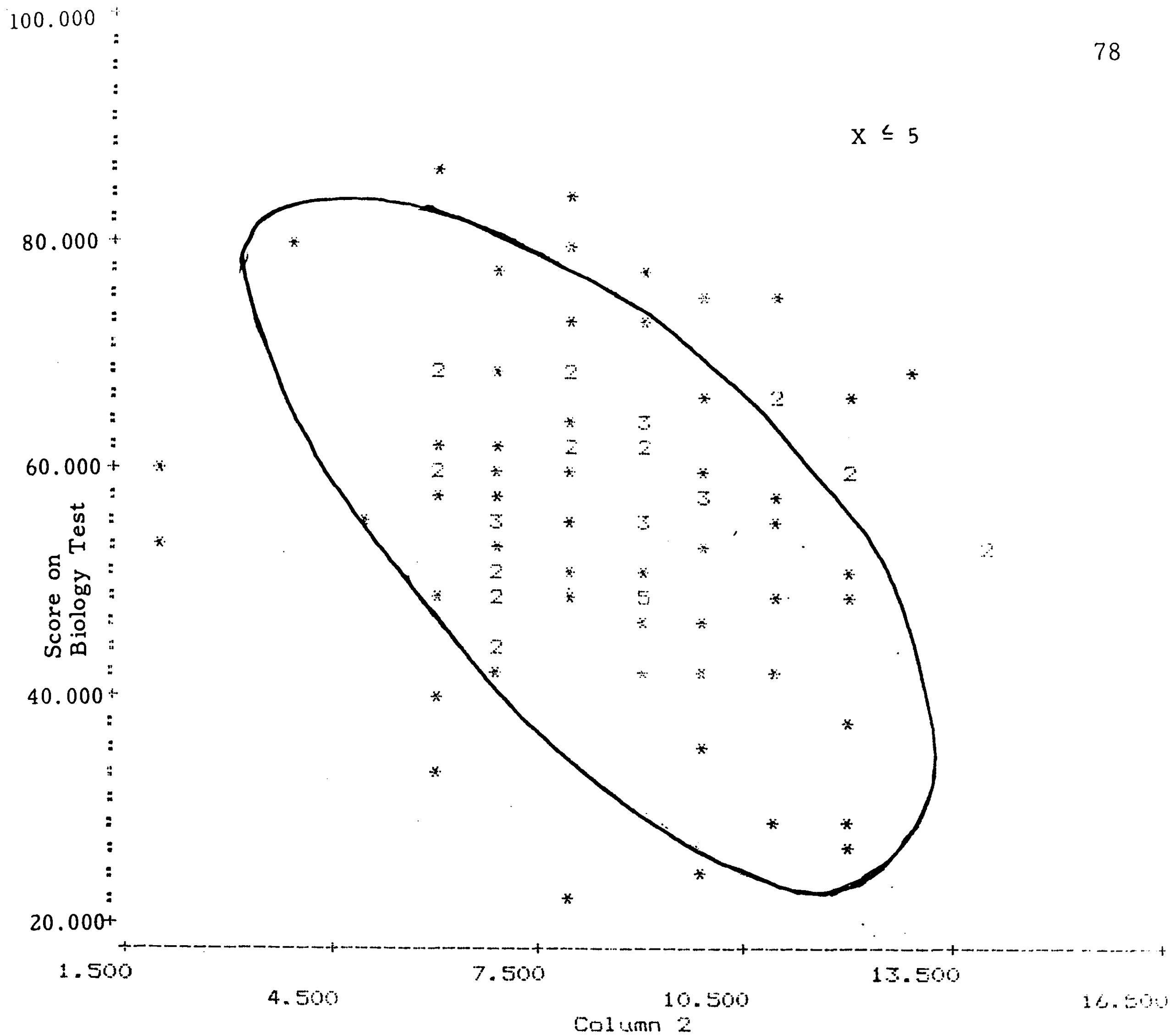
2 - The moderator, the students' X-space, was determined, as explained previously. It is the maximum number of items of information or discrete chunks which the student can hold in mind at any one time during the solving of the question.

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

Testing Hypothesis No. 1 (page 68)

There is a relationship between FD/FI and biology performance. By using scatter diagrams and Pearson Product-Moment Correlation to relate scores in biology and scores on the FD/FI test, we obtained a positive correlation significant at the 5% level. So there is a relationship between the students' FD/FI scores and their attainment in biology examinations. This can also be seen by comparing the students' mean scores within the three groups of different degrees of FD/FI in two class examinations.

Table (6.3) shows the students' mean scores and standard deviations in two biology class examinations.



Columns 2 and 1

Pearson corr = −0.1793

Score on FD/FI Test

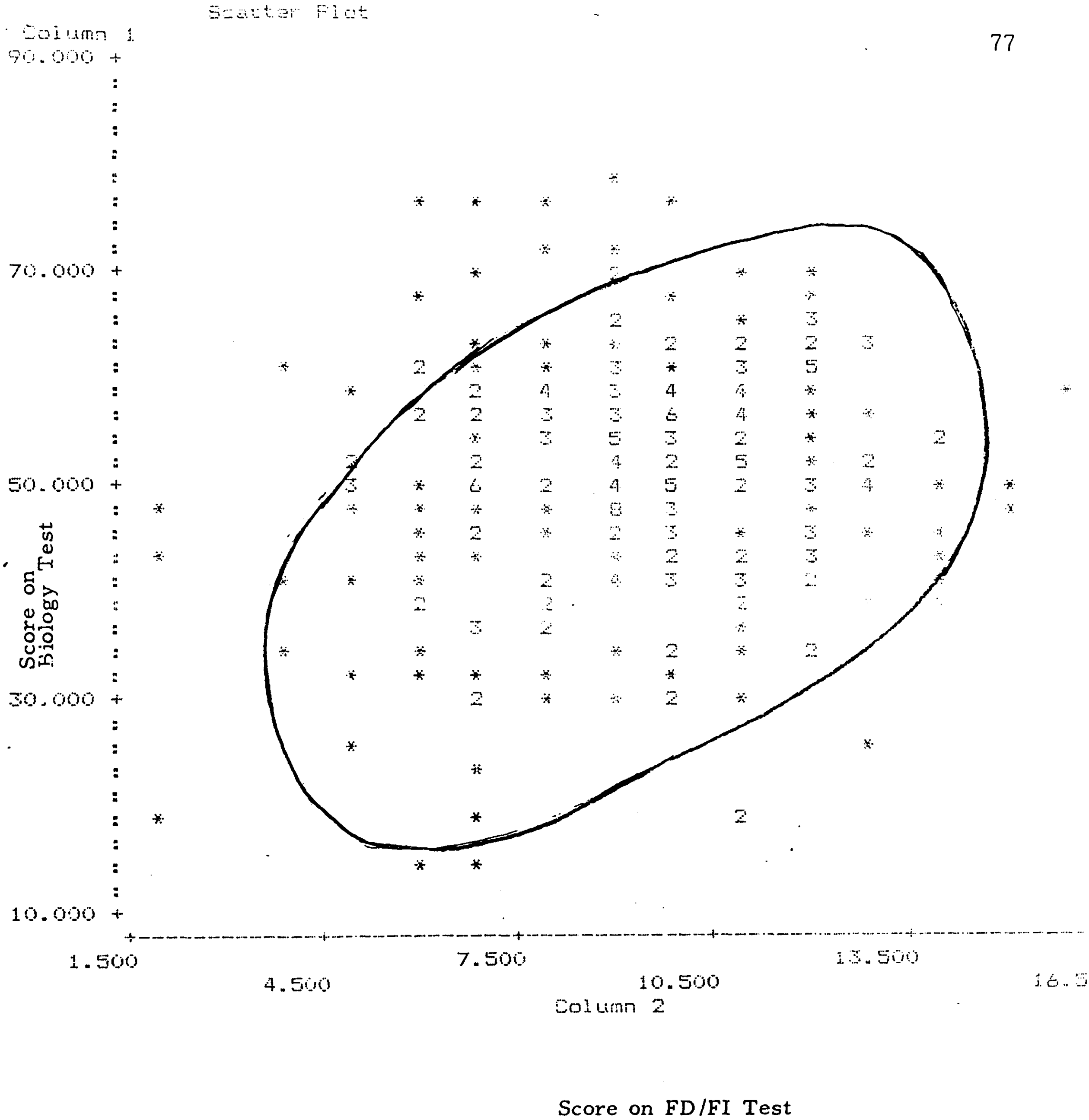
Degrees of freedom = 89
Tail probability = 0.0426

Columns 1 and 2

Pearson corr = −0.1793

Degrees of freedom = 89
Tail probability = 0.0426

Figure 6.3. Scatter diagram for X ⩽ 5 of class examination December 1987 1st Year Biology Students.

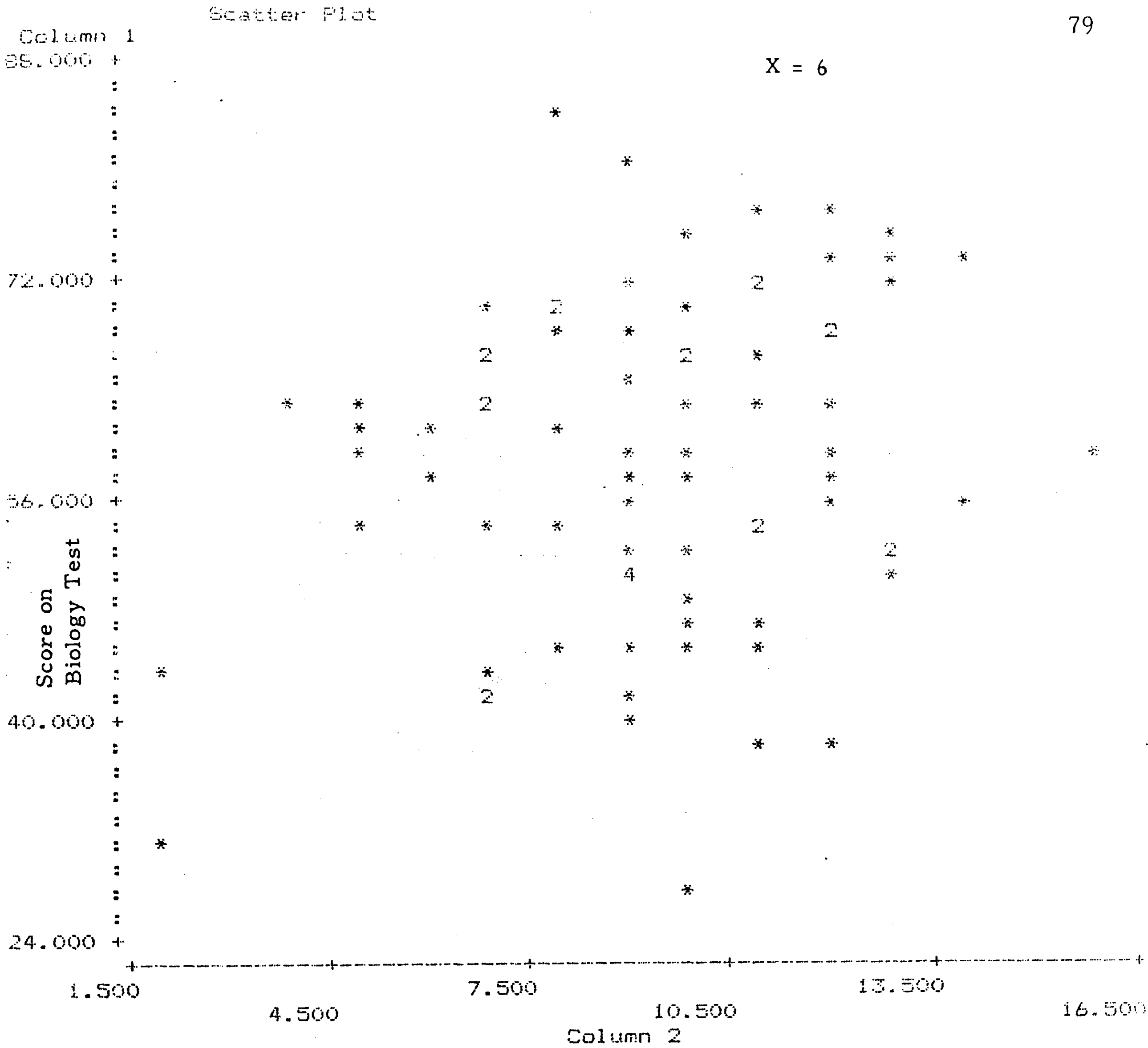


Columns 1 and 3

Pearson corr = 0.1897

Degrees of freedom = 263
Tail probability = 0.0012

Figure 6.2. Scatter diagram for students' scores of HFT and their scores in Biology examination - December class exam 1987.



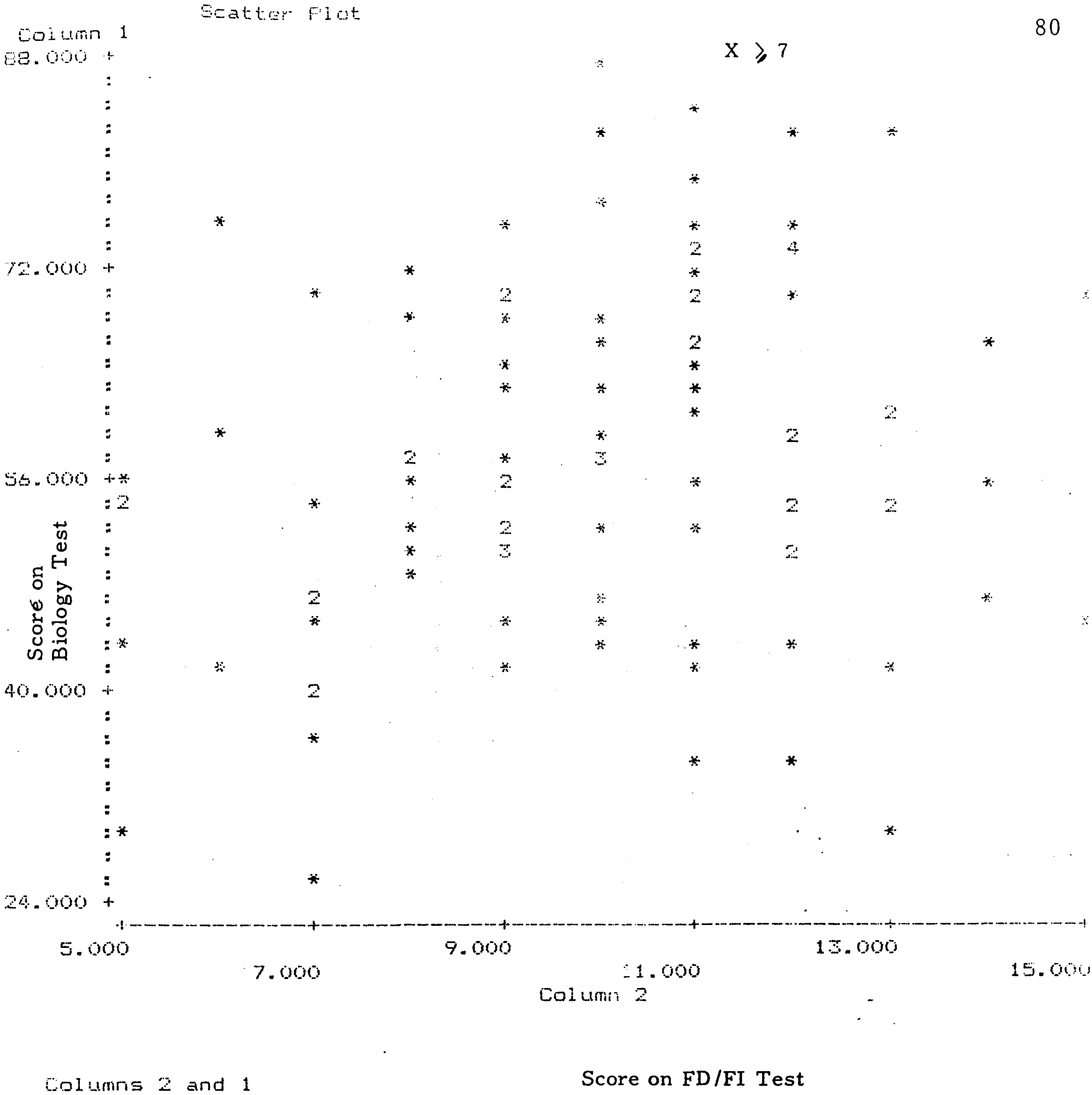
Score on FD/FI Test

Columns 2 and 1

Pearson corr = 0.2050

Degrees of freedom = 78
Tail probability = 0.0324

Figure 6.4. Scatter diagram for X = 6 of class examination December 1987 1st Year Biology Students.

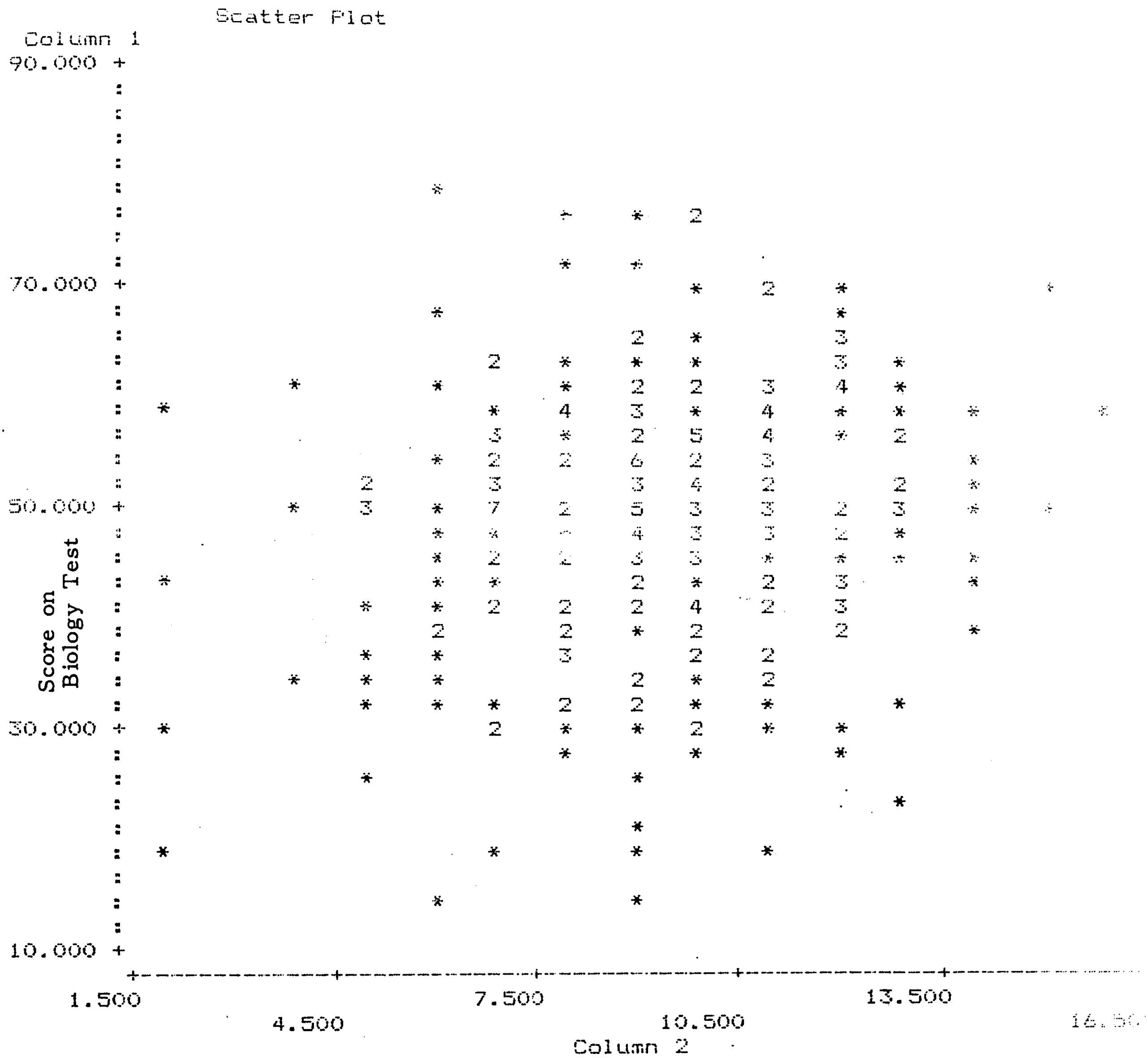


Columns 2 and 1

Pearson corr = 0.2415

Degrees of freedom = 98
Tail probability = 0.0074

Figure 6.5. Scatter diagram for X ≥ 7 of class examination December 1987 1st Year Biology Students.

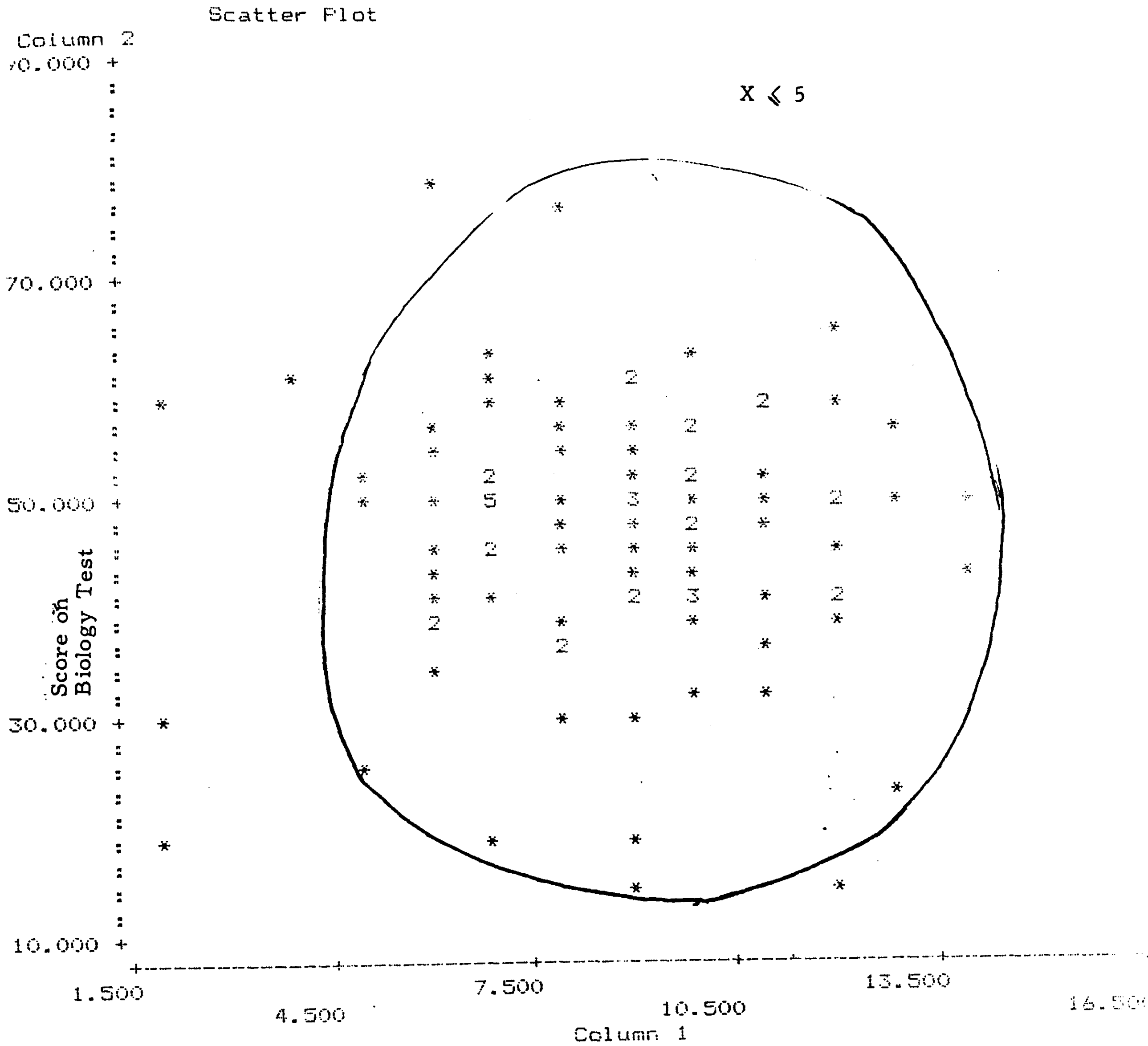


Columns 1 and 2 **Score on FD/FI Test**

Pearson corr = 0.1803

Degrees of freedom = 263
Tail probability = 0.0018

Figure 6.6. Scatter diagram for students' scores of EFT and their scores in Biology examination - March class exam 1987.

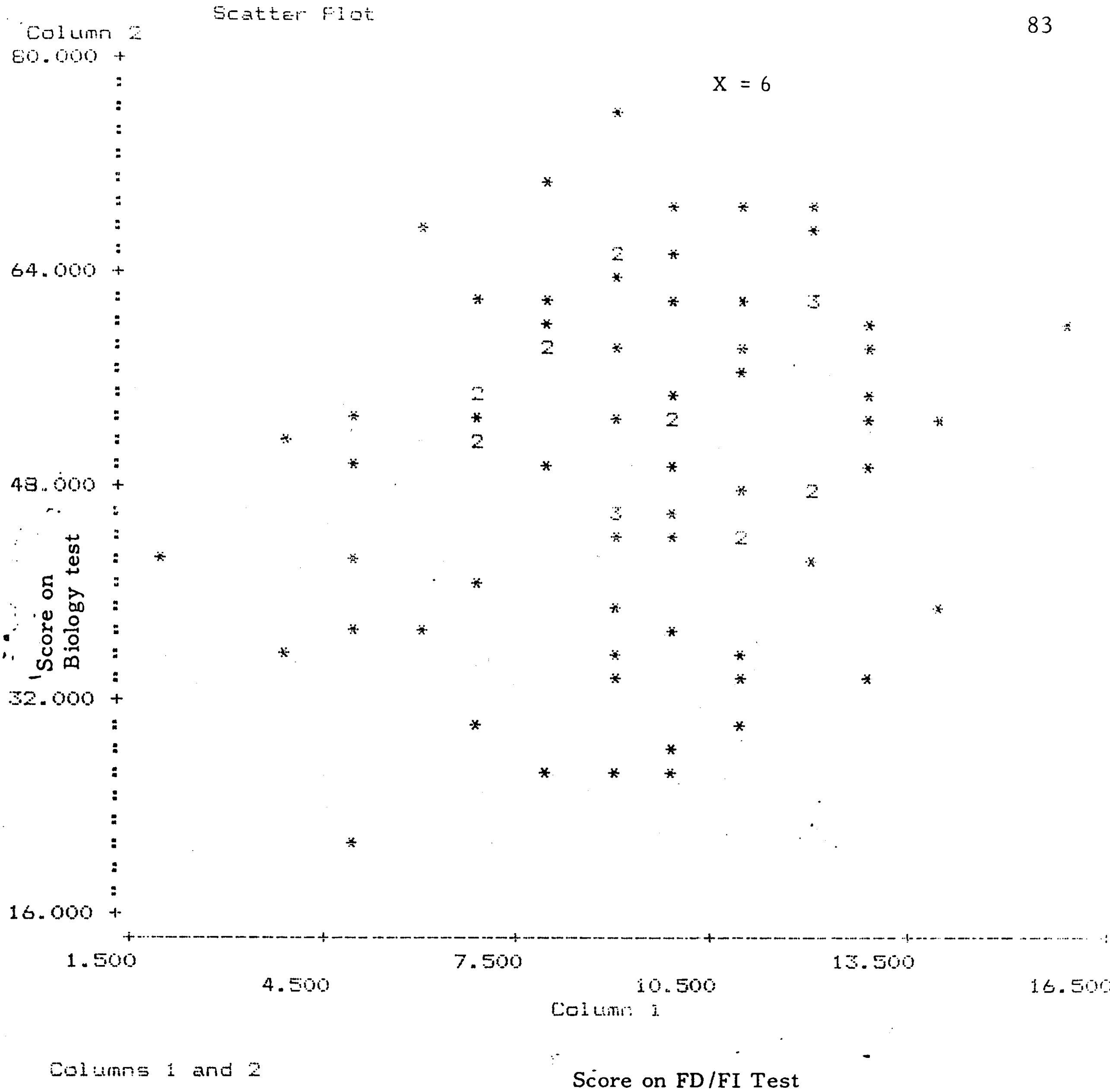


Columns 1 and 2

Pearson corr = 0.0003

Degrees of freedom = 93
Tail probability = 0.4965

Figure 6.7. Scatter diagram for X ≤ 5 of class examination March 1987 1st Year Biology Students.

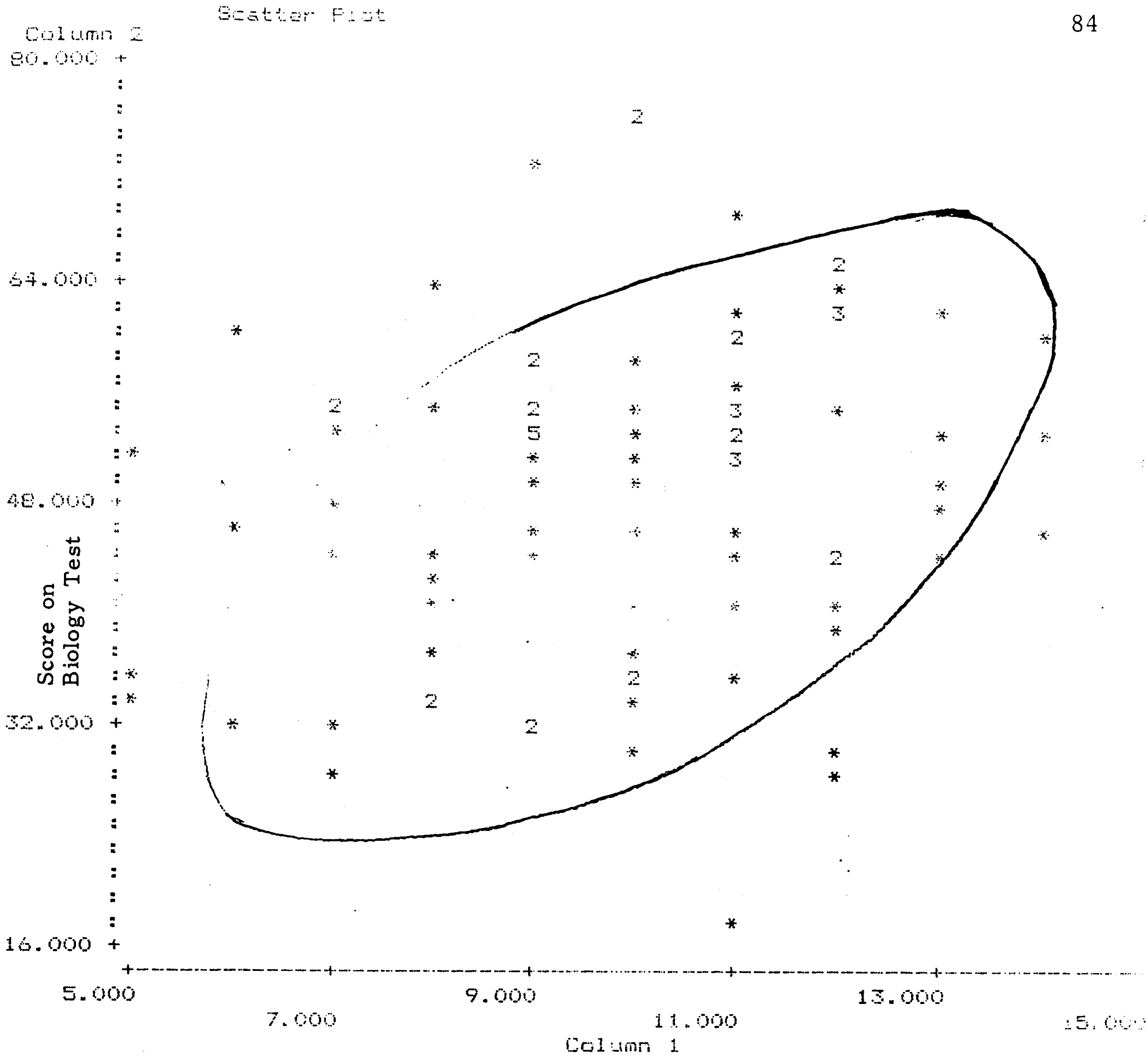


Columns 1 and 2

Pearson corr = 0.1858

Degrees of freedom = 76
Tail probability = 0.0498

Figure 6.8. Scatter diagram for X = 6 of class examination March 1987 1st Year Biology Students.



Columns 1 and 2

Pearson corr = 0.2489

Degrees of freedom = 90
Tail probability = 0.0079

Score on FD/FI Test

Figure 6.9. Scatter diagram for X ⩾ 7 of class examination March 1987 1st Year Biology Students.

Table (6.3)

Groups	1st Class Exam		2nd Class Exam	
	Mean score	SD	Mean score	SD
FD (N=92)	55.8	12.9	47.5	11.9
F.Inter (N=88)	57.5	11.8	48.4	12.4
FI (N=93)	60.8	12.1	51.8	11.5

Testing Hypothesis No. 2 (page 68)

FI subjects should perform better in biology than FD. Table (6.3) shows the results of the students in two examinations. The results indicated that the mean score of a FI student is higher than a FD student, so there is a relation between cognitive style (FD/FI) and students performance, but not significantly.

Also from the results in Table (6.3) and Figures 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, we infer that ability in biology is related to the ability to distinguish "signal" from "noise". Therefore, in general, there is a trend in support of hypothesis No. 2 on page 68

Testing Hypothesis No. 3 (page 68)

FI with high X-space should perform better than low X-space with FI; in other words, the best biology performance should be found among students with high capacity and who are Field Independent.

Table (6.4) shows the means and standard deviations in two biology class examinations for all groups of different X-space.

Table (6.4). Means and standard deviations for students of different X-space in two biology class examinations (N = 273)

Groups		FD		F.Inter		FI	
		Mean	SD	Mean	SD	Mean	SD
X ⩽ 5	1st Class Exam	57.2	13.2	56.0	11.8	54.7	12.1
	2nd Class Exam	47.7	12.6	46.1	10.9	46.0	11.4
X = 6	1st Class Exam	57.2	11.7	56.5	11.8	61.1	11.4
	2nd Class Exam	50.0	11.4	48.7	14.2	51.9	11.1
X ⩾ 7	1st Class Exam	51.2	12.5	59.7	11.5	61.7	13.8
	2nd Class Exam	44.2	10.3	50.7	11.9	52.2	11.1

(possible score = 100)

Therefore, we observe from Table (6.4) that FI subjects with higher X-space had higher mean scores in both biology tests. These are in support of hypothesis 3 on page 68.

So the following are the main observations

1 - The highest scores in the biology exams came from students of higher working memory capacity who are Field Independent.

2 - Students of highest capacity (⩾ 7) who are Field Dependent, had the lowest mean scores of all the groups.

3 - Students of lowest capacity (⩽ 5) who are Field Dependent, had a slightly higher mean score than others in their capacity group.

These results seem to be contradictory and difficult to interpret. However, a consideration of the nature of the exams may help to explain the results.

Each exam consisted of 50% multiple choice questions which are mainly at recall level. The remaining 50% is made up of comprehension and application questions involving data handling, graph interpretation and other higher order skills. It could be that fixed response, recall (recognition) questions favour the Field Dependent candidates, while the open ended, open response extraction of relevant data questions favour the Field Independent candidates.

Field Independent students may have difficulty with fixed response questions in that none of the responses available may seem to them to be satisfactory.

6.6 Conclusions

The findings in this Chapter lead to the following conclusions:

1 - There is evidence in favour of there being a relationship between the students' scores of FD/FI, and their attainment scores in the biology examinations (supporting hypotheses 2 on page 68).

2 - Since there is weak correlation between the students' scores of HFT and their scores in the biology examinations, in the case of $X \leqslant 5$ students, it could be that the multiple choice element favours FD over FI.

3 - The mean biology scores of students with high capacity who are Field Independent are the best (supporting hypothesis 3 on page 68).

4 - In the Field Independent column, the mean scores of $X \geqslant 7$ students are higher than $X = 6$ and both are higher than $X \leqslant 5$ students.

5 - There is a relationship between the students measured X-space and their scores of FD/FI (supporting hypothesis 1 on page 68

6 - In the FD column, the mean scores of low capacity are higher than for high capacity students.

Now we can summarise all that has been mentioned into the following figures.

Figure 6.10 shows the relationship between students' X-space and the score of FD/FI - and each with their biology performance.

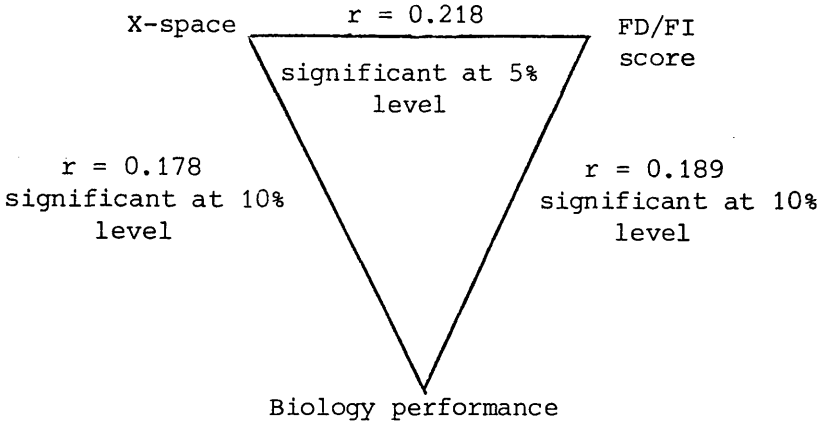


Figure 6.11 shows the relationship between students' X-space and their degree of FD/FI.

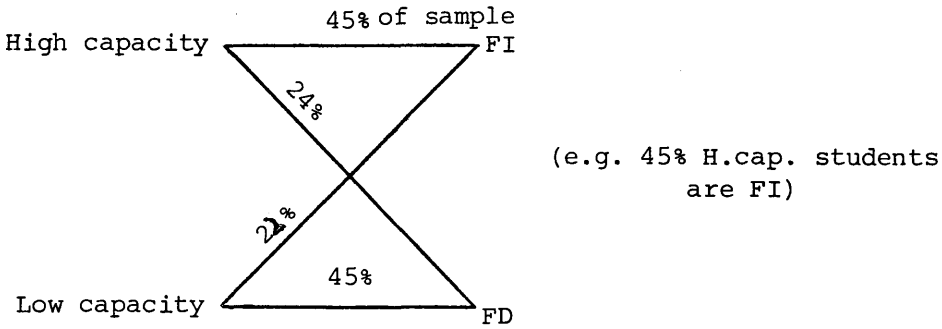
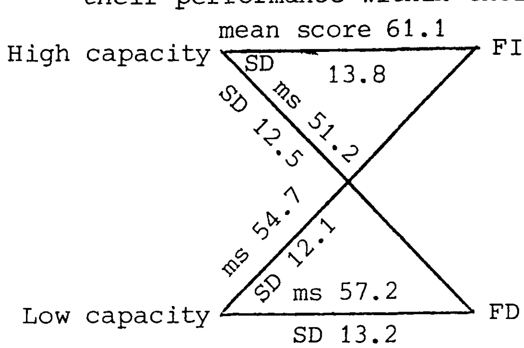


Figure 6.12 shows the relationship between students' score of FD/FI and their performance within their X-space.



CHAPTER 7

SUMMARY AND CONCLUSIONS

Part of the research which has constituted this work has been into the literature of mental capacities.

Now we shall try to relate the results of our investigations to the predictive model which was described in Chapters 2 and 3, and will thus make some tentative conclusions about the students' X-space capacities.

We will also consider some possible implications of such suggestions for the classroom teacher, and make some recommendations which, we hope, could lead to some general improvements in learning.

7.1 Summary of the Work

An individual has limited space in which to hold information and to think about it. This leads us to think how we can improve that use of space to cope with questions of greater complexity. In this way we are attempting to improve the student's performance in science.

Johnstone (59) proposed a model that laid emphasis on the relationship between students' working memory space and their chemistry performance. This model was considered to be a predictive model, based on information-processing for problem-solving. We attempted to use the model to raise testable hypotheses for use with biology students at the University of Glasgow. The study consisted of two parts.

First of all we measured students' working space (X-space) by three standardised psychological tests, and divided the students into three groups: i) students with high X-space capacity (X = 7,8), ii) students with low X-space capacity (X = 4,5), and iii) students with medium X-space capacity (X = 6).

We related students' X-space to their performance in biology class examinations and final results of degree exams over a two-year period. We analysed each exam for the demand of its questions and their facility values for each capacity sub group.

We came to the following conclusions:-

1 - There is a limited holding-thinking space for an individual which can limit the ability to solve problems of different complexity.

2 - There is strong negative correlation (r = 0.8) between the two variables of facility value and question demand.

3 - There is a relationship between students' working memory space and their performance.

4 - The mean score of students of high X-space is better than that of students with low X-space. In other words, students with high X-space tend to perform better than students with low X-space.

5 - A question of low demand ($Z \leqslant 4$) does not discriminate between sub groups of capacity. In other words, the results could be interpreted to conclude that when the demand of biological items is relatively low (4,5), X-space of students is not an important factor in students' success. This was confirmed by Niaz. (82)

6 - In all cases, when the demand of the question increases, the performance will decrease. This is also confirmed by Niaz. (83)

In general, the students of X ⩽ 5 dropped before students of X = 6, and both before X ⩾ 7 students.

This and other evidence show that the X-space is necessary for success, but is not a sufficient condition, as shown in the following diagram.

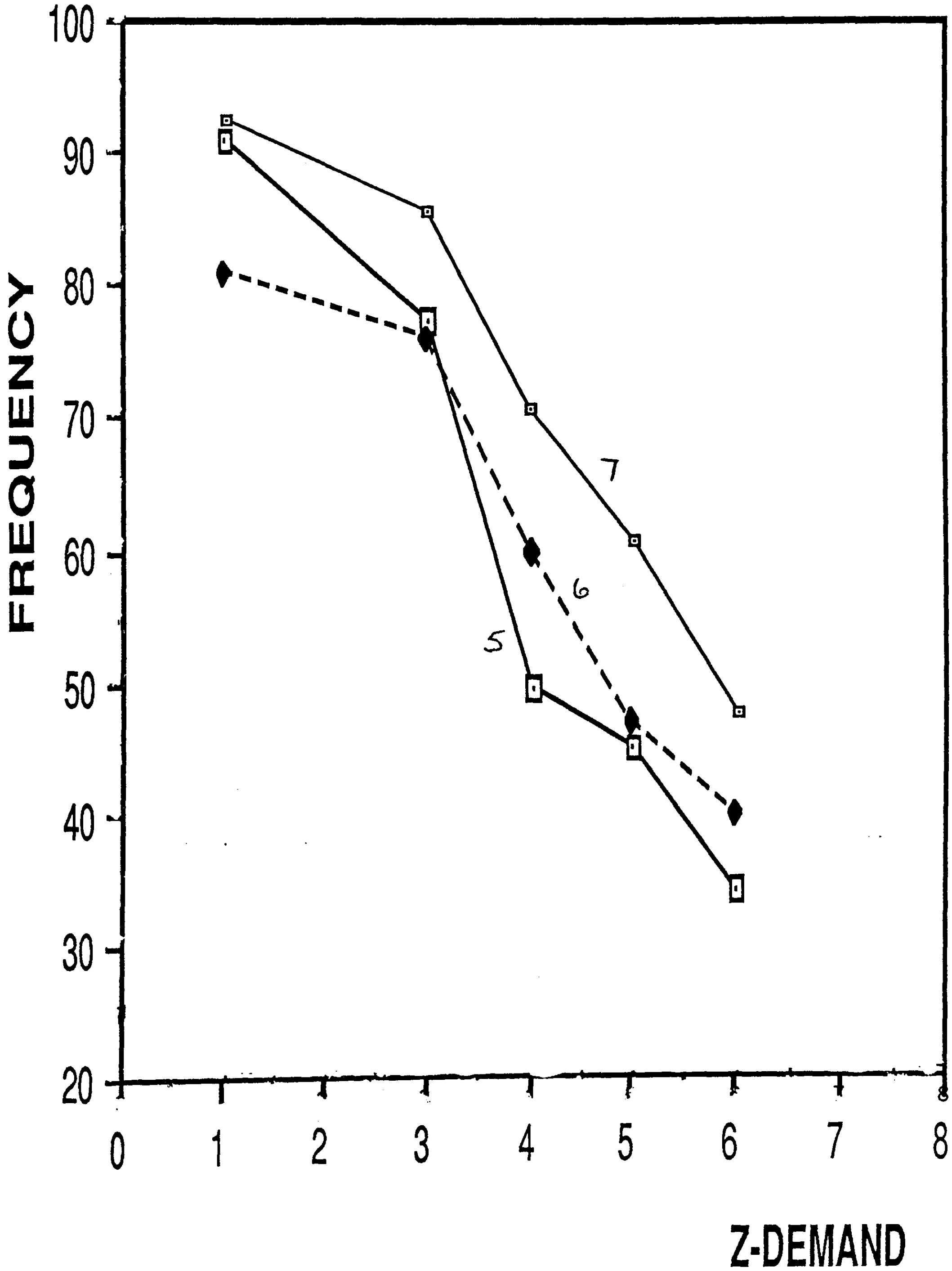
7 - At final degree exam stage, students with high capacity were most likely to be exempt and least likely to fail. Low capacity students were least likely to be exempt and most likely to fail. The following table shows this.

<u>Table shows the percentages of exemption, pass, and failure for each sub-group's capacity - 1st year biology students - over two-year period</u>

Group	Exemption		Pass		Failure	
	1986-87	1987-88	1986-87	1987-88	1986-87	1987-88
X ⩽ 5	26%	31%	55%	50%	19%	18%
X = 6	35%	47%	53%	36%	12%	17%
X ⩾ 7	62%	40%	34%	50%	3%	10%

8 - In all cases, even with questions which were within their capacity, (Z ⩽ X), student performance was not perfect (100%).

9 - When some students in each sub group survive to solve the questions which have demands greater than their X-space capacities, we conclude that they are using strategies.

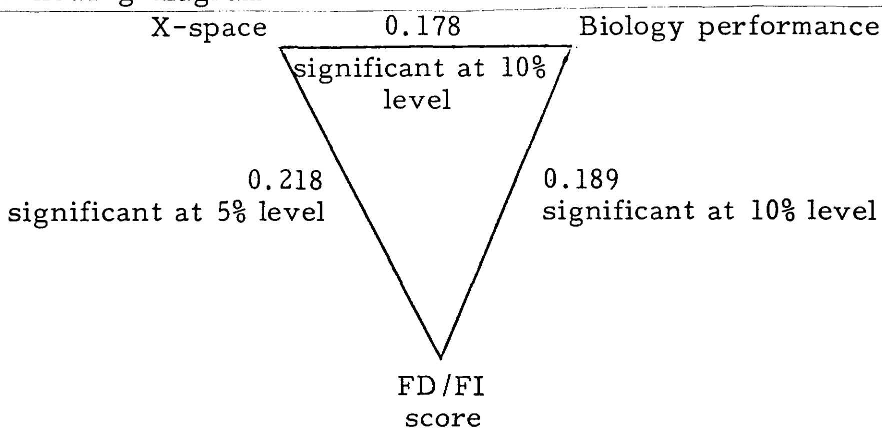

FREQUENCY
100
90
80
70
60
50
40
30
20
0
1
2
3
4
5
6
7
8
Z-DEMAND
7
6
5

The second part of the study was involved with other factors affecting students' performance, such as cognitive style (FD/FI).

Students were divided into three groups: those who were largely Field Dependent, those who were Field Independent, and a Field Intermediate group.

After relating, on the one hand, X-space capacity to the degree of Field Dependence Independence, and on the other hand, the extent of biology performance to Field Dependence/Independence, the following patterns were noted.

1. There is direct relationship between students FD/FI scores and their biology performance.
2. There is a direct relationship between students' FD/FI scores and their measured X-space. These relationships are summarised in the following diagram



3 - Most people with high capacity are Field Independent.

4 - Most people of low capacity are Field Dependent.

5 - In most cases, Field Independent students out-perform Field Dependent students.

6 - The sub-group having the best performance is the <u>high capacity</u>

Field Independent group.

7 - Exceptional case. The performance of students of low capacity who are Field Dependent is better than the performance of students of low capacity who are Field Independent.

8 - The mean score of all sub groups decreases as the demand of the items increases.

9 - In general, students' working memory space and their cognitive style are related to their success.

7.2 Implications

The main idea arising from the 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 below the capacity of the learner, at least to begin with.

The experimental results obtained in this study revealed a degree of consistency in the predictive power of the working model. These results lead us to suggest that care must be taken to allow for the learner's limitations of working memory space and Field Dependency. It seems unlikely that anything can be done to extend the absolute capacity of students' X-space or to alter their degree of Field Dependence. 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. Also, the sequence of the course may have to be rearranged to help students to be able to "chunk" the information into processable size. Organised knowledge has to be provided for the students. The information should be presented in small portions, and a summary of the lesson or course should be provided to help students grasp this meaningful information in smaller and meaningful "chunks", or students should be taught strategies which could enable them to use their limitations as efficiently as possible. This will involve the teacher in understanding these limitations and teaching in such a way as to provide students with the means for meaningful learning. What students learn is the new material for making their own chunking devices.

To allow for his Field Dependent students, a teacher should reduce extraneous, irrelevant information "noise" and highlight the "signal". He must also help students to recognise "signal" from "noise" when it occurs.

Opportunities should be given to the students to practice the organisation of their thinking before doing calculations. In this way the load is broken into a planning stage and a doing stage.

In some cases, according to the nature of the material to be learned, the information content may, if necessary, be high. However, the information could be presented in the form of diagrams, graphs, charts, pictures through microscope or concept maps, which could then function as "chunking devices".

It is anticipated, taking into account the psychological limitations explored in this work, that sympathetic teaching would greatly improve the teaching of biology.

7.3 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 briefly in questions as follows:

1 - Is there any relationship between students' X-space and their ability to converge or diverge in their thinking?

2 - Is there any relationship between the students' X-space and their ability to solve numerical questions of different Z-demand in biology?

3 - Does FD affect students' performance with low capacity when the question is open-ended, as opposed to fixed response demand?

4 - When the question demand is less than the student's capacity, why does the student not attain perfect performance?

5 - Why are the $X \geqslant 7$ students generally better in each question than the $X = 6$ students, and both give a better all-over performance than $X \leqslant 5$?

6 - Why do Field Dependent students with low X-space perform better in biology than Field Independent students with low X-space in fixed response questions?

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 biology?

8 - To what extent does information given and the arrangement of the data in the question affect the question's demand?

9 - 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?

10 - How can we use the theory to give direction to the improvement of all forms of teaching and learning?

References

1. R.M. Gagné, The Conditions of Learning, (2nd ed.), New York: Holt, Rinehart and Winston, 1970, pp.20-30.
2. J. Stewart, F. Finley and W. Yarroch, "Science Content as an Important Consideration in Science Education Research", J. Research in Science Teaching, 1982, 19, 425-432.
3. R.M. Gagné, The Conditions of Learning and Theory of Instruction, (4th ed.), London: Holt, Rinehart and Winston, 1985, pp. 2,3,47.
4. R.M. Gagné, The Conditions of Learning, (3rd ed.), London, Holt, Rinehart and Winston, 1977, pp. 3, 47.
5. J. Stewart, "Cognitive Science and Science Education", European J. of Science Education, 1985, 7(1), 1.
6. A. Newell and H.A. Simon, Human Problem Solving, New Jersey: Prentice-Hall, Inc., 1972.
7. S. Toulmin, The Philosophy of Science: An Introduction, New York: Harper and Row, 1953.
8. S. Toulmin, Foresight and Understanding on an Enquiry into the Aim of Science, New York: Harper and Row, 1961.
9. N.R. Hanson, Patterns of Discovery, Cambridge: Cambridge University Press, 1958.
10. T. Kuhn, The Structure of Scientific Revolution, Chicago: University of Chicago Press, 1962.
11. N. Chomsky, "Review of B.F. Skinner's Verbal Behaviour", Language, 1959, 35, 26-58.
12. P.N. Johnson-Laird and P.C. Wason (Eds.), Thinking, Readings in Cognitive Science, Cambridge: Cambridge University Press, 1985, pp.1-5.

13. R.C. Anderson, R.J. Spiro and W.E. Montage (eds), Schooling and the Acquisition of Knowledge, L. Erlbaum Association, Hillsdale, N.J., 1977.

14. D. Shallert, The Significance of Knowledge: A Synthesis of Research Related to Schema Theory, in W. Otto and S. White (eds), "Reading Expository Material", New York Academic Press, 1982, p16.

15. E. Hunt, "On the Nature of Intelligence", Science, 1983, 219 141-146.

16. R. Sternberg, Information Processing and Analogical Researching: The Componential Analysis of Human Abilities. L. Erlbaum Association, Hillsdale, N.J., 1977.

17. B.F. Bell and R. Driver, "The Children's Learning in Science Project", Education in Science, 1984, 108, 19-20.

18. R. Driver, The Pupil as Scientist? Milton Keynes, The Open University Press, 1983, p.2-3.

19. P.F.W. Preece, "A Decade of Research Science Education, Science Education Notes". The School Science Review, 1988, 69(248), 583-585.

20. B.Y. Woodsworth, Piaget's Theory of Cognitive Development: An Introduction for Students of Psychology and Education, New York, Mount Holyok College, 1974, pp 3, 4, 7, 112, 118.

21. J. Piaget, Biology and Knowledge, Edinburgh, Edinburgh University Press, 1971, pp145-150.

22. J.D. Herron, "Role of Learning and Development, Critique of Novak's Comparison of Ausubel and Piaget", Science Education, 1978, 62(4), 595-598.

23. K. Lovell, Understanding of Scientific Concepts and Different Developmental Levels and a Technique for Investigating the Degree of Understanding Illustrated by Reference to Electrostatic and Gravitational Potential, in K. Frey and M. Lang (eds), Cognitive Processes and Science Instruction, Bern, Huber Verlag, 1973, pp286-302.

24. A. Floyd, Cognitive Development in the School Years, London, Croom Helm Ltd., 1979.

25. D.P. Ausubel, The Psychology of Meaning Verbal Learning, New York, Grune and Stratton, 1963.

26. D.P. Ausubel, Meaningful Reception Learning and the Acquisition of Concept, in H.J.K. Klousmic and C.W. Harris (eds), "Analysis of Concept Learning", New York, Academic Press, 1966, pp160-161.

27. D.P. Ausubel, A Cognitive Structure View of World and Concept Meaning, in "Readings in the Psychology of Cognition", R.C. Anderson and D.P. Ausubel (eds), New York, Holt, Rinehart and Winston, Inc., 1965, pp67-69.

28. J.D. Novak, "The Reception Learning Paradigm", J. Res. in Sci. Teaching, 1979, 16(6), 483.

29. D.P. Ausubel, J.D. Novak and H. Hanesian, Educational Psychology in a Cognitive View, (2nd ed.), New York, Holt, Rinehart and Winston, 1978.

30. D.P. Ausubel, R.G. Robinson, Schooling Learning - An Introduction to Educational Psychology, London, Holt, Rinehart and Winston, 1969, pp.57, 58, 100, 105, 111, 145, 167, 168, 541-543.

31. J.D. Novak, "An Alternative to Piagetian Psychology for Science and Mathematics Education". Studies in Science Education, 1978, 5(1), 1-30.

32. R.M. Gagné, The Acquisition of Knowledge, in R.C. Anderson and D.P. Ausubel (eds), "Readings in the Psychology of Cognition", London, Holt, Rinehart and Winston, Inc., 1965, pp122-123.

33. R.M. Gagné, "Learning Hierarchies". Educational Psychologist, 1968, 6, 1-9.

34. R.M. Gagné, "Contributions of Learning to Human Development", Psychological Review, 1968, 75(3), 177-191.

35. R.M. Gagné and R.T. White, "Memory Structures and Learning Outcomes", Review of Educational Research, 1978, 48(2), 187-222.

36. J.H. Stewart and J.A. Atkin, "Information Processing Psychology: A Promising Paradigm for Research in Science Education". J. Nat. Assoc. for Res. in Sci. Teaching. John Wiley and Sons, Inc., 1982, 19(4), 321.

37. K.A. Strike and G.J. Posner, "Epistomological Perspectives on Conceptions of Curriculum Organisation and Learning", in L.S. Schulman (ed). Review of Research in Education, 1976, 1, 118-119.

38. G.A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information", Psychological Review, 1956, 63(2), 87-97.

39. A.D. Baddeley, "Working Memory and Reading, in P.A. Kolers, M.E. Wrolstadand H. Bouma (eds), Processing of Visible Language. New York, Plenum Corporation, 1979, pp355-370.

40. A.D. Baddeley, Working Memory, Oxford, Oxford Science Education, Clarendon Press, 1987.

41. R.C. Atkinson and R.M. Shiffrin, Human Memory: A Proposed System and its Control Processes, in K.W. Spence (ed), "The Psychology of Learning and Motivation: Advances in Research and Theory", Vol. 2, New York, Academic Press, 1968, pp89-195.

42. R.C. Atkinson, R.M. Shiffrin, "The Control of Short-Term Memory", Cognitive Psychology, 1971, 2, 290-299.

43. A.D. Baddeley, "The Cognitive Psychology of Everyday Life", British Journal of Psychology, 1981, 72, 257-269.

44. M.J.A. Howe, Introduction to Human Memory: A Psychological Approach, New York, Harper and Row, 1970.

45. A.D. Baddeley and G. J. Hitch, Working Memory, in G. Bower (ed), "Recent Advances in Learning and Motivation", Vol. VIII, New York, Academic Press, 1974, pp47-90.

46. R.C. Atkinson, "The Control of Short-Term Memory", Scientific American, 1971, 225, 82-90.

47. J.S. Bruner, "Toward a Theory of Instruction", Cambridge, Mass., Harvard University Press, 1966.

48. H.A. Simon, "How Big is a Chunk?", Science, 1974, 183, 482-487.

49. S. Chandran, F.D. Treagust, and K. Tobin, "The Role of Cognitive Factors in Chemistry Achievement", Journal of Research in Science Teaching, 1987, 24(2), 146.

50. A. Sanford, "The Mind of Man: Models of Human Understanding", Brighton, Harvester Press, 1987.

51. D. Child, "Psychology and Teacher" 4th Edition, London, Casell Educational Ltd., 1986.

52. A.H. Johnstone and N.C. Kellett, "Learning Difficulties in School Science: Towards a Working Hypothesis", European Journal of Science Education, 1980, 2, 175-178.

53. A.J. Sanford, "Cognition and Cognitive Psychology", London, Weidenfeld Nicolson, 1985, pp.104-105.

54. J. Green (ed), "Memory, Thinking and Language in Cognitive Psychology", London, Methuen and Co. Ltd., 1987, pp2,3,4.

55. R.T. White, "Learning Science", Oxford, Basil Blackwell Ltd., 1988.

56. M. Scardamalia, "Information Processing Capacity and the Problem of Horizontal Décalage - A Demonstration using Combinational Reasoning Task", Child Development, 1977, 48, 28-37.

57. J. Pascual-Leone, "A Mathematical Model for the Transition Rule in Piaget's Developmental Stages", Acta Psychologica, 1970, 32, 301-330, 333-336, 340-345.

58. J. Pascual-Leone, "Piaget's Period of Concrete Operations and Witkin's Field Dependence: A Study on College Students and Children", paper read at C.P.A., Montreal, University of British Columbia mimeo 1966.

59. A.H. Johnstone and H. El-Banna, "Capacities, Demands and Processes - A Predictive Model for Science Education", Education in Chemistry, 1986, 63, 80-84.

60. C. Bereiter and M. Scardamatia, "Pascual-Leone's M-construct as a Link Between Cognitive-Developmental and Psychometric Concepts of Intelligence", Journal Intelligence, 1971, 3, 41-63.

61. A.H. Johnstone and A.J.B. Wham, "The Demands of Practical Work", Education in Chemistry, 1982, 19(3), 71-73.

62. R.S. Woodworth, "Experimental Psychology", London, Methuen and Co. Ltd., 1951, pp.695, 698.

63. G.M. Johnson, "The Development of Metaphor Comprehension, I.K. Mental Demand Measurement and to Process Analytical Models". Doctoral dissertation, York University, Canada, 1982.

64. H. El-Banna, "The Development of a Predictive Theory of Science Education Based upon Information Processing Theory", Ph.D. Thesis, 1987, Glasgow University.

65. B.S. Bloom (ed), Taxtonomy of Educational Objectives: Classification of Education Goals. Handbook I, Cognitive Domain, New York, McKay 1956.

66. J. Greene and M. D'Oliveira, "Learning to use Statistical Tests in Psychology", Milton Keynes, Open University Press, 1987.

67. N.C. Kellett, "Studies on the Perception of Organic Chemical Structures", Ph.D. Thesis, University of Glasgow, 1978.

68. D.P. Ausubel and D. Fitzgerald, "The Role of Discriminability in Meaningful Verbal Learning and Retention", J. of Educational Psychology, 1961, 52, 266-274.

69. H.A. Witkin, "Cognitive Style in Personal and Cultural Adaptation", Clark University Press, 1978, pp 22, 24, 27.

70. D.R. Goodenough and S.A. Karp, "Field Dependence and Intellectual Functioning", Journal of Abnormal and Social Psychology, 1961, 63(2), 241-246.

71. C.I. Saarni, "Piagetian Operations and Field Independence as Factors in Children's Problem Solving Performance", Child Development, 1973, 44, 338-345.

72. H.A. Witkin, C.A. Moore, D.R. Goodenough, P.W. Cox, "Field Dependent and Field Independent Cognitive Styles and their Educational Implications", Review of Education Research", 1977, 47, 1-64.

73. A.K. Kiewra and B.M. Frank, "Encoding and External Storage Effects of Personal Lecture Notes and Detailed Notes for Field Independent and Field Dependent Learners", Journal of Educational Research, 1988, 81(3), 143-147.

74. J. Pascual-Leone and J. Smith, "The encoding and decoding of symbols by children: A new experimental paradigm and a new Piagetian Model. Journal of Experimental Child Psychology, 1969, 8, pp328-355.

75. S.A. Karp and N.L. Konstadt, "Manual for Children's Embedded Figures Test", New Jersey. Cognitive Tests, P.O. Box 4, Vanderveer Station, Brooklyn, 1963.

76. R.F. Kempa, "Learning Theories and the Teaching of Implications for Science Teacher Training", in P. Tamir et al. (eds)"Preservice and Inservice Training of Science Teachers" Rohovot: International Science Service, 1983.

77. H.A. Witkin et al, "A Manual for Embedded Figures Tests". California Consulting Psychologists' Press, 1971.

78. H.A. Witkin, R.B. Dyk, H.A. Faterson, D.R. Goodenough and A. Karp, Psychological Differentiation, New York, Wiley, 1962.

79. R. Case, "Validation of a Neo-Piagetian Capacity Construct", Experimental Child Psychology, 1972, 14, 287-302.

80. R. Case, "Structures and Strictures: Some Functional Limitations on the Course of Cognitive Growth", Cognitive Psychology, 1974, 6, 544-573(b).

81. R. Case and J. Globerson, "Field Independence and Central Computing Space", Journal of Child Development, 1974, 45, 772-778.

82. M. Niaz, "Relation between M-space of Students and M-demand. Different Items of general Chemistry and its Interpretation Based upon the Neo-Piagetian Theory of Pascual-Leone", Journal of Chemical Education, 1987, 64(6), 504.

83. M. Niaz, "The Information-processing Demand of Chemistry Problems and its Relation to Pascual-Leone", International Journal of Science Education, 1988, 10(2), 231-238.

APPENDIX 1(A)

Digits Backward

Instructions for the Administration of the Digit Span Backwards (DIB) Test

We are trying to improve the quality of our teaching and your learning by trying to understand better how people handle information.

We would like you to undergo a simple psychological test to help us in our understanding. In no way will the results of this test be held against you but we would like to have your name and, if possible, your matriculation number.

The idea is to give you a set of pairs of tasks to do. Each successive pair will be harder than those before and eventually your "brain will hurt". We would like to know at what level you can operate before it does hurt. Try as hard as you can to succeed.

As an easy warm up, we are going to give you two pairs of preliminary tasks.

On the tape recording you will be asked to commit a set of numbers to memory and, when the speaker stops, write down the numbers from left to right in the boxes provided. For example, if I say, 917, you would write down 719. Now, no cheating. Do not write from right to left. In the first two tasks there will be four numbers and in the second pair there will be five numbers. Listen carefully, turn the number over in your mind and write and write down. Are you ready? Then Let's begin.

<u>Series</u>

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

Thank you very much for your co-operation.

NAME ______________________________ Male/Female

MATRIC NO. | | | | | | |

DIGIT SPAN TEST

PRACTICE ITEMS

4					
5					

TEST ITEMS

2								
3								
4								
5								
6								
7								
8								

APPENDIX 1(B)

NAME ______________________________ Male/Female ________

MATRIC NO. | | | | | | |

DIGIT SPAN TEST

Scoring Key

PRACTICE ITEMS

4					
5					

TEST ITEMS

2	4	2						
	8	5						
3	9	2	6					
	5	1	4					
4	9	7	2	3				
	8	6	9	4				
5	6	8	2	5	1			
	3	4	8	1	6			
6	8	1	4	9	3	5		
	6	5	8	4	2	7		
7	5	6	3	9	2	1	8	
	8	2	1	9	3	7	4	
8	8	5	2	6	7	3	4	9
	3	5	6	9	1	8	2	7

APPENDIX 2(A)

Letters Backward

Instruction for the Administration of the Letter Span Backwards (LIB) Test

We are trying to improve the quality of our teaching and your learning by trying to understand better, how people handle information. We would like you to undergo a simple psychological test to help us in our understanding. The result will not affect your University work in any way.

The idea is to show you a set of pairs of tasks to do. Each successive pair will be harder than those before, and eventually your "brain will hurt". We would like to know at what level you can operate before it does hurt. On the overhead projector you will be asked to commit a set of letters to memory and, when the exposure stops, write down the letters in reverse order from left to right in the boxes provided. No cheating, no writing during the exposure procedure. Have you got that? Let's begin.

Series

2 - B D

E H

3 - F B I

D A E

4 - C B G I

D I F H

5 - A E B H F

F A H D C

6 - E C I D A H

G B D N E F

7 - N A G I C F E

D G C I A B H

8 - I D C G F B E H

G B H A I F E C

Thank you very much for your cooperation.

NAME ______________________________ Male/Female

MATRIC NO. | | | | | | | Date of Birth | | | | | | |

LETTER SPAN TEST

TEST ITEMS

2								
3								
4								
5								
6								
7								
8								

APPENDIX 3(A)

FIGURAL INTERSECTION TEST

NAME: SEX:

DATE OF BIRTH:

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 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 left may differ in size or position from those on right, but, they match in shape and proportions.

(2) In some items on 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 to mislead you but try to ignore them.

(3) The overlap should be shaded clearly by using a pen.

APPENDIX 2(B)

NAME ________________________________ **Male/Female**

MATRIC NO. [| | | | |] **Date of Birth** [| | | | |]

LETTER SPAN TEST

Scoring Key

TEST ITEMS

2	D	B						
	H	E						
3	I	B	F					
	E	A	D					
4	I	G	B	C				
	H	F	I	D				
5	F	H	B	E	A			
	C	D	H	A	F			
6	H	A	D	I	C	E		
	F	E	N	D	B	G		
7	E	F	C	I	G	A	N	
	H	B	A	I	C	G	D	
8	H	E	B	F	G	C	D	I
	C	E	F	I	A	H	B	G

Notice

1. Show the students each serial separately.
2. Move the cover to reveal only one letter at a time.
3. Make sure you stick strictly to the time.
4. Make sure students do not write till series is complete.

(4) The results of this test will not affect your schoolwork in any way.

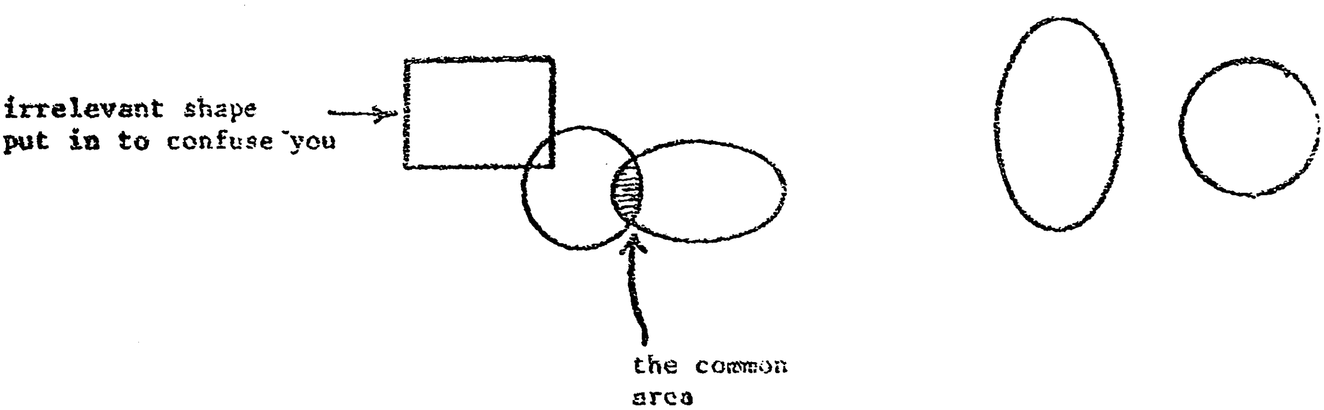
* This test may not be used without permission from:

Professor J. Pascual-Leone, Room 246 B.S.B., York University
4700 Keele Street, Downsview,
Ontario, M3J 1P3.

Here are some examples to get you started.

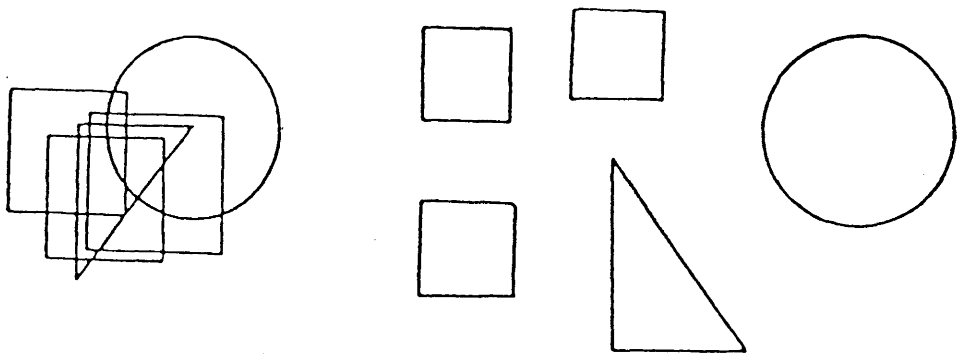
Example (1)

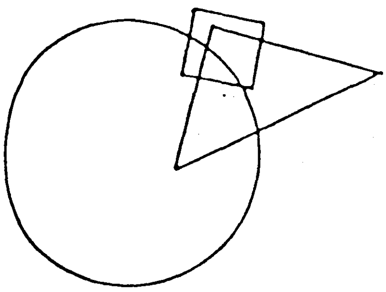
Example (2)

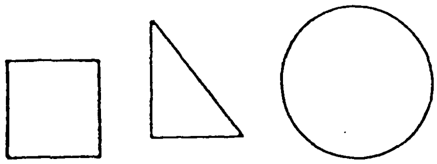


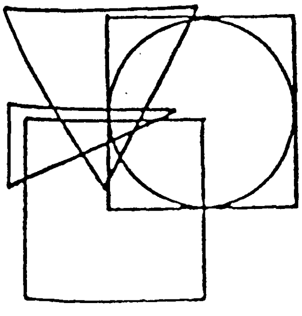
Example (3)

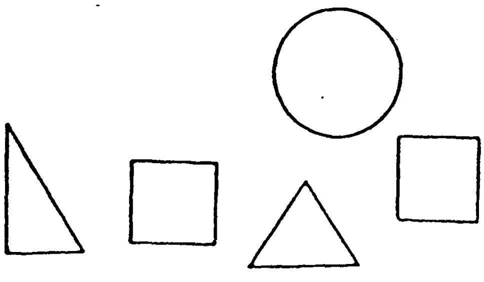
Now attempt each of the items on the following sheets:-

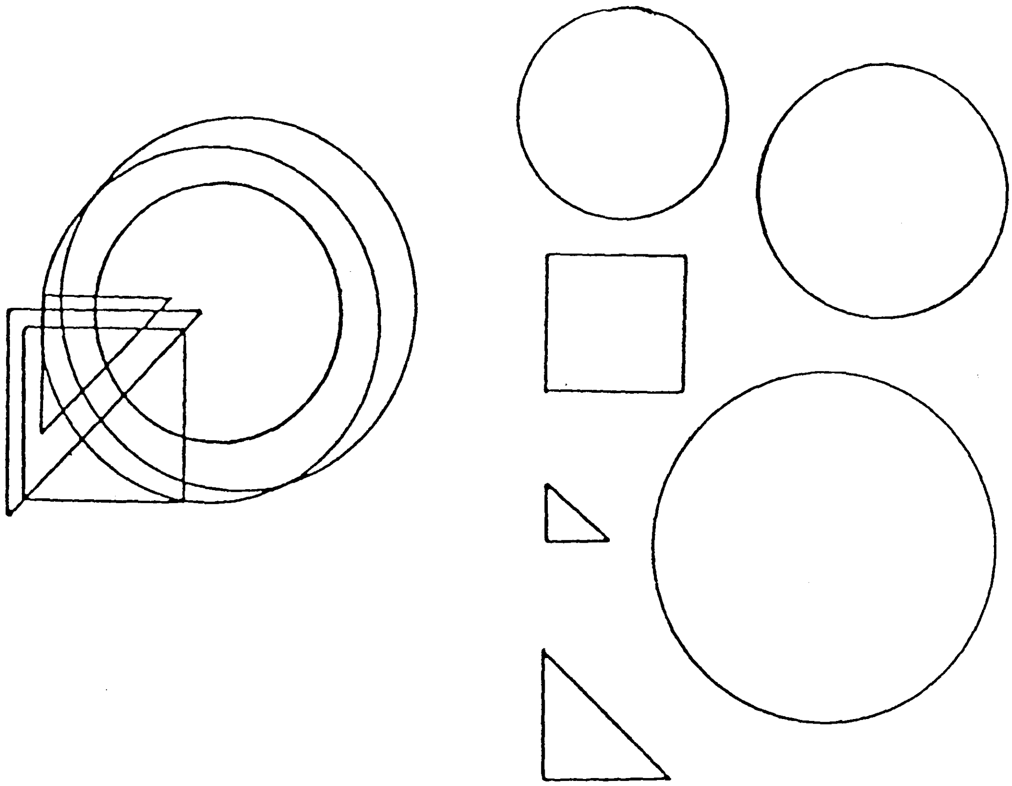


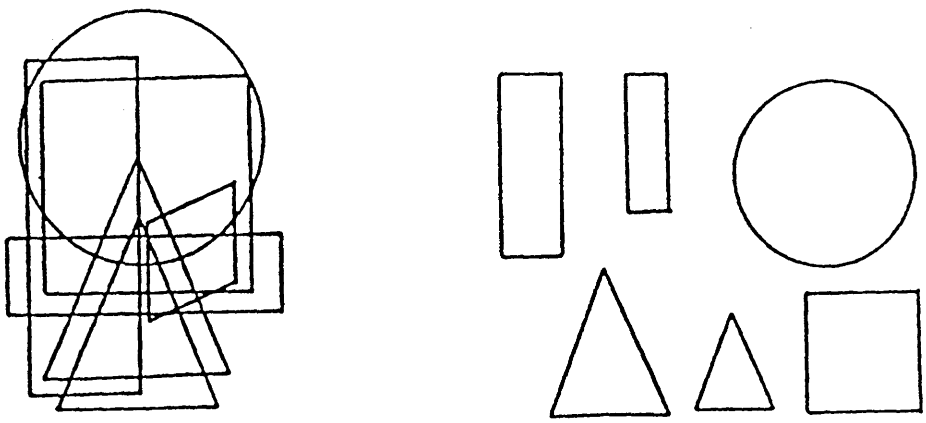


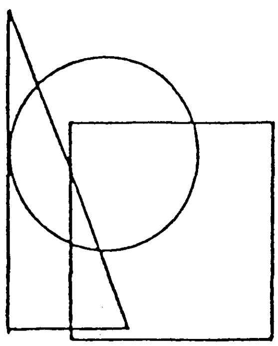


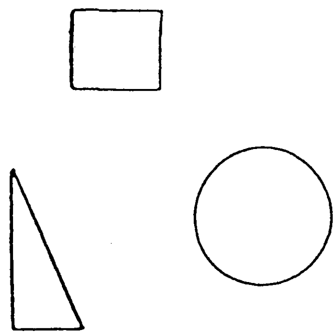


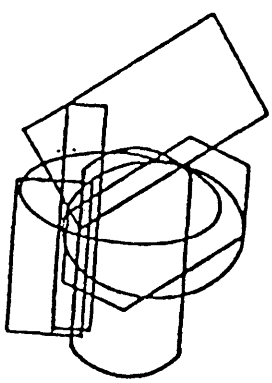


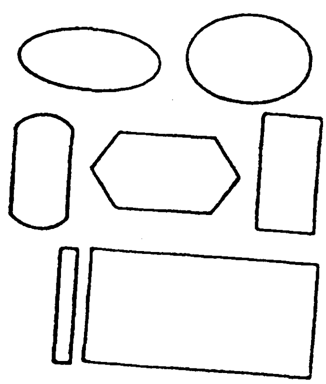


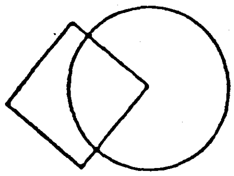


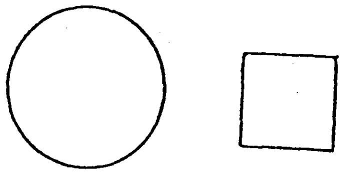


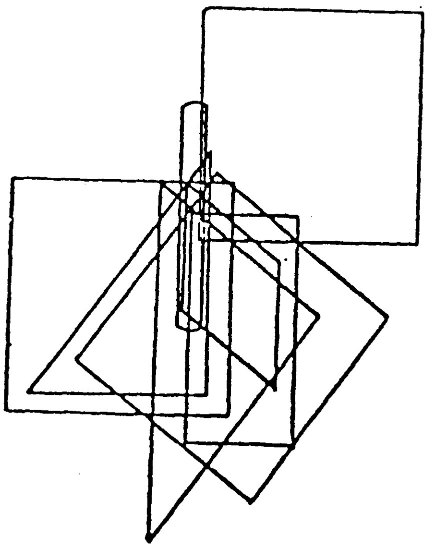


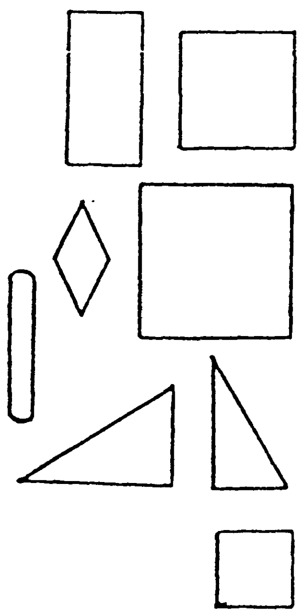


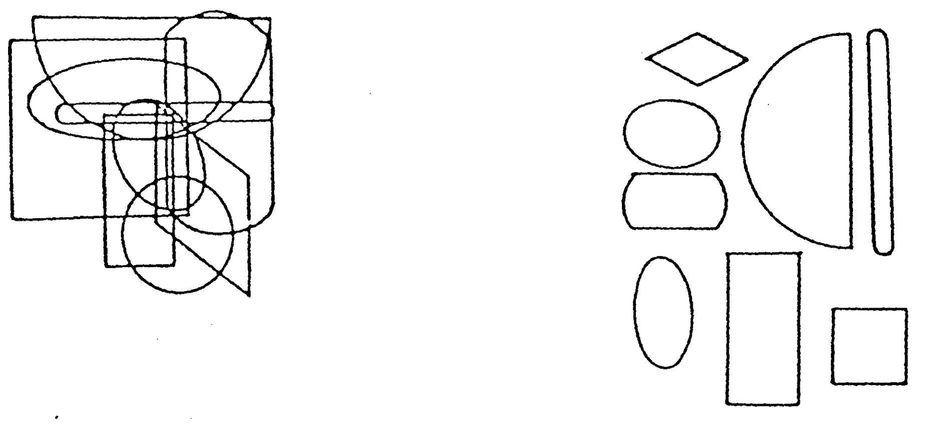


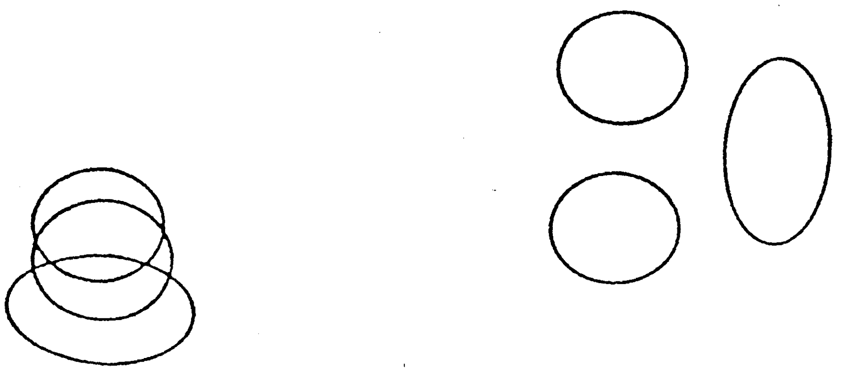


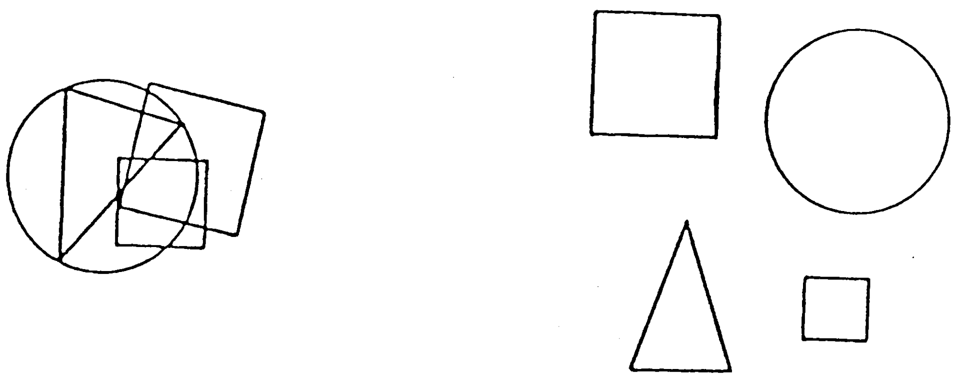


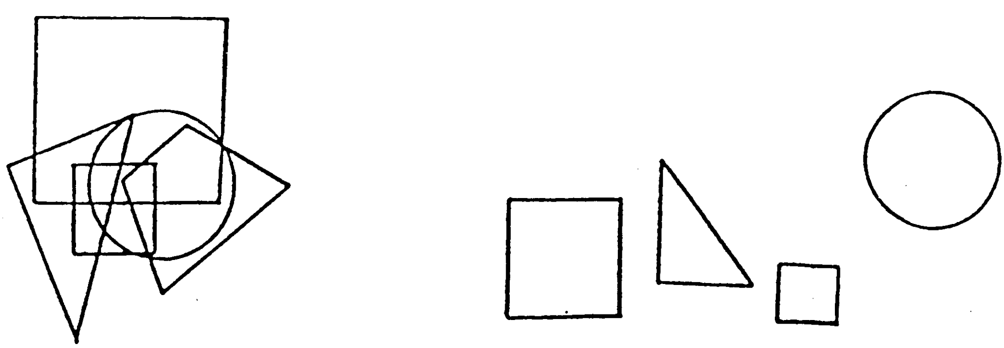


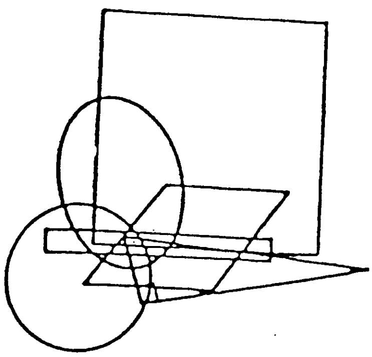


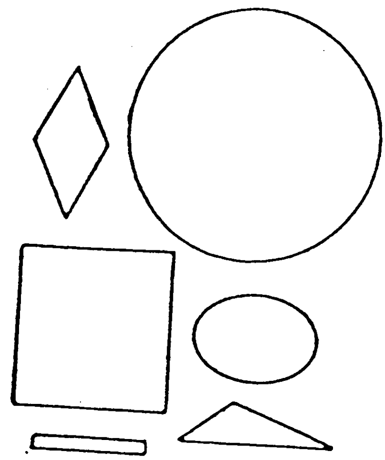


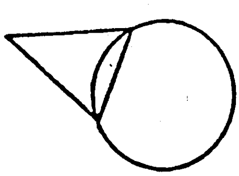


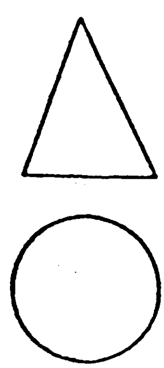


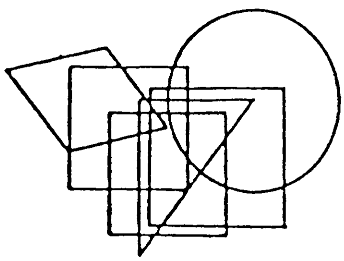


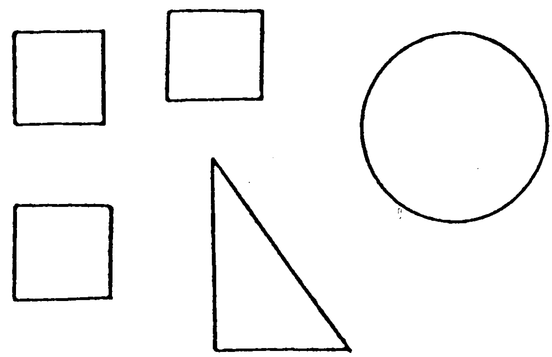


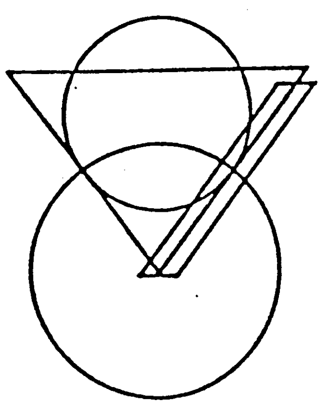


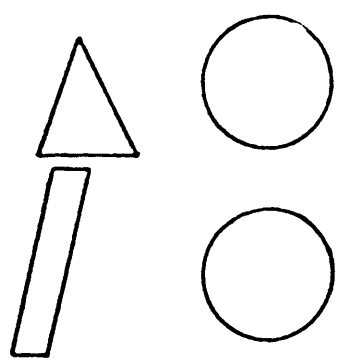


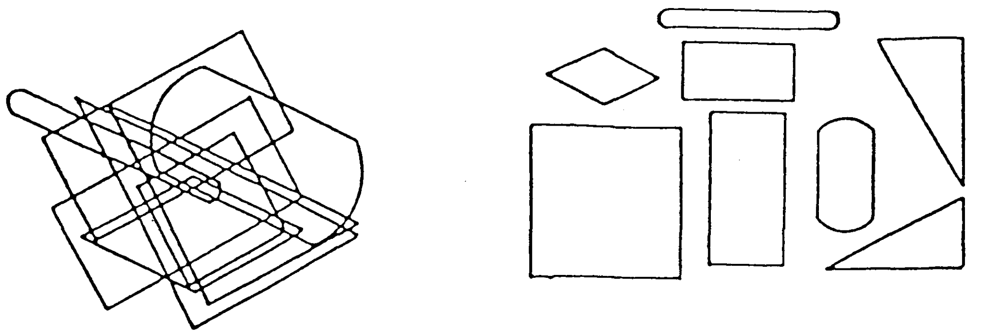


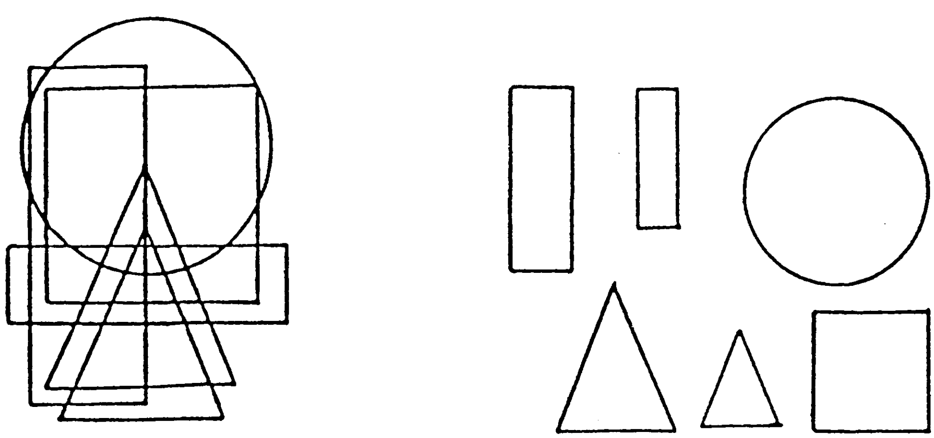


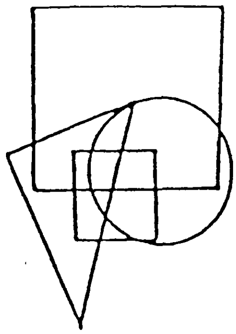


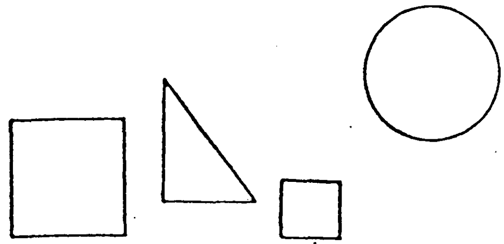


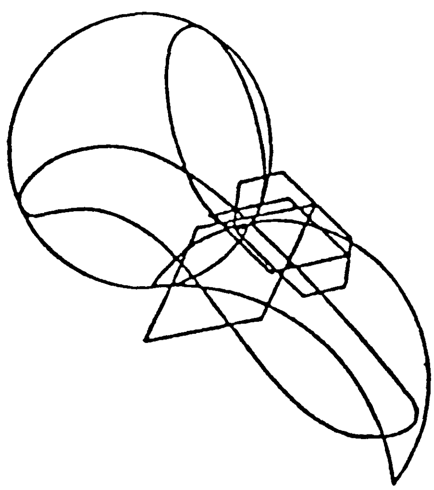


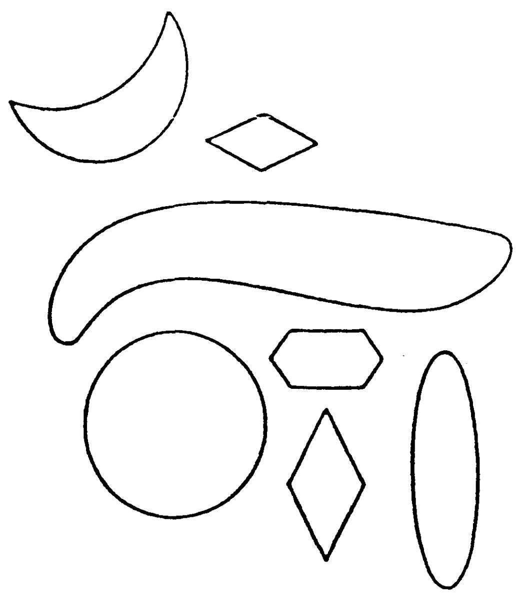


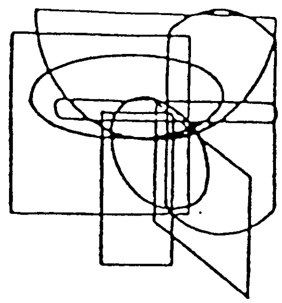


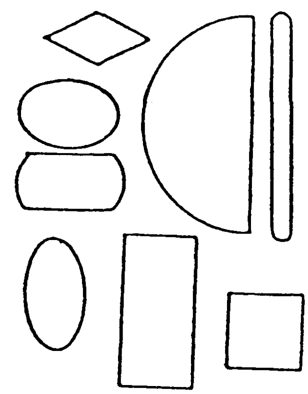


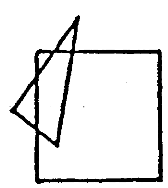


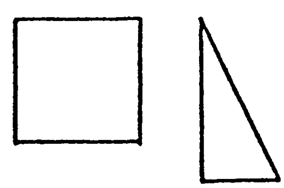


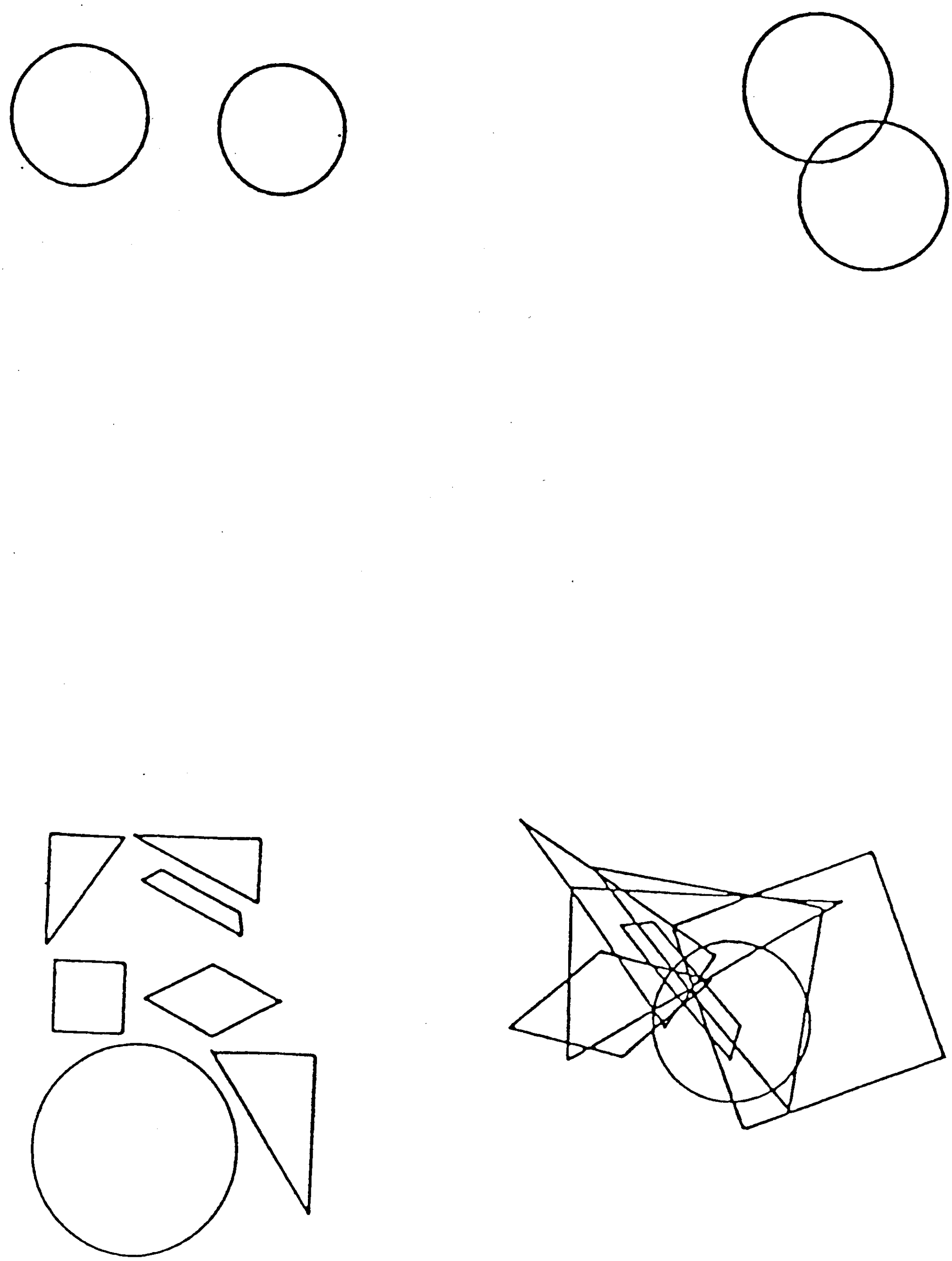


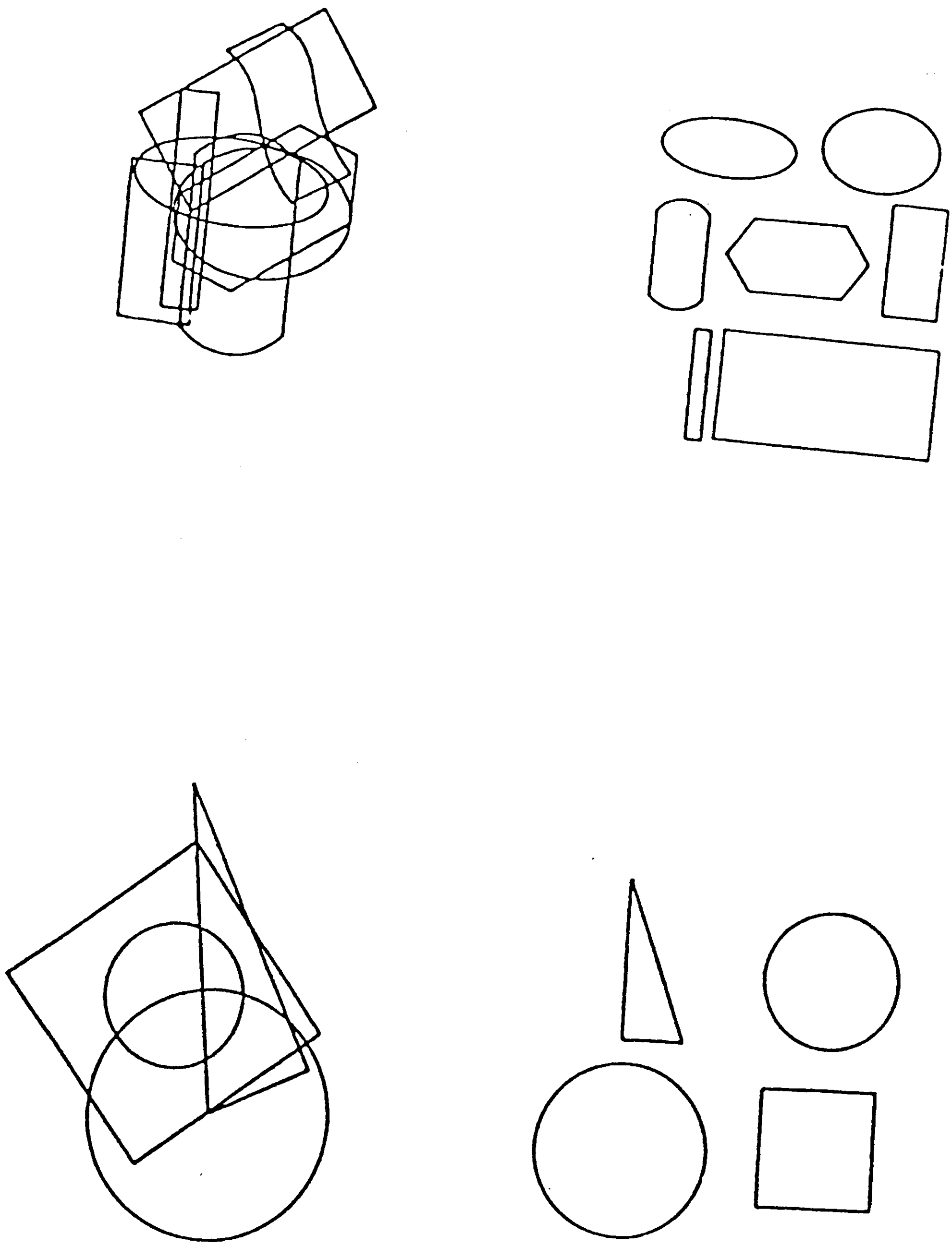


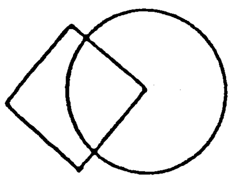


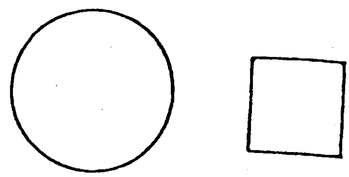


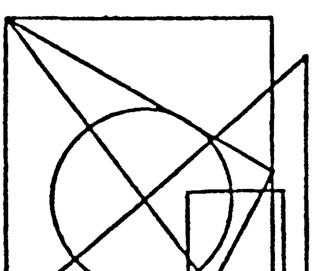


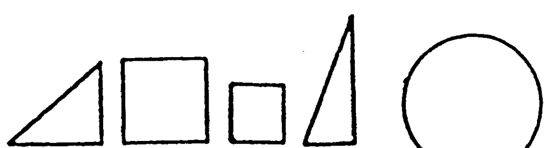


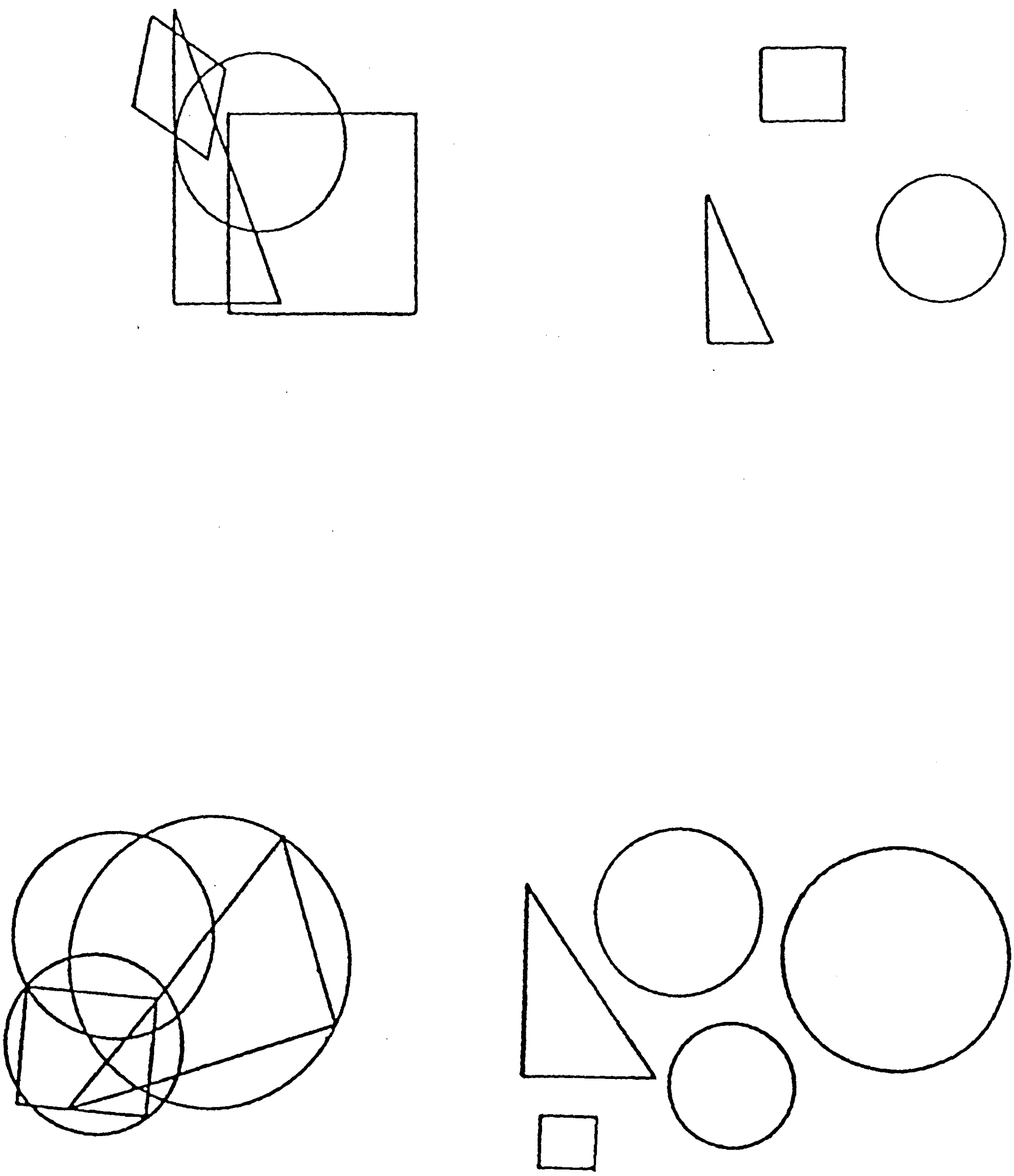


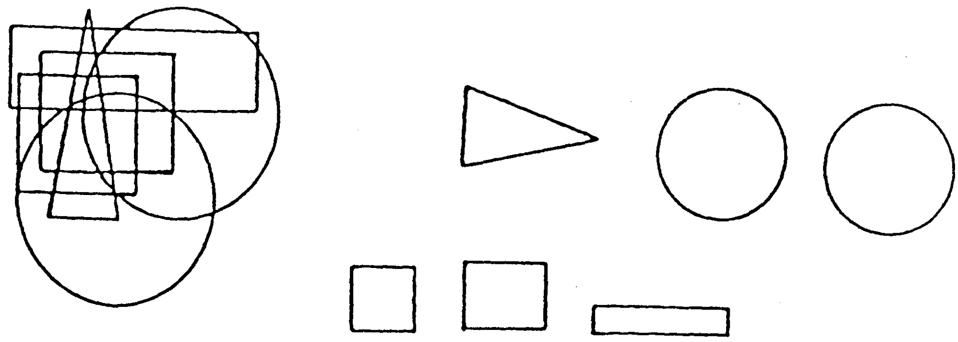


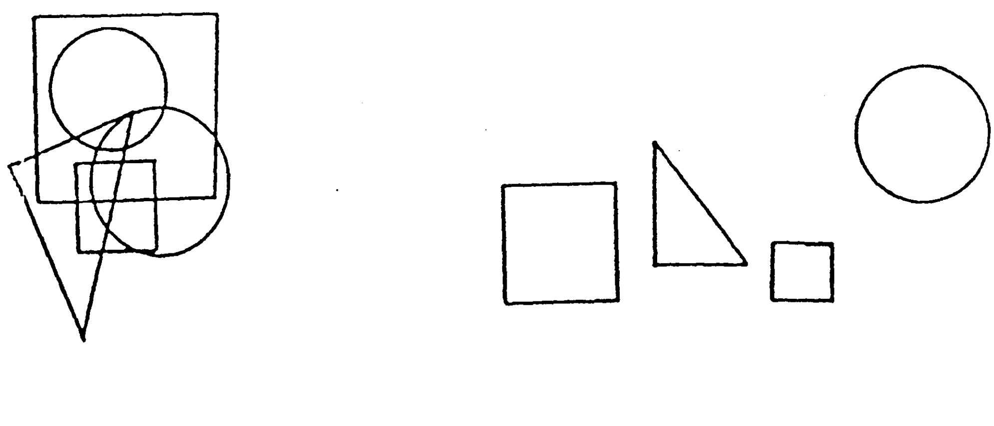


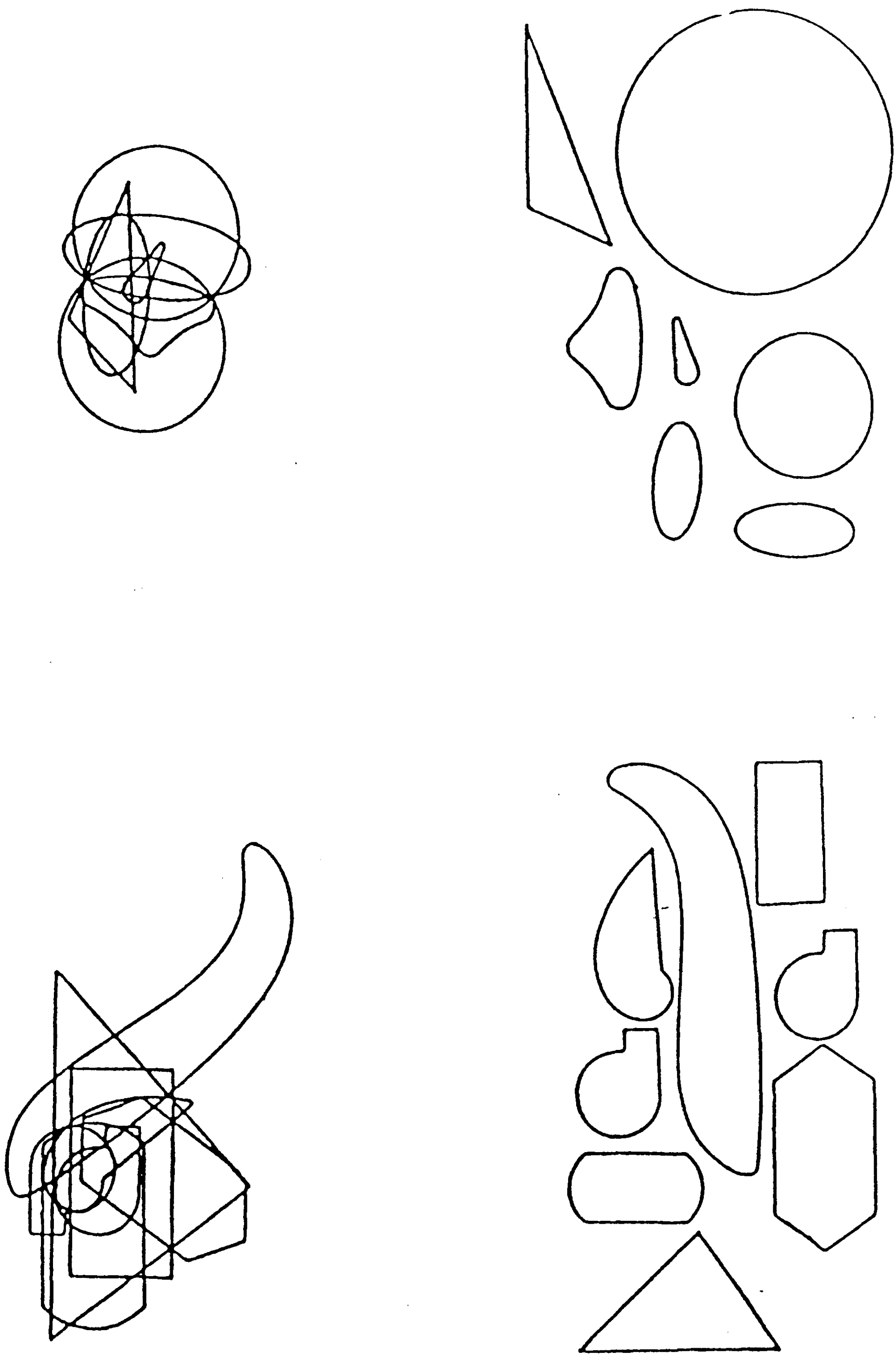






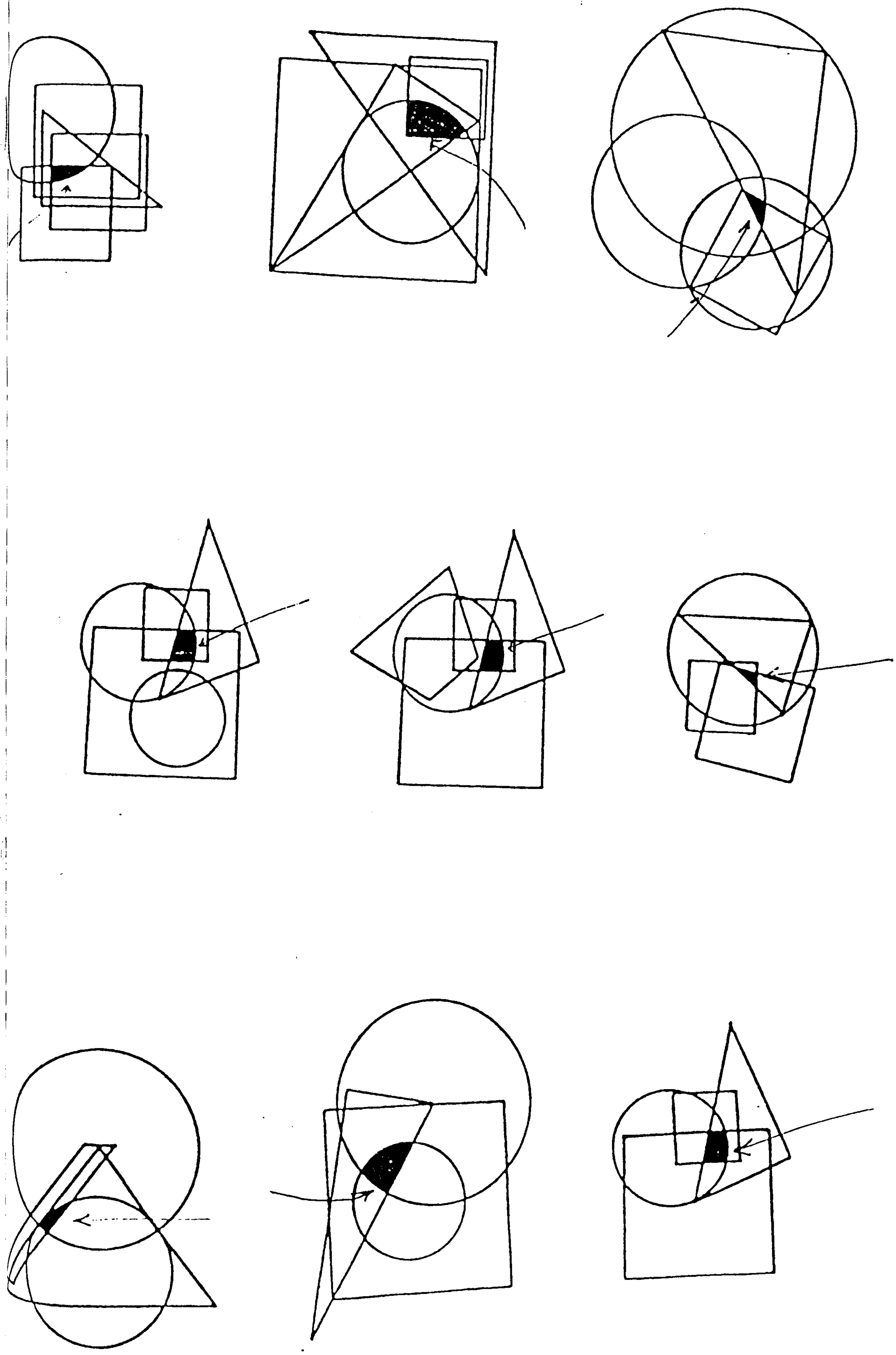


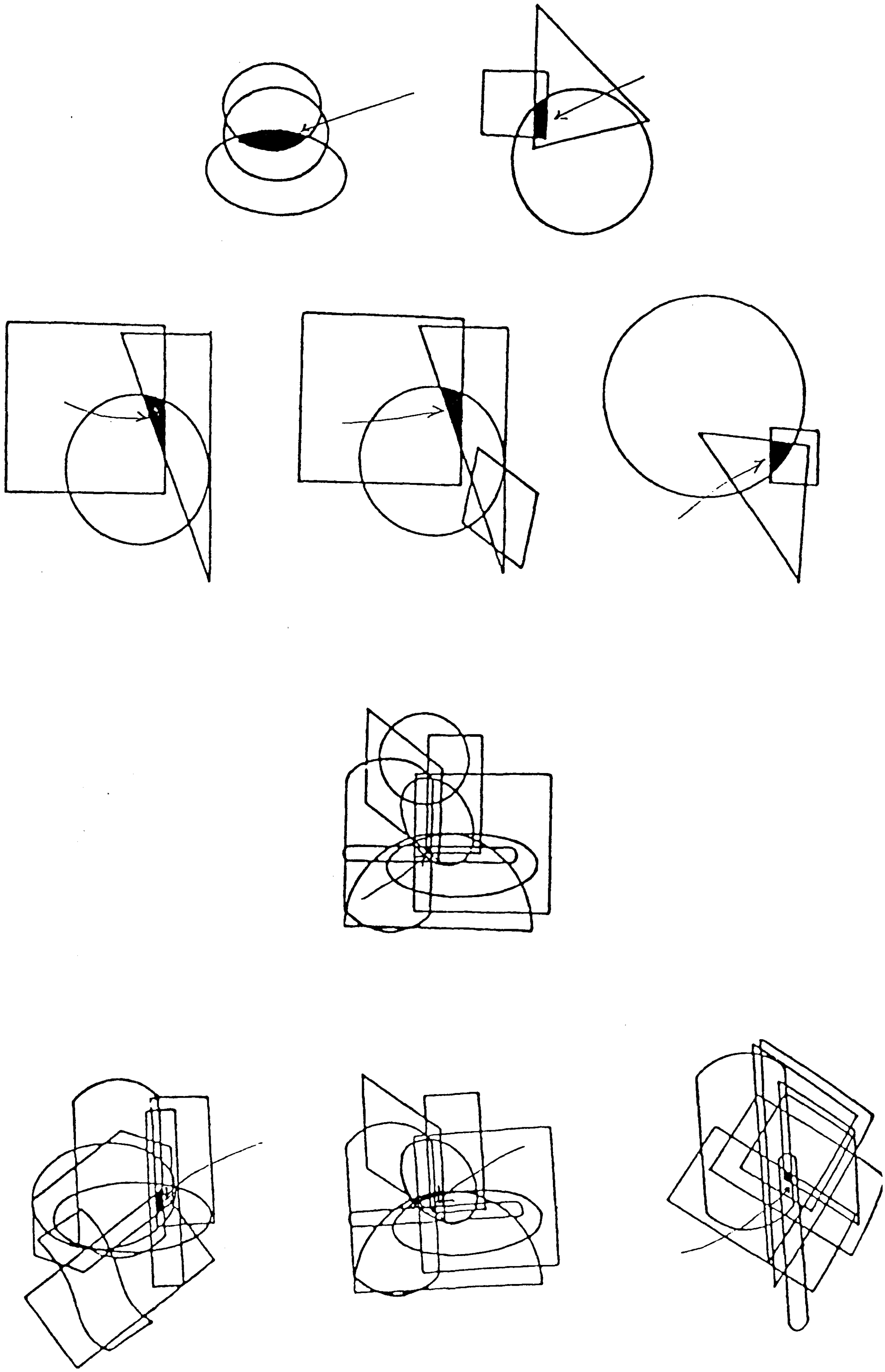


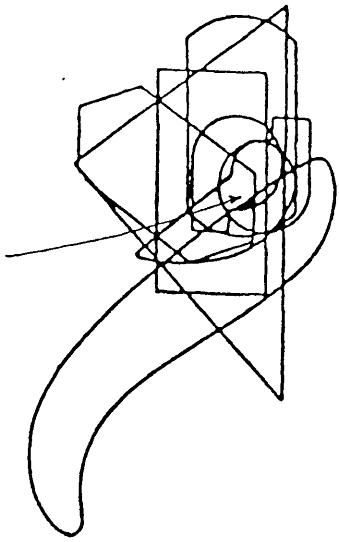


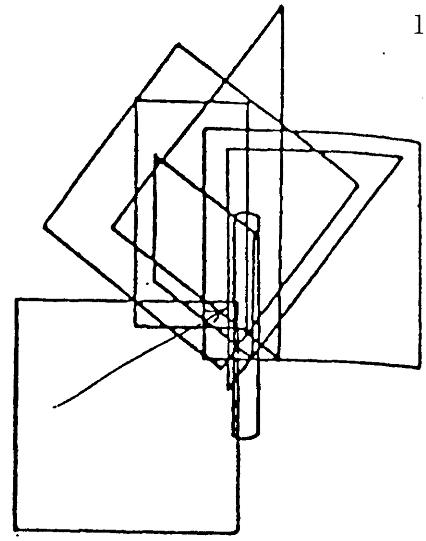
APPENDIX 3(B)

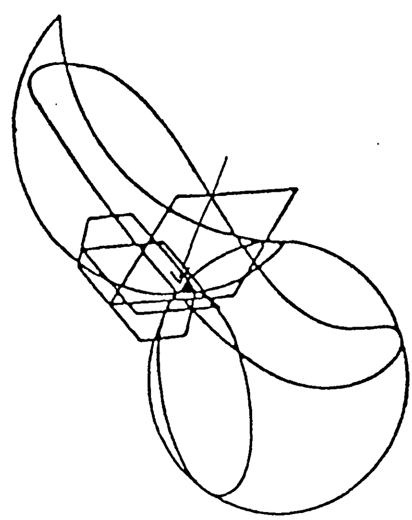
F.I.T. SCORING KEY

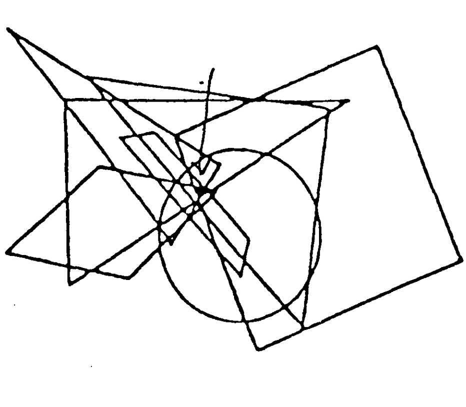


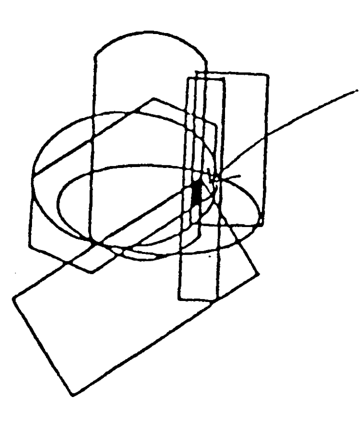


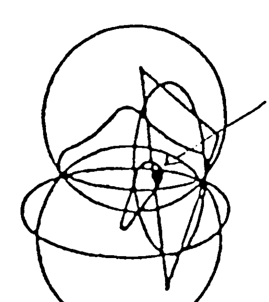


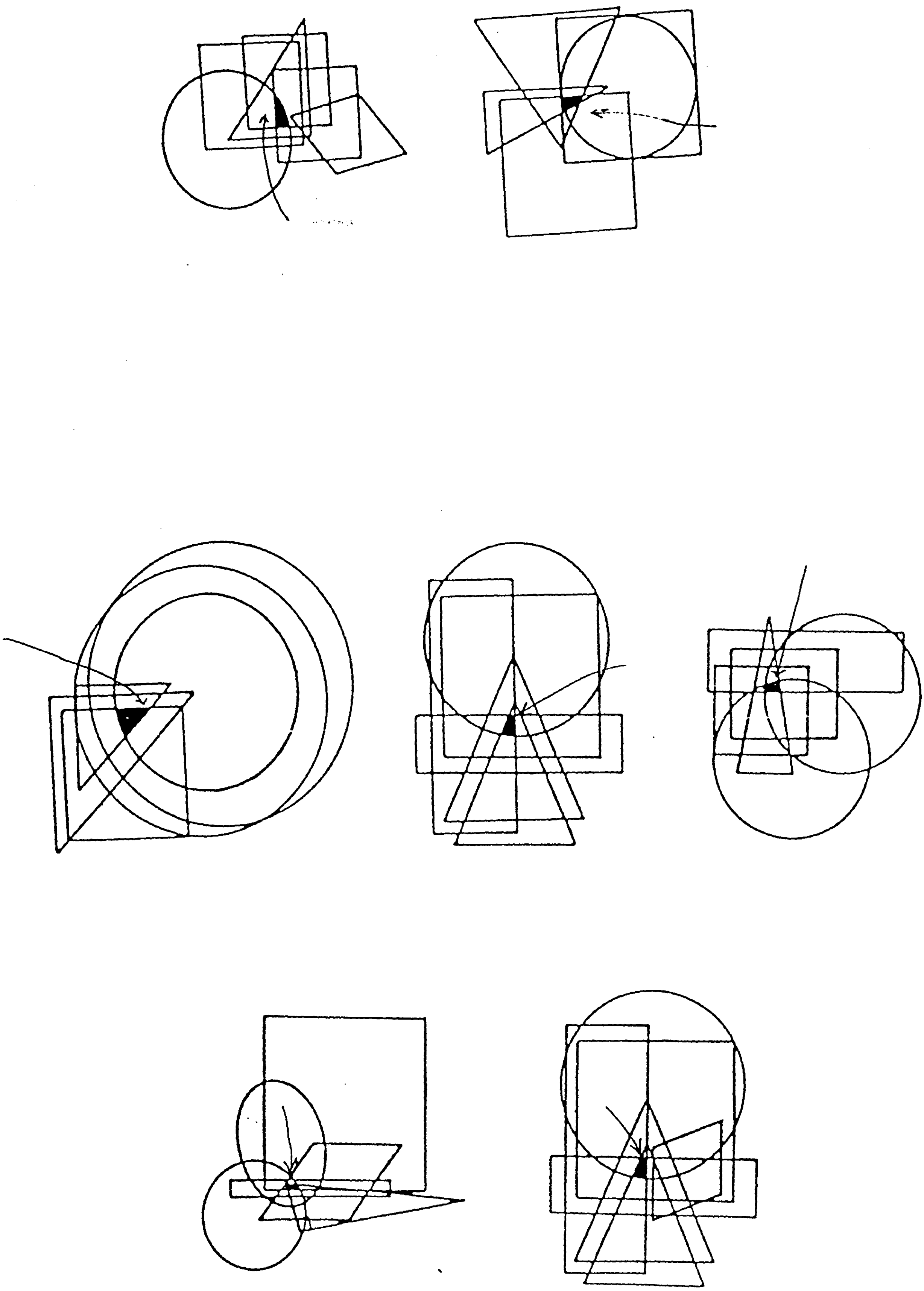












APPENDIX 4

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 (Garcia, Aragon, Owen, & Sachse, 1976; Parkinson, 1975; Skakich, 1978) that items with an irrelevant shape in the compound actually have an Md of x+1. Thus, 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 (Furman, 1981; Goodman, 1979b; Parkinson, 1975;

Pascual-Leone & Burtis, 1975; Skakich, 1978; Van Esch, 1978). 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% 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: $\underline{K}_{.75}$ and $\underline{K}_{.75}$.

The second kind of k score is the S1-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, she/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 C-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 (personal communication, 1982) suggests that the SIT score may be more reliable, because it is based on data from all

Table C-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	21-25	20-24
6	26-30	25-29
7	≥ 31	≥ 30

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.

APPENDIX 5

1 - In Duroc-Jersey pigs the coat colour is usually red. However, two different true-breeding sandy-coloured lines (A and B) are known. If sandy pigs from either of these lines are mated with the normal reds, the F_1 is red and the F_2's come out in a ratio of 3 red to 1 sandy.

i) If a sandy from line A is mated with a sandy from line B, the F_1 is all red. Make a hypothesis to cover this situation, using appropriate gene symbols and assigning plausible genotypes to the F_1 animals.

ii) If the F_1's in (i) care carried into an F_2 generation the proportion of colour types obtained is 9 red: 6 sandy: 1 white. Make a plausible interpretation of this situation. State whether this interpretation is consistent with your hypothesis for (i). If not, give a new, more appropriate, answer to (i).

(Thought steps=9) (8 marks)

2 - You are provided with centrifuge tubes, a centrifuge, physiological saline, Pasteur pipettes, microscope slides and a microscope. Separate blood samples are collected into heparan (an anticoagulant) from four donors who have different ABO blood groups. How could you identify the AB and O individuals and how far could you go in

determining the ABO blood group of the remaining two blood samples? (Thought steps = 9) (8 marks)

3 - In 1902, Bateson reported a study of a cross differing in two characters. White Leghorn chickens, having large "single" combs and white feathers, were crossed to Indian Game Fowl, with small "pea" combs and dark feathers. The F_1 was white with pea combs. A cross F_1 x F_1 produced the following:

F_2: 111 white pea, 37 white single, 34 dark pea, 8 dark single.

Provide a genetic hypothesis to explain these results and test your explanation statistically, using the chi-squared method. What phenotypes and proportions would you expect from crossing the F_1 to the dark-feathered single-combed F_2? (Thought steps=10)

Information: $X^2 = \Sigma \frac{(\text{observed} - \text{expected})^2}{\text{expected}}$

Probability

Degrees of Freedom	0.95	0.50	0.10	0.05	0.01	0.001
1	0.004	0.46	2.71	3.84	6.64	10.83
2	0.10	1.39	4.60	5.99	9.21	13.82
3	0.35	2.37	6.25	7.82	11.34	16.27

(12 marks)

4 - One of the areas hardest hit by radioactive fallout from the recent Chernobyl nuclear disaster was Lappland in northern Sweden. The vegetation in this part of the world, on which the reindeer and ultimately man depends, has a large component of lichens which are

notorious for accumulating metal ions from the environment. This property of lichens can be studied in the laboratory by a very simple method. A cork borer is used to cut uniform circular discs about 1 cm diameter from the flat thallus of a suitable lichen such as Peltigera polydactyla. These are then dyed by immersion in methylene blue, a cationic dye, which binds to anionic sites on the cell wall of the fungal component of the lichen. Groups of equal numbers of dyed disks are then added to 5 ml of a 10 mM solution of a metal chloride, such as NaCl. The Na+ ions displace some of the methylene blue from the lichen into the supernate whose optical density is read in a spectrophotometer. The greater the affinity of the lichen for the metal cation, the more methylene blue is released. In this way the relative affinities of different metal cations for the lichen can be compared.

In a class experiment the following results were obtained:

Metal chloride to which the disks of dyed lichen were exposed under standard conditions	Optical density of supernate at 540 nm	Atomic Weight (to nearest whole number)	Valency
aluminium	0.228	27	3
caesium (Cs)	0.105	133	1
calcium (Ca)	0.135	40	2
cobaltic (Co)	0.163	59	2
ferric (Fe)	0.239	56	3
lithium (Li)	0.075	7	1
magnesium (Mg)	0.127	24	2
potassium (K)	0.084	39	1
sodium (Na)	0.081	23	1
strontium (Sr)	0.155	88	2

a) Using the chemical symbols, arrange the elements in order of increasing binding affinity for the lichen, starting with the lowest, i.e. in a format:

$$X < Y < Z < \ldots\ldots$$

b) Comment briefly on the relationship between this order and the valency and atomic weight of the elements. (Thought steps = 7.)

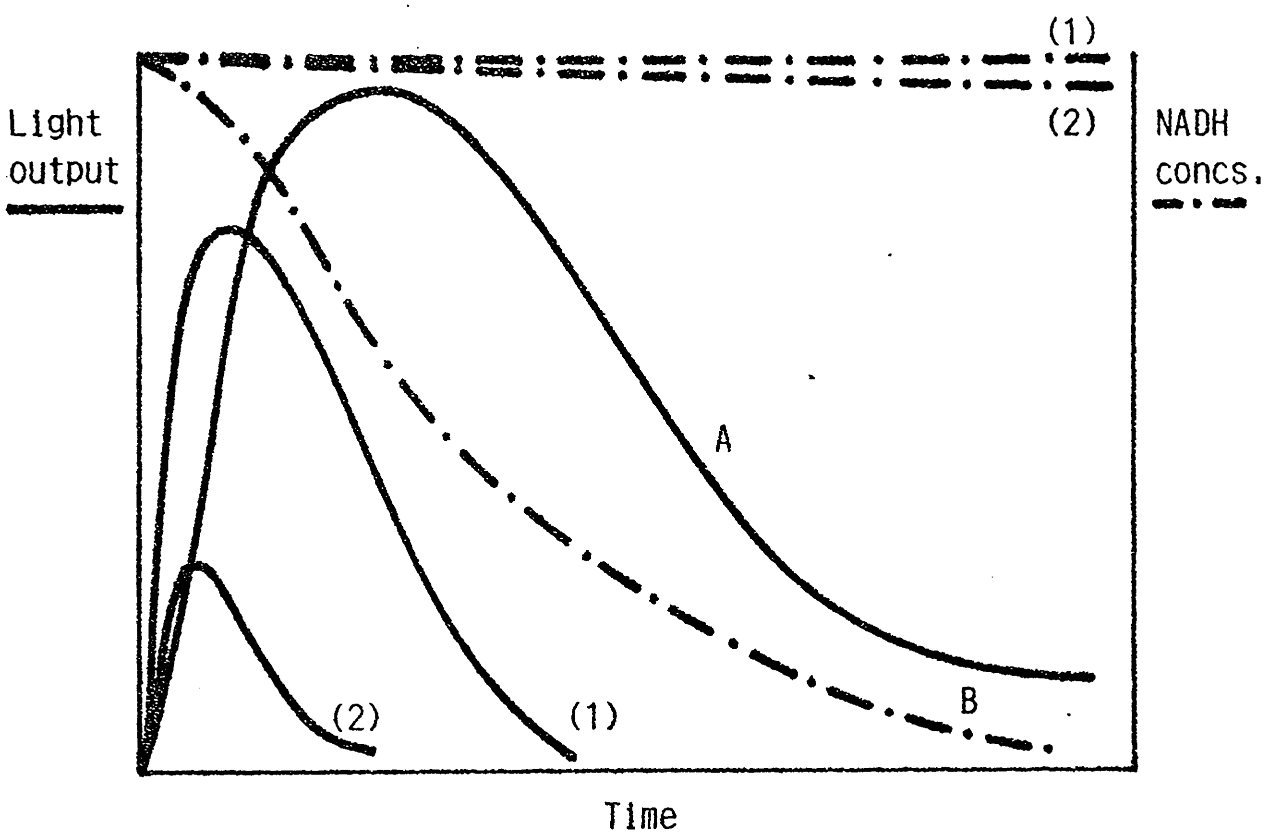
(5 marks)

5 - Oxidative phosphorylation may be detected as ATP production which in turn can be quantified as light output using the luciferin-luciferase system (firefly tails). An experiment is carried out in which liver mitochondria, pyruvate, NADH and oxygen are present. When placed in appropriate light-measuring apparatus the following curve of light output is obtained marked "A" in the figure below. Simultaneously the concentration of NADH is obtained by a second procedure; this is plotted as curve "B". The procedure is then repeated in the presence of two different concentrations of reagent "C" at concentrations 1 and 2 (labelled 1 and 2 on the graph). The concentration of "C" is higher in "2" than in "1". Light output and NADH curves were obtained as shown on the figure.

Explain what reagent "C" may be doing to the system.

(Thought steps = 6)

(6 marks)



(1)
(2)
Light output
NADH concs.
A
B
(2)
(1)
Time

APPENDIX 6 (A)

FIGURE HIDDEN TEST

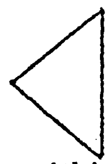
NAME : SEX :

CLASS: SCORE:

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 university work in any way.

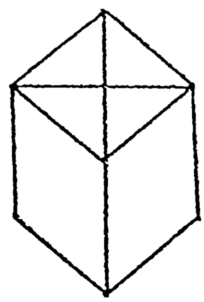
Example (1)

Here is a simple shape which we have labelled (X) :



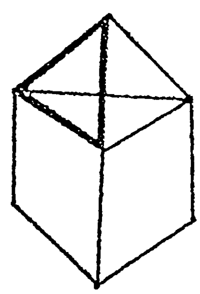
(X)

This simple shape is hidden within the more complex figure below:



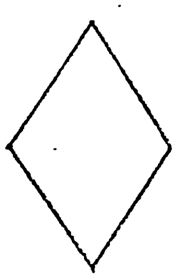
Try to find the simple shape in the complex figure and trace it in pen directly over the lines of the complex figure. It is the same size, in the same proportions, and faces in the same direction within the complex figure as when it appeared alone.

Here is the answer you should have obtained :

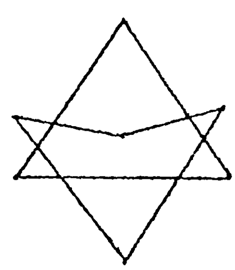


Example (2) :

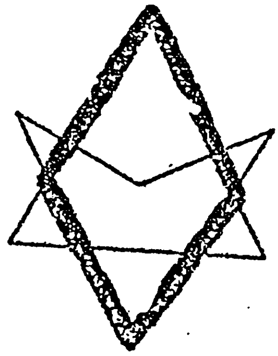
Find and trace the simple shape (Y) in the complex figure beside it.



(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.

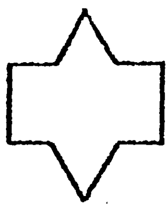
(3) Trace only one simple shape in each problem. You may see more than one, but just trace one of them.

(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.

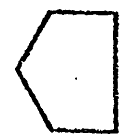
Now: Attempt each of the items on the following sheets:-

SIMPLE FORMS

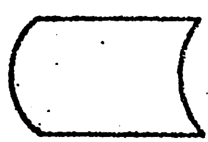


A

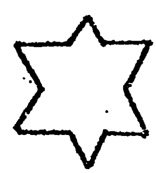
B



C



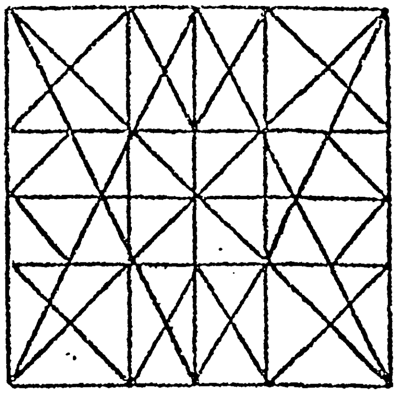
D



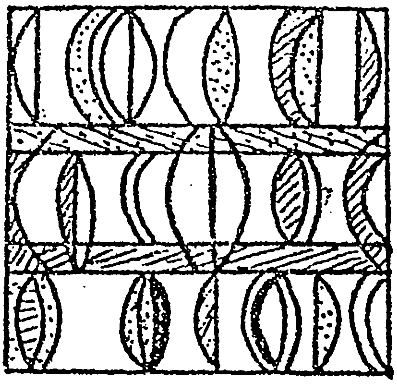
E

G

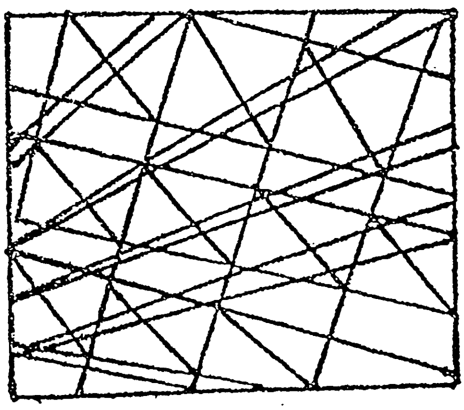
Find Simple Form "C"



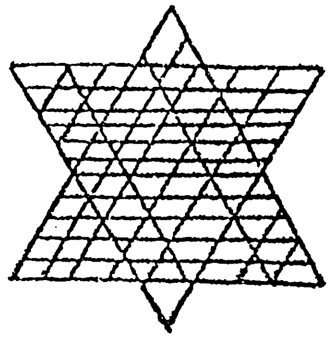
Find Simple Form "D"



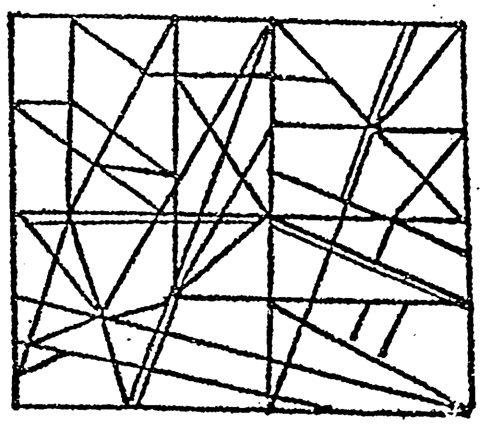
Find Simple Form "B"



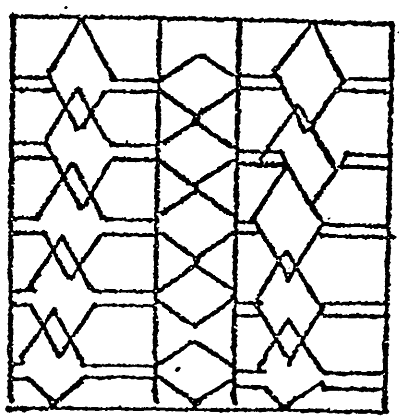
Find Simple Form "E"



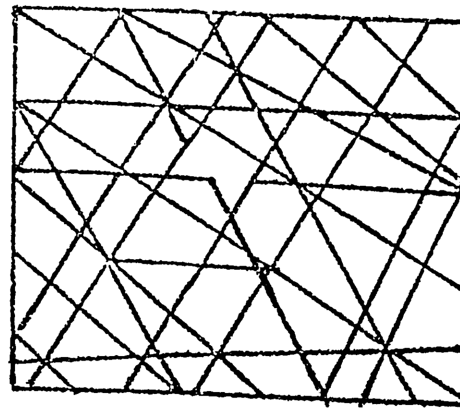
Find Simple Form "B"



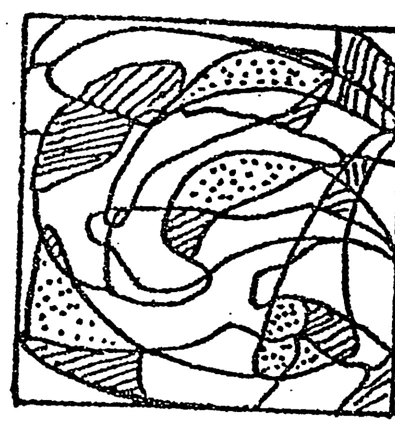
Find Simple Form "A"



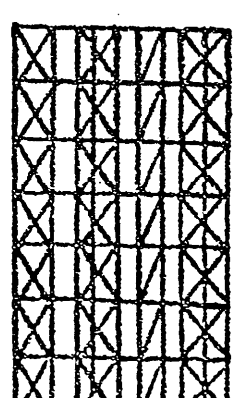
Find Simple Form "E"



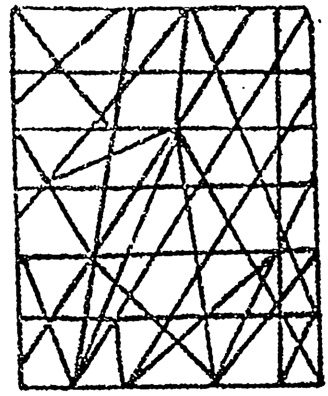
Find Simple Form "G"



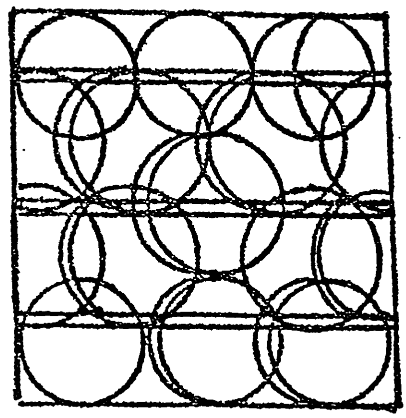
Find Simple Form "C"



Find Simple Form "C"

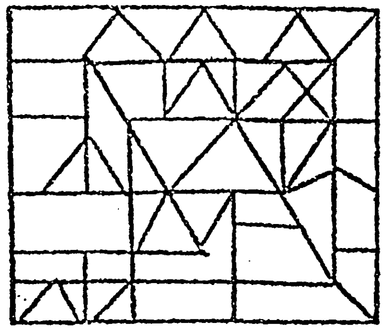


Find Simple Form "D"

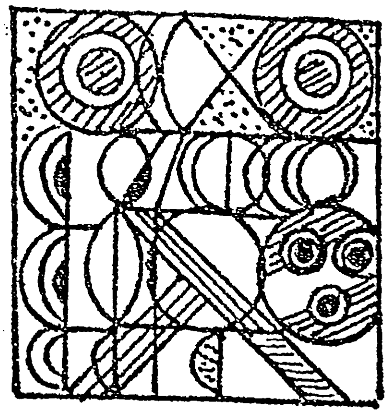


Find Simple Form "G"

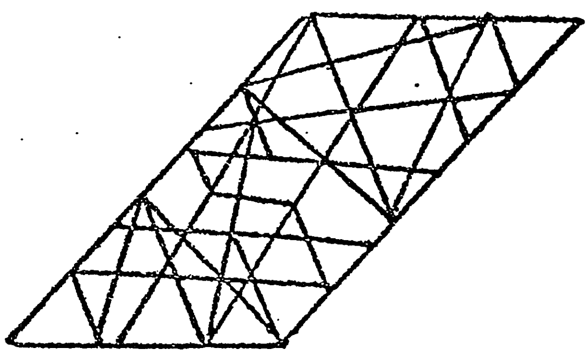
Find Simple Form "A"



Find Simple Form "D"



Find Simple Form "E"



H.F.T. SCORING KEY