INVESTIGATION OF BIOLOGY STUDENTS' COGNITIVE STRUCTURE THROUGH WORD ASSOCIATION TESTS, MIND MAPS AND STRUCTURAL COMMUNICATION GRIDS

by

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**TO MY WIFE SIDIKA AND
TO MY DAUGHTER BELINSU SENA**

ABSTRACT

The primary aim of this research study was to investigate the cognitive structure (i.e. the relationship between concepts in mind) of biology students/pupils. Three techniques, namely Word Association Tests (in the topic "Genetics"), Mind Maps (in the topic "Seed Structure") and Structural Communication Grids (in the topics "Food Digestion, Chemistry of Respiration and Haemophilia") were used for this purpose. Furthermore, it was also planned to investigate the effect of some psychological factors (i.e. Field Dependence/Field Independence, Convergence/Divergence and Working Memory Capacity) on the relationship between concepts in students' long term memory as well as to reveal the relationship between these three psychological factors.

101 pupils at Higher Grade Biology (age 16-17) from four different secondary schools in the Central Belt of Scotland and around 400 first year biology students in Glasgow University have participated in this research.

The results of the word association test (WAT) showed that students generated many ideas related to given key words. However, the results of both maps (in order to map the structures, relatedness coefficient values and response frequencies were used) clearly revealed that the ideas about genetics clustered as only a few isolated islands in students' cognitive structure and they did not appear to see the overall picture as a network of related ideas. In terms of the relationship between psychological factors and the WAT, *only* the Convergence/Divergence thinking style showed a significant relationship with the WAT. That is, students who had divergent thinking style gave a larger total number of responses and a wider range of responses to the key words in the WAT than the students who had convergent thinking style.

Mind maps were used in this research study as an alternative to a linear way of planning essay writing and also to gain an insight into students' ideas lodged in cognitive structure. The results showed that there was a statistically significant difference (in favour of mind mappers) between essay (on Seed Germination) marks of mind mappers and non-mind mappers. A statistically significant correlation between mind map scores and essay scores also appeared, indicating that students who drew better mind maps, had higher scores in essays. The examination of mind maps and the essays of the students also revealed that some students did not mention the same major ideas in their maps and in their essays. In addition, some misconceptions appeared in the students' mind maps as well as in their essays. In terms of the effect of psychological factors on mind mapping (only Convergence/Divergence thinking styles were examined), the mind maps of divergent students were more complex and branched than those of convergent students.

For the secondary schools, the results of Structural Communication Grids (SCG) showed that pupils had misconceptions about the topics of "Food Digestion and the Chemistry of Respiration." SCG were also used as an evaluation tool for the first year biology students on the topic "Haemophilia." The effect of some psychological factors (i.e. Field Dependence/Field Independence and Convergence/Divergence) were also examined. The results revealed that overall performance of the field independent pupils in the grids was better than field dependent pupils. Pupils/students who had a divergent thinking style had higher scores than the pupils/students who had a convergent thinking style on grid questions.

All results of these three techniques (i.e. word association tests, mind maps and structural communication grids) showed that they are very effective as diagnostic tools to illuminate the relationship between ideas in the long term memory of the students/pupils. Structural communication grids are also effective assessment tools.

Implications for using these three techniques in the classroom as well as a self instructional method for students and as a supplement to the exams are also discussed.

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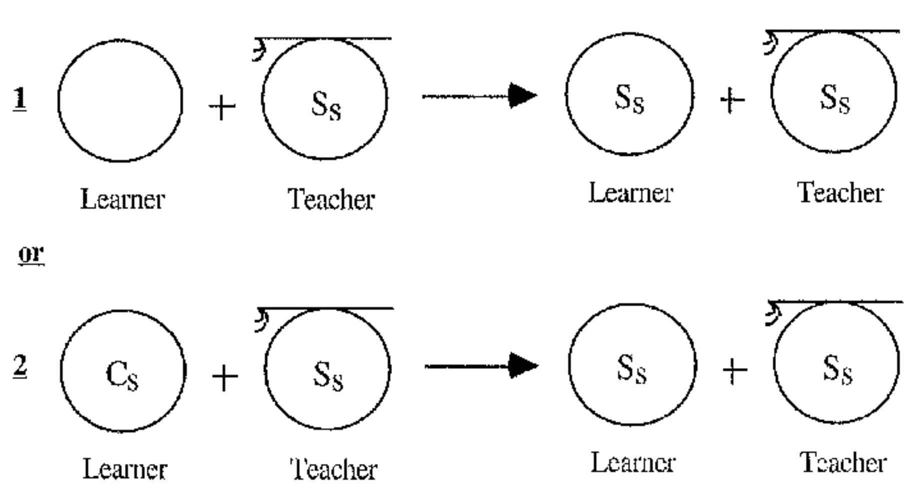
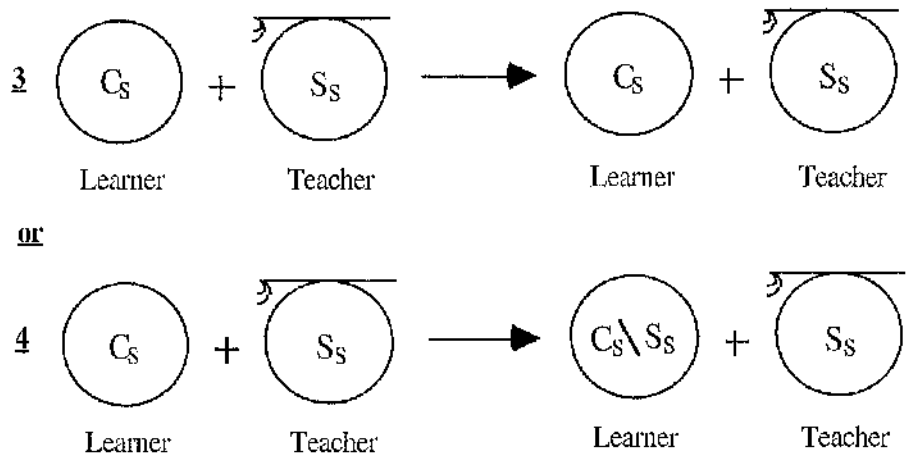
INTRODUCTION

Much of the innovation in teaching and learning is based on a "black box" model. We change the content or the methodology (input) and then provide means for checking the output, for instance, exams, questionnaires, essays and even interviews. We vary the input and hope for improvement in the output. However, everyone who teaches science of any kind may experience the disappointment of seeing, in examination papers, the misunderstandings or inadequacy exhibited by students.

The following representations below which were done by Gilbert et al. (1982) show the possible interactions between teacher and a learner:



In the first situation a learner, whose mind is a "blank slate" regarding the science being taught, comes across a teacher with scientist's science, Ss, in mind. Under the right conditions, as a result of teaching, the learner acquires the same knowledge as the teacher. In the second situation, the learner with a childlike view of the science concerned, Cs, also acquires the same knowledge as the teacher, as the naive ideas Cs are replaced by the teacher's knowledge, Ss. However, these two representations do not reflect the real situations and it is not tenable to believe that information and understanding can be transferred intact from the head of the teacher into the head of the student. Many research studies in the field of science education suggest that very different situations (as in 3 and 4 below) often apply:



In 3, the learner's naive ideas have not been changed although he has been taught (i.e. the persistence of misconceptions). In 4, some learners acquire the Ss knowledge without altering their Cs view of the topic. In other words the new knowledge has been attached to the existing one without affecting it or Cs may distort Ss to make a confused mess. But, whatever the prior knowledge is or whether it contains naive ideas or not, from a constructivist point of view, every student uniquely reconstructs knowledge and understanding from the information the teacher presents, in the light of the knowledge and understanding the student already has (i.e. the importance of prior knowledge). Therefore, it is desirable to find a method that would enable the teacher to "look inside the students' heads" ("black box") and see how ideas are lodged and see where the misconceptions are in their cognitive structure.

In this research study, the following questions have been addressed;

1- *How is it possible to explore the pattern of relationships among concepts in students' Long Term Memory? How can it be established whether they have good patterns of knowledge or have understood what they are taught?* To answer these questions, at the university and secondary school level biology, three techniques have been applied ;

1- Word Association Tests
2- Mind Maps
3- Structural Communication Grids

The word association test is one of the commonest and oldest methods for investigating cognitive structure and has been used by several researchers (Deese, 1965; Shavelson, 1973, 1974; Geeslin and Shavelson, 1975; Preece, 1976, 1978; Johnstone and Moynihan, 1985; Cachapuz and Maskill, 1987). Mind maps which were proposed by Buzan (1995) are used primarily for note taking and for brain storming. In this research study mind maps were introduced to students to help in the planning of their essay writing as well as to gain an insight into ideas lodged in a student's cognitive structure, because mind maps can serve as a vehicle for obtaining a graphic representation of information held in memory. Structural communication grids, which are powerful assessment techniques, were used in this study as an alternative method of diagnostic and summative testing as used by other researchers (e.g., Duncan, 1974; Johnstone and Mughol, 1978, 1979; Johnstone, 1981; Johnstone et al., 1981, 1983; MacGuire, 1981; Carrie, 1984; MacGuire and Johnstone, 1987).

2- *To what extent do some psychological factors (i.e. Field Dependence/Field Independence and Convergence/Divergence and Working Memory Capacity) influence the pattern of relationship between ideas in pupils/students' Long Term Memory? By using the three techniques, is it possible to look at the effect of particular psychological factors in the network of ideas in students' minds?*

3- In addition to these two main questions, *it was also intended to find out if there is any connection between these psychological factors and to examine the overlap between them if any.*

CHAPTER 1

INFORMATION PROCESSING MODEL, SEMANTIC MEMORY AND THEORY OF AUSUBEL

1.1 Introduction

As stated in the previous section (in Introduction), the main purpose of this research study was to see how ideas are lodged and see where the misconceptions are in students' cognitive structure. According to Kempa and Nicholls (1983), cognitive structure is a hypothetical construct referring to the organisation of concepts (or the pattern of the relationships between concepts) in memory. The construct of cognitive structure can be defined by a model of human information processing (Shavelson, 1974). There are many versions of an information processing model formulated by several authors. One such model, the Information Processing Model, (which was proposed by Johnstone (1993a) and used by many researchers in the Centre for Science Education in the University of Glasgow) will be used in this study to conceptualise the laying down and interconnecting processes in students' long term memory.

The purpose of this chapter is to describe and discuss the importance of the Information Processing Model for science education, the organisation of the knowledge in the semantic long term memory and Ausubel's Theory of Learning.

1.2 The Information Processing Theory - A Model of Learning

According to Ashcraft (1994) a standard model of information processing should contain three components namely, sensory memory (sensory registrar or perceptive filter), short term memory (working memory or working space) and long term memory. Information enters the system through the sensory memory and then it is transferred into working memory which can interact with long term memory. In this study the Information Processing Model (Figure 1.1) proposed by Johnstone, (1993a) will be used. This model includes the key characteristics emphasised by Ashcraft (1994) above and as a model of learning it involves something of all of the other models such as, Piaget's stage model, Ausubel's importance of prior knowledge in meaningful learning, Gagne's learning hierarchy, Pascual-Leone's idea of limited space related to age (Neo-Piagetian Ideas). It represents the flow of the information through the memory system and the processing of such information. Such a model makes predictions about how input information is dealt with in the human mind so that meaningful learning can take place.

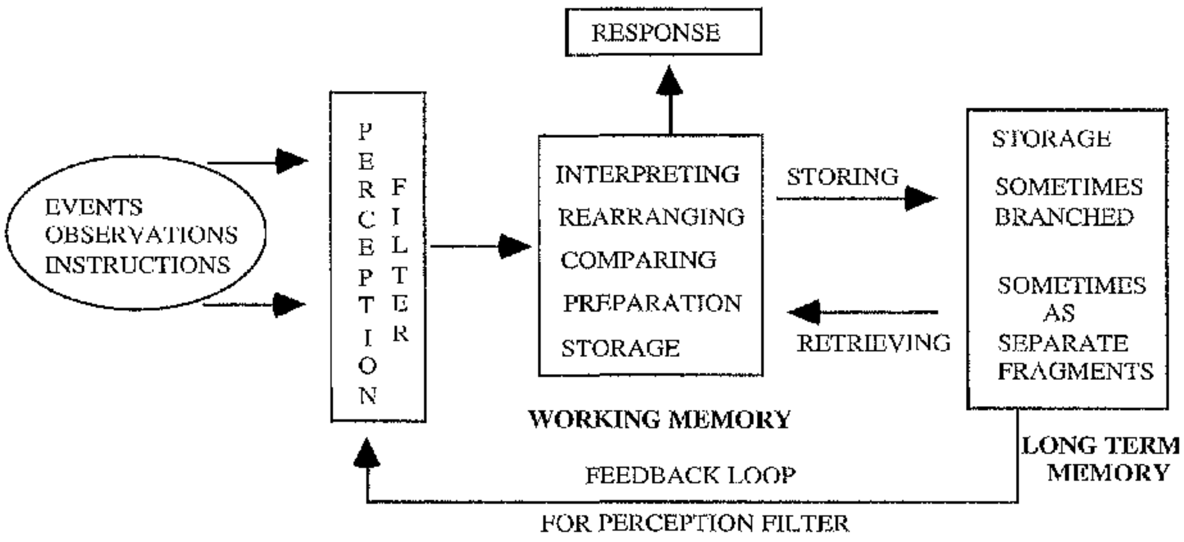


Figure 1.1 The Information Processing Model (From Johnstone, 1993a)

1.2.1 Sensory memory (Perception Filter)

This kind of memory has been approached and explained in various ways by different researchers. Ashcraft (1994) describes two types of sensory memory, namely auditory sensory memory which receives auditory stimuli and visual sensory memory which receives visual stimuli. Atkinson's and Shiffrin's multi-store model of memory (1968) considered a separate sensory system for each sense, each corresponding to a different sensory modality; auditory information, entering through ears, is initially stored in the auditory sensory memory (also termed 'echoic memory' by Neisser (1967)) while visual information, entering the systems through the eyes, is initially stored in the visual sensory memory, also known as 'iconic memory' (Neisser, 1967).

Studies suggest that sensory memory, which initially receives input stimuli, holds information in a relatively uninterpreted form for very short periods of time; about one-quarter to one-half of a second in iconic memory and no more than 2 or 3 seconds in echoic memory (Ashcraft, 1994).

In the Information Processing Model, the sensory memory was proposed as a perception filter and the environmental inputs or stimuli, for example; events, observations and instructions, come through this perception filter. In this model, the perception filter is driven by the long term memory, because it uses the prior knowledge in the long term memory to select information. According to Johnstone (1991) our previous knowledge, biases, prejudices, preferences, likes and dislikes, and beliefs (religious, political, cultural) must all play a part in perception.

White (1988) indicates that the selection of events is vital in learning and what is selected is affected by the learner's previous knowledge, attitudes and abilities. Also it depends upon: i) the attributes of events; properties like absolute intensity of a stimulus, motion and relative intensity of a stimulus, ii) attributes of the observer; general level of alertness, range of cognitive strategies available to the observer, iii) interaction between events and the observer; selection is affected by whether the observer finds the events unusual, interesting or understandable, and on the observer's construction of patterns and seeing events as a collection of meaningful units. If it cannot be combined with a set of stimuli into a unit, it is unlikely to be selected for attention.

1.2.2 Working Memory

Many studies in information processing would seem to suggest that when the stimuli and the information are admitted through the perceptive filter (sensory memory) they pass into a working memory (Working Space, Short Term Memory or M-Space) where they are held and manipulated before being rejected or passed on to long term memory for storage.

There are two important functions of the working memory (or working space), these are; "(i) it is the conscious part of the mind that is holding ideas and facts while it thinks about them. It is a shared holding and thinking space where new information coming through the perceptive filter consciously interacts with itself and with information drawn from the long term memory store in order to *make sense*. (ii) It is a limited shared space in which there is trade-off between what has to be held in conscious memory and the processing activities required to handle it, transform it, manipulate it and get it ready for storage in long term memory store. If there is too much to hold there is not enough space for processing; if a lot of processing required, it cannot hold much" (Johnstone, 1997).

In literature, short term memory and working memory are used interchangeably. Some researchers prefer to use the term short term memory (Atkinson and Schiffrin, 1968; White, 1988) but the others persist using the term working memory (Schneider and Shiffrin, 1977; Baddeley, 1986; Johnstone, 1988). There is still some debate about the difference between short term memory and working memory. However, the distinction between short term memory and working memory is obvious in Johnstone's (1984) explanation. For instance, if someone has been asked to memorise a set of numbers such as new telephone numbers then she/he recalls them back in the same order within seconds. In this case there is no processing (i.e. working on function) and the space is used completely as a short term memory. However, in another case, if someone receives input in the form of numbers and if he is asked to sum the first and the last and then multiply by the middle number, a working process begins to operate and the space is called in this case, not short term memory but, as working memory which can be defined as "that part of the brain where we hold information, work upon on it, organise it, and shape it, before storing it in the long-term memory for further use" (Johnstone, 1984).

Working on a function involves the conversion of new material selected through perception into a comfortable form for storage (Baddeley and Hitch 1977; Johnstone, 1988; Klatzky, 1980). Processes that involve interpreting, comparing, storage preparation and interrelation of new information with that already existing in long term-storage could result in the retention of information in long term memory. Working memory was also found to possess great speed and suffer fast decay. It can hold information for a short while, but if no rehearsal of the information has occurred, the information will be either lost or will decay.

1.2.2.1 Measuring Working Memory Capacity and Chunking

For many years, the capacity of working memory was measured by using a *digit-span task,* in which subjects are read a series of digits (e.g., '6 2 0') and must immediately repeat them back. If the subjects do this successfully, they are given a slightly longer list (e.g., '8 3 1 6') and so on. This task draws directly on short term memory; the mistakes should begin to appear when there is more on the list than the memory can hold. As it turns out, with seven or eight items subjects perform quite well. However, with eight or nine items, subjects start to make mistakes. With lists longer than this, many mistakes will happen. Subjects tend to make mistakes primarily in the middle of the list because of primacy and recency effect. Reisberg (1997) states that subjects are more likely to remember the first few items on the list, something known as the primacy effect, and are also likely to remember the last items on the list, a recency effect.

There are other different techniques used to measure working memory capacity. These involve holding and processing. For example, in another version of the digit span test called *digit span backwards test* in which subjects are given a series of digits and they must recall them in reverse order rather than recall them in the same order. This involves the process of reversal. Also in another different version, subjects are given a date in words, for example "Nineteenth of April" and they are required to convert the date into digits (1 9 4) and arrange them in numerical order from the smallest to the largest (1 4 9). This is done entirely in the head. Then subjects are given a slightly longer date and so on until they begin to make mistakes. In the *figure intersection test,* students are required to shade in a common area from increasingly complex patterns of overlapping shapes. In all these tasks the upper limit at which subjects can achieve this is taken as the measure of their capacity.

Procedures like the digit-span task imply that the capacity of the short term memory is around seven items, and probably not more than nine items. These estimates are often summarised by the statement that "7 plus-or-minus 2" items of information can be stored or can be held in the short term memory space at a time (Miller, 1956). However, working memory space, which has to allow for processing, usually appears to be smaller in terms of what it can handle. It is necessary to make clear what is an item. Can seven sentences be remembered as easily as seven words? Seven letters as easily as seven equations? In his classical paper, Miller (1956) suggested that short term memory holds 7 plus-or-minus 2 **chunks** or packages and what those packages contain is largely up to the subject. The limitation of the working memory is on the number of 'chunks' of information which may be stored or retrieved. Johnstone and Kellett (1980) describe a chunk as that which the observer perceives or recognises as a unit, for instance, a word, a letter or a digit and is controlled by students' previous knowledge, experience and acquired skills (Johnstone and El-Banna, 1986). The chunk refers to any familiar unit of information based on previous learning (Eysenck, 1984). According to White (1988), we chunk the world, that is we combine our sensations into a small number of patterns and so chunking is a function of knowledge. Therefore, the size and number of chunks perceived in a situation is one of the big differences between the knowledgeable person (e.g. expert, teacher, adult) and the novice (e.g. beginner, student, child). The knowledgeable person can collect the phenomena or events into a smaller number of units.

1.2.2.2 Overloading of Working Memory Capacity and Implications for Learning

As stated earlier one of the most important characteristics of the working memory is that "it is a limited shared space in which there is trade-off between what has to be held in conscious memory and the processing activities required to handle it, transform it, manipulate it and get it ready for storage in long term memory store. If there is too much to hold there is not enough space for processing; if a lot of processing required, it cannot hold much" (Johnstone, 1997). Many research studies in the field of science and mathematics education suggested that; (i) because of its limited capacity, working memory can be easily overloaded (e.g. with unnecessary information, unfamiliar vocabularies, negative questions) and, (ii) overloading the working memory can be an obstacle to acquiring the information and, (iii) if working memory is overloaded by too many pieces of information, the processing of this information cannot take place unless such information can be effectively chunked, (iv) there is a relationship between the working memory capacities of students and their performances in problem solving and in exams.

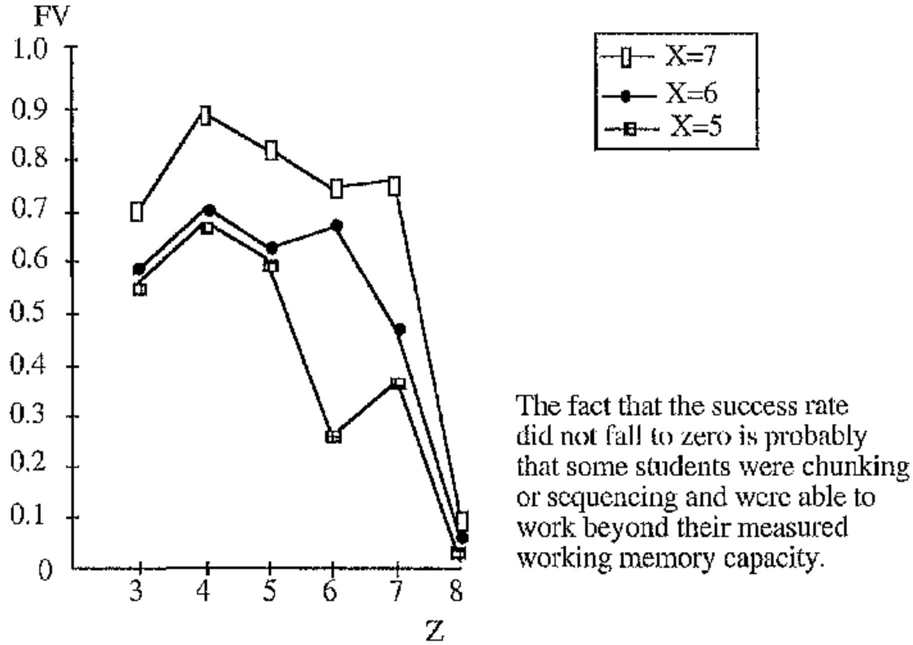
Barber (1988) stated that "if the information we are concerned with reaches the upper limits of our working space, an overloading in the capacity of working memory could occur. A loss in productivity may arise."

Johnstone and Wham (1982) proposed that learning in the laboratory situation may result in a state of working memory overload because students are usually bombarded with a large amount of information at once and they cannot differentiate the noise (irrelevant information which is not important) from the signal (relevant information which is important to understand the topic). They indicated that "the signal should be enhanced by clarifying what is preliminary, peripheral and preparatory in order to suppress the irrelevant information i.e. the noise. The experiment can be redesigned in order to avoid recipe following."

Several research studies in the field of science education especially in biology, in which Latin and Greek words are heavily used, suggested that language is one of the reasons for the difficulty in understanding of some topics (Bahar, 1996; Selepeng, 1995; Johnstone and Cassels, 1985). According to Johnstone (1991) what goes on in working memory occurs in visual or verbal forms. An unfamiliar word or known word in an unfamiliar context takes up valuable working space. For a second language learner the problem is even more serious because the working memory space is used not only for holding and processing, it is also used for translating which takes up valuable space.

Also language in multiple choice questions was shown to influence the thinking processes necessary to answer the question. If the question was posed in a negative form, this needs more processing and may be beyond the capacity of the working memory space needed to hold, organise, sequence, process and solve it (Cassels and Johnstone, 1982). Therefore, thoughtless use of the language can overload the working space and can have a detrimental effect in learning and teaching and may also reduce a student's performance in the exam.

The relationship of working memory capacity to the success in problem solving has been a subject for various studies. Johnstone and El-Banna (1986) demonstrated that if the number of things students have to keep in mind at one time in order to solve the problem exceeds their working memory capacity, then they will find the problem difficult or even impossible. They analysed chemistry problems into the number of thought steps that an unsophisticated student would take in solving them. They also measured the working memory capacities of 471 upper secondary school and university students. After the students had attempted the problems the fraction answering each one correctly was plotted against the "number of thought steps" required, with separate curves for students with working memory capacities of five, six and seven items. "Number of thought steps" was the sum of units of information in the question, units to be recalled and processing steps. The results showed a fall-off in proportions of students solving chemistry problems when the number of thought steps required exceeded a student's working memory capacity (see Figure 1.2). However, it is important to mention that these results do not imply that a student with a small working memory capacity is not able to solve problems and incapable of learning. If he/she can develop a strategy of chunking he/she can use limited working space more efficiently. However, because chunking is a function of knowledge it is difficult for a new learner to develop a strategy of chunking in a new area.



X= Working Memory Capacity

Z= Number of thought steps necessary to solve problem

FV= Proportion of people solving the problem

Figure 1.2 Demonstrating fall-off in proportions of students solving problems when the number of thought steps required exceeds a student's working memory capacity (Johnstone and El-Banna, 1986)

Case (1974) indicated that the designing of effective instruction with a minimum load on working memory must highlight all stimuli to which the subject must attend, making them salient, either because their physical features makes them stand out from their context, or because they are pointed out verbally by the instructor. The more salient a stimulus, the less working memory is needed in the task of extracting it. Pascual-Leone (1970), recommended reducing to a bare minimum the number of items of information that require the attention of a student. By definition, the smaller the number of items of information with which the student must deal at any time, the smaller the load on working memory.

In the light of all this research evidence, it seems to be essential to minimise the load on the working space so that teaching and learning processes can be facilitated. The following points may be considered:

i) teachers and text book writers should keep the content of the information at a minimum and within the capacity of students.

ii) irrelevant and unimportant information should be avoided and the information that is fundamental to understand the topic should be made obvious to first time learners.

iii) the information should be presented to the students in a language which should be easy enough to understand, and also teachers and text book writers need to be selective in the terminology they use.

iv) because chunking certainly reduces memory load, teachers should train students to see things as larger and fewer chunks.

1.2.3 Long Term Memory

Long term memory is a large store where facts are kept, concepts are developed and attitudes form (Johnstone et al., 1994). It is the ultimate destination for information we want to learn and remember, the memory system responsible for storing information on a relatively permanent basis (Ashcraft, 1994). The capacity of long term memory seems limitless, and its duration virtually endless (Solso, 1995). According to Tulving (1986) our permanent or long term memory is not a single entity; it has distinct components: episodic and semantic memory. Episodic memory is an individual's autobiographical record of past experience and the semantic memory holds our knowledge of language, rules and concepts, in other words it is the memory for meanings. Other long term memory distinctions have also been made in the last two decades. For example, declarative and procedural long term memory (Anderson, 1982; Squire, 1987). They indicated that basic facts and conceptual knowledge are stored in a declarative long term memory system, whereas knowledge of how to do something is part of one's procedural knowledge base.

Learning is a flow of information from perception to working memory, where it is encoded and then further movement takes place in the form of chunks to store in long term memory and become available for further use. According to the Information Processing Model (Johnstone, 1993a) long term memory has links with working memory and the perceptive filter. The long term memory controls perception because what is selected by the perceptive filter is directed by long term memory and provides information for working memory for processing new information. What is available in long term memory is very important because it may distort the selection process and provide, for the working memory, information which is incompatible with what is coming in from outside (Driver et al., 1985).

1.3 Storage and Recall - Implications for Learning

Stewart and Atkin (1982) indicated that the human memory works analogously to a library. It posses an effective card-cataloguing system. It seems to know what information has or has not been stored and can retrieve and also recognise any particular item by applying an appropriate search procedure. But for this purpose, memory uses some control processes such as pattern recognition, rehearsal and a set of manipulative logic rules such as induction and deduction that seem to play an important role in both storage of information (or learning) and problem solving.

Johnstone (1997) suggested that on a simple level storage and recall can be compared to a filing system in which new information is related to existing files and placed there. If an incoming letter does not fit the system, a new file is created and cross-referenced or indexed in some way to facilitate its retrieval. But the problem appears at the stage of retrieval because the operator has to understand the logic of the original filing. It is very difficult to take over someone else's filing systems and find the things again.

Furthermore, Johnstone (1997) indicated that storage can take place in at least four ways:

(i) *The new knowledge finds a good fit to existing knowledge and is merged to enrich the existing knowledge and understanding (correctly filed).* It is necessary to mention that this is not likely to happen all times or, if it happens, the new knowledge is not attached to existing knowledge without any changes being made, because the current view in educational psychology, from a constructivist point of view, is that the knowledge has to be reconstructed as it passes from one person to another. Learning is not the transfer of material from the head of teacher to the head of the student intact. He must reconstruct the knowledge into his own terms and understanding.

(ii) *The new knowledge seems to find a good fit (or at least a reasonable fit) with existing knowledge and is attached and stored, but this may, in fact, be a misfit (a misfiling).* These misfits are often semantic in origin. For example, in genetics, which is one of the most difficult topics in biology (Bahar et al., 1999; Johnstone and Mahmoud, 1980), after the students were given a lecture about the terms gene and allele (an allele is merely a particular form of a gene), it was assumed that students had wrong ideas about gene and allele, such as genes contain alleles, alleles contain genes or genes and alleles are the same. However, it is often the case that students come up with ideas that have never been taught. This also brings up the issue of misconceptions and alternative frameworks.

In the light of the Information Processing Model the misfit of new knowledge into the existing knowledge can disturb the selection process in later perception because the perception filter uses what is available in long term memory in order to select the important information and also may provide wrong ideas for working memory which may interrupt the working function. So the difficulties in some concept areas like genetics (in biology), the mole (in chemistry), force and motion (in physics) might arise due to misfitting of new knowledge to the existing corpus. But it is also possible that students attach the new knowledge into an existing situation that has already had some problem in it, such as misconceptions and alternative frameworks.

(iii) *Storage can often have a linear sequence built into it, and that may be the sequence in which things were taught.* Johnstone (1997) suggested that in normal life there are sets of linear memories that can be accessed in only one way. To answer "what is the tenth letter in the alphabet" involves going to A and counting through to J. This type of memorisation and retrieval is necessary, but is slow and awkward, and needs a lot of effort. The access and retrieval become easier if the linearity can be broken down by branches (Reisberg, 1997).

(iv) *The last type of memorisation is that which occurs when the learner can find no connection on which to attach the new knowledge.* In this type of memorisation it is extremely difficult to retrieve the information. Because it does not fit the filing system, it may be left "lying in the mental desktop" and not to be filed at all. It can be easily lost or consciously rejected. Ausubel et al. (1978) describe this type of learning as rote learning in which there is no interaction between learner's existing knowledge with new learning, in other words learning consists of receiving new knowledge as discrete, unconnected bits. At the other extreme, there is meaningful learning which is a nonarbitrary, substantive, non-verbatim incorporation of new knowledge into a cognitive structure and occurs when interactions takes place. In other words learning consists of associating the new knowledge in some way with what is already known. In terms of the Information Processing Model, meaningful learning can occur when the new idea or concept that has to be learned can be consciously related to branched, well-integrated relevant concepts and ideas that the learner already has in long term memory.

1.4 Semantic Memory And Representation Of Knowledge

Within the category of declarative memory many researchers like Tulving (1983) and Squire (1987) have differentiated between memory of personal experience and memory of general knowledge, namely episodic and semantic memory. Tulving (1983, 1986) indicates that episodic memory refers to storage and retrieval of personally dated, autobiographical experiences such as recall of childhood experiences, recollection of the details of a conversation with a friend. It is linked with a particular time and place. A great deal of what we must recall so as to function effectively in our personal lives is episodic. On the other hand, semantic memory refers to memory of general concepts and principles and their associations. Unlike episodic memory, semantic memory is not linked with a particular time and place. It contains such information as the facts that lemons are yellow, a robin is a bird. The organised knowledge that we have about words and concepts and how they are associated is also in semantic memory (or lexical memory). Recalling the meanings of words, geographical locations, and chemical formulae require searches of semantic memory.

Different models such as Clustering Model (Bower, 1970), Set-Theoretical Model (Meyer et al., 1974), Semantic Feature-Comparison Model (Smith et al., 1974) and Network Model (Collins and Loftus, 1975; Anderson, 1983) have been proposed to represent the semantic organisation of the information in long term memory. The recent view is that knowledge exists in memory as independent units connected in a network and the storage of words is tied to a complex network of relationships (Network Model).

1.4.1 Network Models of Semantic Memory

Knowledge is represented by a web or a network in the Network Models of memory, and memory processes are defined within that network (Anderson, 1993). In most models of this kind, the networks are hypothesised to consist of nodes, which consist of cognitive units (usually either concepts or schemata) and links, which represent relationships between these cognitive units (Bruning et al., 1995). From Reisberg's (1997) point of view, nodes within the net are just like the knots within a fisherman's net. These nodes are tied to each other through connections that are called associations or associative links. He thinks of nodes as being akin to cities on a map, and associations as being the highways that link the cities. Building a highway between two cities, or perhaps improving an existing highway, so that it can be travelled easily and quickly would be similar to learning. In this view, what it means to search through memory is to begin at one node (one city) and to travel through connections until the target information is reached. However, not all associations are of equal strength. For example, some cities are linked by superhighways, some by country roads or some are not linked directly to each other at all. One can get there by travelling through some intermediate cities. According to Reisberg this will provide some explanation for why some memories are easily called up, while others are not: For example, the answer to the question "when is your birthday?" can be given quickly and easily, because there is a strong connection between the birthday node and the node representing a specific date. This connection has been established by the fact that this date and the idea of birthdays have frequently been thought about in conjunction with each other, creating an easily travelled path from one to the other.

1.4.1.1 The Model of Collins and Quillian

The best known of the early network models was proposed by Collins and Quillian (1969) as a model of semantic memory. They devised a computer program namely Teachable Language Comprehender (TLC) which was based on the assumption that memory could be presented by a semantic network arranged into a hierarchical structure. In this hierarchy the nodes were concepts arranged in superordinate and subordinate relationships. Properties of each concept are labelled with relational links or pointers going from the node to other nodes (Bruning et al., 1995). An example of such hierarchical structure is presented in Figure 1.3.

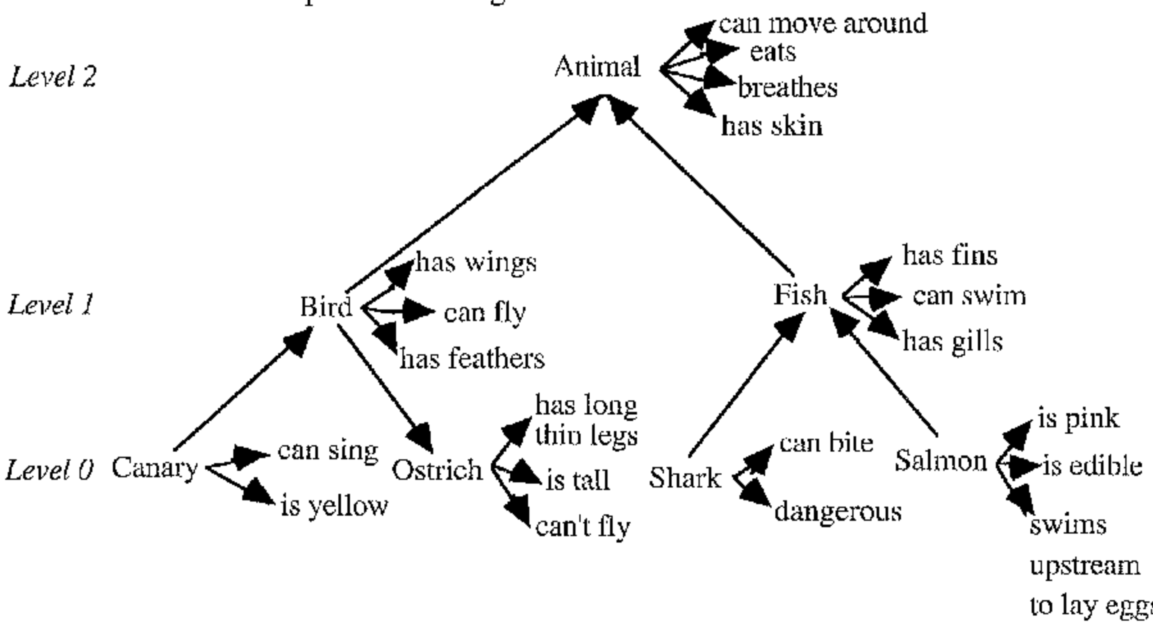


Figure 1.3 Hypothetical memory structure for a three-level hierarchy (Adapted from Collins and Quillian, 1969)

Another central idea in the Collins and Quillian theory was that of cognitive economy. For example, we all know that canaries can fly, robins can fly, sparrows can fly and so on. However, from Collins and Quillian's point of view, it would not be cognitively economical having the information about being able to fly stored with each bird name. In place of that, they suggested that properties common to virtually all birds like "can fly, has wings etc." are stored only at the bird node. Only those properties that differentiate one species of bird from others such as canaries are yellow are stored at the lowest level of the hierarchy. On the other hand, properties which are common to virtually all animals such as animals eat, animals breathe are stored at the animal node. In other words, properties particular to a concept are assumed to be stored along with the concept and those not unique to that concept, however, are assumed to be stored with more general concepts higher in the hierarchy.

Activation spreads from node to node as one searches through the network and it takes some time to traverse each level in the hierarchy. Search through the network is like a journey and therefore if one has to travel further, the longer it will take to reach one's destination. Because of that the time required for retrieval from memory structure will depend on the number of links traversed in the memory search. Collins and Quillian (1969) tested these ideas using a sentence verification task. They showed sentences to subjects like "A robin is a bird' or "A robin is an animal," or "Cats have claws," or "Cats have hearts." Subjects were given both true and false sentences and they had to hit a true or false button as quickly as possible. Figure 1.4 shows the results.

As can be seen from the graph that response times were fastest when no links in the network had to be traversed like the sentence "A canary is a canary." However, response time for the sentence such as "A canary is a bird" was slower because it requires the traversing of one link, from canary to bird. But, the response time of the sentence for "A canary is an animal" was the slowest because it requires the traversing of the two links, from canary to bird and then from bird to animal. According to this data of Collins and Quillian if one counts the number of associative steps that must be traversed to support a response the response times can be predicted. Thus, the evidence seems to fit nicely with the claim that material is not stored redundantly in memory (cognitive economy). Instead information is stored as high as possible in the hierarchy, so that what we remember best is properties of classes not properties of individuals (Reisberg, 1997).

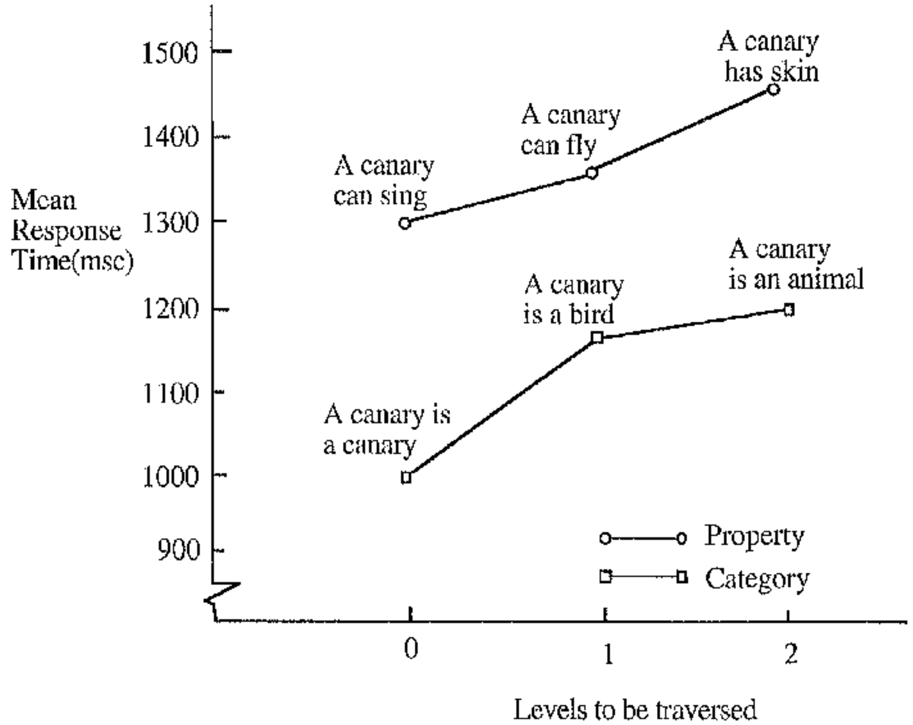


Figure 1.4 The results of sentence verification tasks (Adapted from Reisberg, 1997)

Like other models, the Collins and Quillian Model has also been challenged (Condrad, 1972; McCloskey and Glucsberg, 1978). Although the prediction that the response times are influenced by the number of associative steps traversed is accepted, there are other effects. For instance, subjects are much quicker to accept to "A robin is bird," than "A peacock is a bird" although these are both one-step connections (Smith et al., 1974). The difference between the response times is because of the *typicality effects* (Reisberg, 1997) or *familiarity* (Bruning et al., 1995). Mainly, the response time is faster the more typical the exemplar used, or if we are more familiar with the exemplar.

1.4.1.2 The Model of Collins and Loftus

Collins and Loftus (1975) extended the model of Collins and Quillian (1969) in their spreading activation theory. They proposed a structure based on semantic relatedness or semantic distance instead of the notion that there is a strict hierarchical organisation in semantic memory. The model is shown in Figure 1.5.

The model of Collins and Loftus as shown in Figure 1.5 is built on a complex association network in which specific memories are distributed in conceptual space with related concepts that are linked by associations. In the model, the length of the connecting lines indicates the strength of associations between the concepts. Long lines like those between Red and Sunsets express somewhat remote association; shorter lines such as that between Red and Fire express a closer association.

In the Collins and Loftus model there is a spreading activation, which may account for the results of priming experiments, among concepts. When memory is searched, activation moves along the links from the node that has been stimulated. This spreading activation constantly expands, first to all of the nodes directly linked with the concept and then to the nodes linked with these nodes and so on.

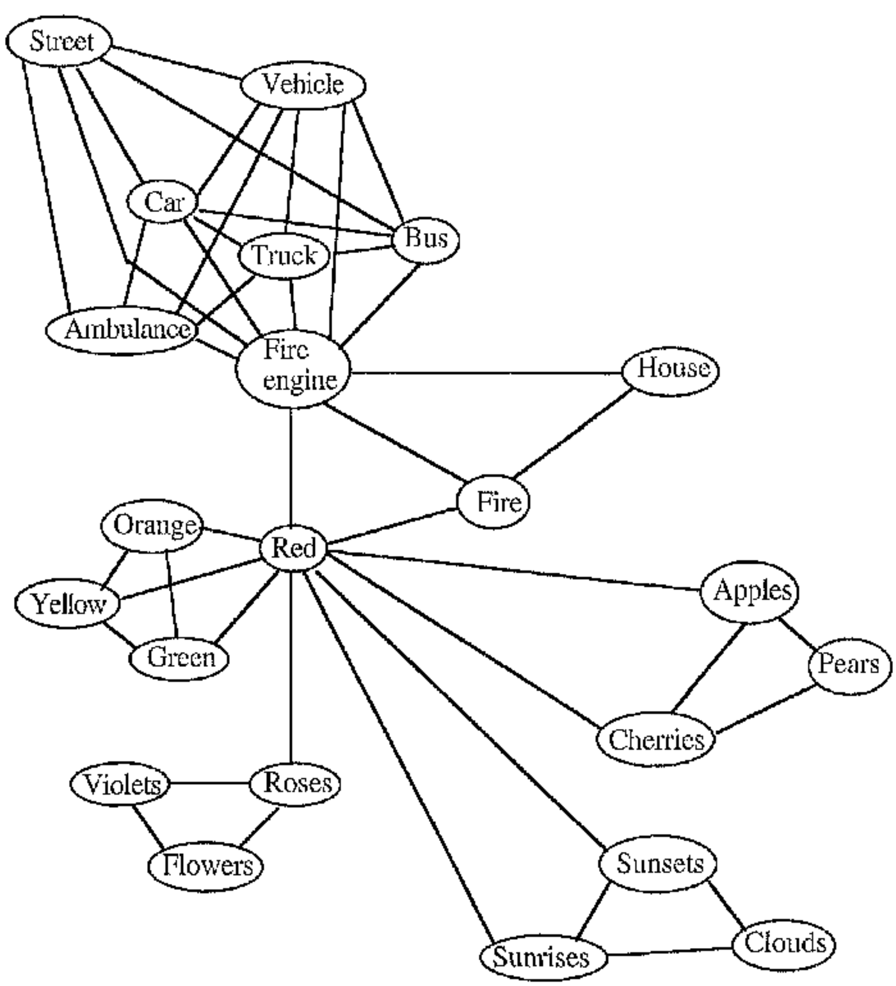


Figure 1.5 A spreading activation theory of semantic processing (Adapted from Collins and Loftus, 1975)

For example, from the assumption of Collins and Loftus that memory is organised according to semantic similarity, if "Vehicle" is primed, activation at any type of vehicle will accumulate from many neighbouring nodes. That is to say, to the degree that "Fire engine" is primed by "Vehicle" will in turn prime "Ambulance," "Truck," "Bus" etc., and each of these in turn will prime others. However, if "Red" is primed, the activation that spreads to "fire engine" will not prime "Cherries," "Roses," or Sunsets" to any great extent, because there are so few connections between these concepts. Instead "Fire engine" will tend to prime other vehicles, and cherries to prime other fruits.

The results of several research studies like this (Rips et al., 1973; Ashcraft, 1978; Kounios and Holcomb, 1992) suggested a great regularity in semantic memory structure. Concepts further removed from one another in the hierarchy require more time for retrieval. Concepts closer together in the hierarchy require less time for retrieval and are more central to the meaning of the concepts or categories. This is the *semantic relatedness* or *semantic distance effect,* which defines a fundamental generalisation. If two concepts are closer in semantic memory (distance) or the more related they are, the faster is the mental search process which retrieves information about concepts. This idea can be easily visualised particularly for network models, where more activation accumulates at the closer concepts because a shorter distance has to be travelled (Ashcraft, 1994).

The most fundamental process of retrieval from semantic memory is the priming. It has been mentioned in the earliest semantic models as well as in the most recent entries like connectionist models. In general terms, it can be said that any stimulus which is presented first and influenced later processes is called a prime. Priming is the fact that the activation of one concept also makes active other concepts which are related to it. When, because of priming, a concept is accessed easier or faster, we then talk of positive influence or facilitation. When it becomes more difficult to access, we talk of inhibition.

Many tasks (e.g., lexical decision and sentence verification) are used to show the priming effects. For instance, in a lexical decision experiment a subject is shown a series of letter sequences on a computer screen. Some of the sequences spell a word; other sequences look like words, but are not (such as "blar" or "tuke"). In this experiment the subject is required to hit the *yes* button if the sequence spells a word and the *no* button otherwise. It may be reasonable to suppose that the subject performs this task by *looking up* these letter strings in their mental dictionary (or lexical memory according to Collins and Loftus) and they base their response on whether they find the string in the dictionary or not. Therefore, the speed of response in this task can be used as an index of how quickly the subject can locate the word in his memory.

In a study by Meyer et al. (1974), subjects were presented with pairs of letter strings and they had to decide whether each letter string was a word or not. In their experiment, subjects had to respond *yes* if both stimuli in the pair are words *(positive pairs)* or *no* if either stimulus in the pair is not a word (*negative pairs*). The main interest in here is when both strings are words (positive pairs), but in one case the words are semantically related *(bread and butter)* while in the other case they are not (*nurse and butter*). Table 1.1 shows the results.

Positive pairs		**Negative pairs**		
Unrelated	Related	Nonword First	Nonword Second	Both Nonwords
Nurse	Bread	Plame	Wine	Plame
Butter	Butter	Wine	Plame	Reab
940 msec	855 msec	904 msec	1087 msec	884 msec

Table 1.1 The results of lexical-decision (priming) experiment (Meyer et al., 1974)

As can be seen from Table 1.1, the quickest response obtained is for the semantically related pair, bread and butter. When the subject sees the related pair, bread and butter, the subject first responds "yes" to bread. Presumably, he located the bread note in his memory, that is equal to saying that this node has been activated. This triggers a spread of activation outward from the bread node, bringing activation to other, nearby nodes. It can be reasonably expected that the association from bread to butter is a strong one, therefore, once bread is activated, activation should also spread to butter node. When the subject turns his attention to the second word in the pair "butter", he must locate butter in his memory. However, the process of activation of this node has already begun, thanks to the activation received from bread. This ought to accelerate the process of bringing this node to the threshold of consciousness, and so it will require less time to activate. Presumably, quicker responses to "butter" in this context would be expected compared to a context in which "butter" was preceded by some unrelated word, or by a non-word. The results show that the subject's lexical decision responses are faster if the present stimulus word was preceded by a semantically related word and it can be discovered how closely associated two nodes are by assessing the degree to which activation of one primes the other. If this is repeated for many pairs of nodes, we can begin to outline the patterns and organisation of memory (Reisberg, 1997).

1.4.1.3 Connectionism

In the last twelve years an important descendent of the network idea has appeared. The name of this approach is Connectionism or Parallel Distributed Processing (PDP) or sometimes it is called the Neural Net Models. Connectionism can be defined as a theory of the mind that posits a large set of simple units connected in a parallel distributed network. Mental operations like memory, perception, thinking, and so on, are considered to be distributed throughout a highly complex neuronetwork, which operates in a parallel manner, occurring simultaneously. In contrast to serial processing theories which suggest that processing between units is done only in sequence, PDP is based on the assumption that units excite or inhibit each other throughout the system at the same time or in parallel. Like other versions of the network models, PDP shares the idea that connections within the network can be strong or weak and refers to the strength of each connection as its *connection weight* or *connection strength.* Presumably, semantic relatedness is embedded in the structure of a PDP Model, by the path weights that connect the nodes.

From Ashcraft's (1994) point of view, a connectionist model is, most fundamentally, a massive network of interconnected nodes and the nodes can represent almost anything. In particular, the nodes can represent simple features as well as complex features, such as a robin has a red breast, has wings and so on. The flexibility of the connectionist model is that, in principle, the nodes and their weighted inter-connected pathways can represent any type of knowledge.

Essentially, the connectionist approach harmonises the network and the feature approaches: features represent the basic nodes in the connectionist structure, and the network pathways that connect the nodes are the instrument for priming effects. Thus, priming, both positive and negative activation, is the basic activity within the structured patterns in the network. The example given in Figure 1.6 shows priming effects in connectionist modelling.

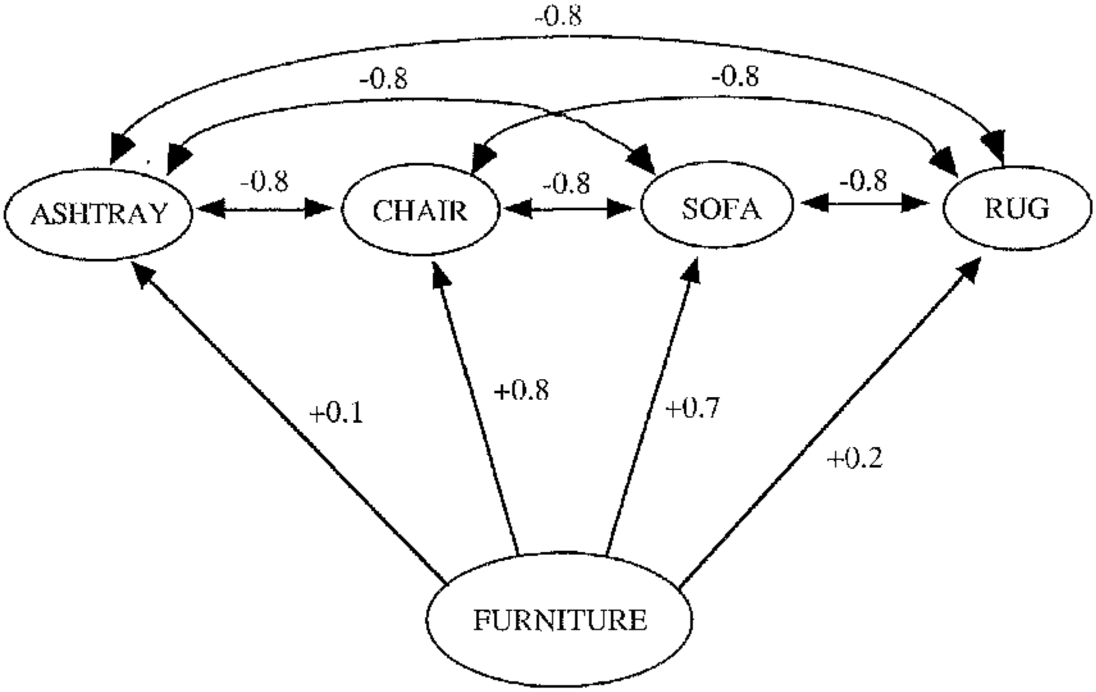


Figure 1.6 A small portion of a connectionist network. Note that the nodes at the same level exert an inhibitory influence on each other, and receive different amounts of facilitation from the category name (Adapted from Martindale, 1991).

In this example pathways with highly positive weights connect a category name "Furniture" with members of the category such as "Chair" and "Sofa". However, the pathways from "Furniture" to "Rug" and "Ashtray" are weak, because those members are not particularly typical in that category. Therefore, it may reasonably be assumed that if category name "Furniture" is presented, Chair and Sofa will be activated to a high level, thus making decisions about them relatively rapid (Typicality effects). However, "Rug" in such a connectionist scheme, will actually be slower to verify. Because, the connection between "Furniture" and "Rug" is weak and "Chair" which is highly activated by "Furniture" will actually spread inhibition to "Rug" (When neighbouring nodes at the same level exert an inhibitory influence on each other, this is called lateral inhibition). Ultimately, the category name primed typical members, but actually inhibited responses to the atypical members (Rosch, 1975).

Are there also priming effects for word pairs that rhyme with each other, for instance claw - law? Are words that rhyme with the prime word automatically preactivated? There are only a few studies in favour of a rhyme priming. For example, Meyer et al. (1975) showed weak, but insignificant priming effects of words that rhyme and are graphemically similar like nail - rail, and inhibition of graphemically similar words that did not rhyme like lemon - demon. Hillinger (1980) found a priming effect of acoustically presented primes that rhymed with the target word and of visually presented primes that rhymed even if both words were graphemically different like fear - beer. On the other hand, Martin and Jensen (1988) could not replicate the findings of Hillinger (1980). McNamara (1992b) found priming effects for conceptually related words however, not for words that rhymed with each other.

1.4.1.4 ACT Model

There is another model that represents semantic knowledge in propositional terms (Anderson, 1983, 1993). This model is called ACT (Adaptive Control of Thought) which is based on an earlier model called human associative memory (Anderson and Bower, 1973). The ACT model is different from the other network models in its attempt to represent knowledge in terms of propositions. A proposition is defined by Anderson (1983) as the "smallest unit of knowledge that can stand as a separate assertion". Ashcraft (1994) defines the term proposition as a simple relationship between two concepts, one that can be expressed by a simple, declarative sentence: for instance "A robin has wings." Figure 1.7 shows a simple network presentation and propositional representation of sentence "A robin has wings".

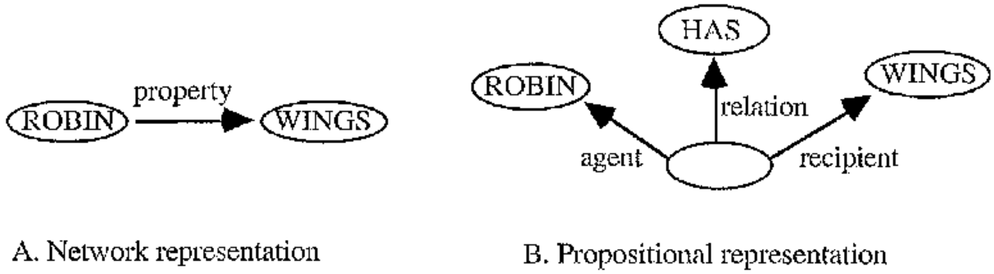


Figure 1.7 Simple network representation and propositional representation of sentence "a robin has wings" (Adapted from Ashcraft, 1994)

To sum up briefly:

1- Semantic memory refers to memory of general concepts and principles and their associations. It contains our long term memory knowledge of words, concepts, and language. Semantic organisation refers to the way concepts are organised and structured in memory.

2- Network models assume that knowledge exists in memory as independent units connected in a network and the storage of words is tied to a complex network of relationships.

3- The Collins and Quillian network model claimed that concepts are represented as nodes which are arranged in superordinate and subordinate relationships, in a semantic network, with connecting pathways between concepts. Also there is a cognitive economy (which can be shown by using sentence verification tasks) in memory; that is properties particular to a concept are assumed to be stored along with the concept and those not unique to that concept are assumed to be stored with more general concepts higher in the hierarchy. Nevertheless, the typicality or familiarity of concepts, in sentence verification tasks, can affect the response times.

4- The spreading activation theory of semantic processing (Collins and Loftus) is based on a complex network in which simple associations (e.g., "red" and "roses") are linked together in conceptual space. The results of Collins and Loftus's research and other studies suggested a great regularity in semantic memory structure. Concepts further removed from one another in the hierarchy require more time for retrieval. Concepts closer together in the hierarchy require less time for retrieval and are more central to the meaning of the concepts or categories (i.e. semantic relatedness or semantic distance effect). If two concepts are closer in semantic memory (distance) or the more related they are, the faster is the mental search process which retrieves information about concepts. This idea can be easily visualised particularly for network models, where more activation accumulates at the closer concepts because a shorter distance has to be travelled.

5- The most fundamental process of retrieval from semantic memory is the priming. Any stimulus which is presented first and influenced later processes is called a prime. Priming is the fact that the activation of one concept also makes active other concepts which are related to it. When, because of priming, a concept is accessed easier or faster, we then talk of positive influence or facilitation. When it becomes more difficult to access, we talk of inhibition. Priming effects can be shown by lexical decision experiments. The subjects' lexical-decision responses are faster if the present stimulus word was preceded by a semantically related word.

6- Knowledge is represented in Connectionist (or Parallel Distributed Processing) Models as a network of interconnected nodes and the nodes can represent almost anything. A connection within the network can be strong or weak and refers to the strength of each connection as its "connection weight". Also, priming, both positive and negative activation, is the basic activity within structured patterns in the network.

7- ACT (Adaptive Control of Thought) Model by Anderson is different from other models in its attempt to represent knowledge in terms of propositions that are the smallest units of meaningful information (e.g., a robin has wings).

Before concluding this chapter the theory of learning of Ausubel will be discussed. In the field of educational psychology, Ausubel is one of the people like Piaget and Gagne who have had some influence on the teaching and learning processes in science and maths. In this study the ideas of Ausubel are particularly important because some of his essential ideas given below have also been used in some other techniques such as in mind maps and in the word association tests.

1.5 Ausubel's Theory of Learning

The most important factor in Ausubel's theory is that prior knowledge is a factor influencing learning. He (1968) claimed that "If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly". There are a number of key concepts in Ausubel's theory of learning which are as follows:

1) Meaningful versus rote learning
2) Subsumption
3) Progressive differentiation
4) Superordinate learning
5) Integrative reconciliation
6) Advance organiser

Meaningful versus rote learning: Meaningful learning is the most important idea in Ausubel's theory and he describes it as "nonarbitrary, substantive, nonverbatim incorporation of new knowledge into cognitive structure". Novak (1984) explains the nonarbitrary incorporation of knowledge as a conscious effort of the learner to relate new knowledge to knowledge that the learner already has in his mind and substantive learning as a conscious effort by the learner to identify the key ideas in new knowledge and to relate these ideas to other ideas. Simply nonverbatim learning is the result of nonarbitrary, substantive learning because the later active learning alters the meaning of the new knowledge learned.

McClelland (1982) indicates that for meaningful learning to take place, three conditions have to be met:

i) The material itself must be meaningful, that is, it must make sense or conform to experience.
ii) The learner must have enough relevant knowledge for the meaning in the material to be within grasp.
iii) The learner must intend to learn meaningfully, that is, must intend to fit the new material into what is already known rather than to memorise it word by word.

The distinction between meaningful learning and rote learning is not a simple dichotomy. Rote learning, in which a learner incorporates new information into cognitive structure in an arbitrary, verbatim and nonsubstantive way is the lower end of the meaningful learning continuum. Depending on the nature of the learner's existing knowledge and how it interacts with the new knowledge, there will be varying degrees of meaningful learning. Ausubel (1973) states that "meaningful and rote learning are not dichotomies, however learning will be increasingly rote to the extent that:

(i) the material to be learned lacks logical meaningfulness,
(ii) the learner lacks the relevant ideas in his own cognitive structure,
(iii) the individual lacks a meaningful learning set.

Any of these conditions alone will be likely to lead to rote learning."

West and Fensham (1974) indicate that meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Rote learning occurs when no such interaction takes place.

To summarise, meaningful learning can be described as "good, well-integrated, branched, retrievable and usable learning" while rote learning is "at best, isolated and boxed learning that relates to nothing else in the mind of learner" (Johnstone, 1997).

Subsumption: In Ausubel's theory of meaningful learning, new learning does not result in a kind of accretion with new knowledge added to existing concepts. Instead new knowledge interacts with existing relevant concepts and is assimilated into these concepts, hence altering the form of both the anchoring concept and the new knowledge assimilated. To emphasise that it is not a simple linking or accretion, Ausubel (1973) has labelled any concept, principle or generalising idea that the learner already has in his mind (which can provide association anchorage for the various components of the new knowledge) a subsumer. New knowledge is usually incorporated (subsumed) into more general concepts (Novak, 1978). Because every learner has a unique cognitive structure, the degree of subsumption of new knowledge into the more general concepts depends on what concepts or misconceptions the learner already has in mind.

Progressive differentiation: The constant modification and elaboration of the concepts in cognitive structure, makes them more precise and by becoming more exclusive. This is called progressive differentiation. For instance, a child's concept of animal, which at first may encompass little more than the difference between cat and dog, soft hair or fur will in time take on much more precise meaning as it is linked to such concepts as mammals, amphibians and birds etc. and will continue to differentiate as they grow older and learn more. According to Novak, (1978) progressive differentiation begins in young children (2 years old or less) and continues throughout adult life.

Superordinate learning: According to Ausubel et al. (1978), in superordinate learning, the previously learned concepts are seen as elements of a large, more inclusive idea and the acquisition of superordinate meanings occurs more commonly in conceptual than in propositional learning as, for instance, when children learn more that the familiar concepts of peas, beans, and spinach may all be subsumed under the new term "vegetable."

Integrative reconciliation: When a learner relates two or more concepts in a new way, integrative reconciliation of the concepts occurs. Superordinate learning always results in some new integrative reconciliation, and both this and subsumption result in additional progressive differentiation of concepts.

Advance Organiser: Ausubel proposed the idea of an advance organiser in order to facilitate learning. The key function of the organiser, that is introduced in advance of the material to be learned, is to bridge the gap between what the learner already knows and what he needs to know before he can successfully learn the task in hand (Novak, 1979). West and Fensham (1974) describe an advance organiser as "a verbal statement, presented to the learner before the detailed new knowledge."

If the learner is not ready in the sense of possessing appropriate subsumers, there is the possibility of using an advance organiser to bridge the gap. When there are no relevant items in the learner's cognitive structure Novak (1978) states that "it is unlikely that any type of advance organiser will function, for the organiser itself must be meaningful to the learner."

Ausubel et al. (1978) also made another distinction between *discovery and reception learning*. They state that "in reception learning the entire content of what is to be learned is presented to the learner in final form..... and the essential feature of discovery learning is that the principal content of what is to be learned is not given but must be discovered by the learner before it can be incorporated into the student's cognitive structure". Depending on what happens after the content to be learned is presented to the student's cognitive structure, they indicated that both reception and discovery learning can be classified either as meaningful or as rote learning.

1.5.1 Utilisation of Ausubel's Theory of Learning

Ausubel's theory of learning has had wide application and his ideas opened new ground in science and maths education.

The concept map which was introduced as an educational tool by Novak (1984), who is one of the close followers of Ausubel, developed as an outgrowth of Ausubel's theory of learning. The concept map has been used in education for a variety of purposes mainly: (i) to explore what the student already knows and to identify missing linkages or misconceptions (ii) to aid meaningful learning and to improve student achievement. In several research studies in which concept maps were used, the importance of the concepts already present in the students' mind was stressed. These initial concepts were not necessarily scientifically true i.e. they could be misconceptions or alternative frameworks. Studies have been about acids and bases in chemistry (Ross and Munby, 1991), in reflection of light in physics (Mohapatra and Parida, 1995), in phases of the moon in geography (Novak and Gowin, 1984), in understanding of cellular respiration in biology (Songer and Mintzes, 1994). They indicated that the presence of misconceptions are potential obstacles to the construction of new, meaningful knowledge. Furthermore, Hazel and Prosser (1991) showed that, depending on the context, prior knowledge has both a direct and indirect impact on post knowledge in photosynthesis and electricity. The indirect impact occurs as a result of the effect of prior knowledge on the adoption of study strategies. Entwistle and Ramsden (1983) also suggested that a lack of prior knowledge was associated with the adoption of more surface approaches to study, and the adoption of deeper approaches was associated with substantial levels of prior knowledge.

Concept mapping has been suggested as an aid to meaningful learning. This theoretical position has been taken based on the claim that the strategies help to organise incoming information, and help to establish mental bridges between what is already known and what is to be learned. New information becomes part of the semantic network by using the processes of accretion and reorganisation (Okebukalo, 1992). The results of recent studies indicate that concept mapping is a formidable strategy for effecting meaningful learning in science and other disciplines. For example, they have been used in the classification and problem solving skills of seventh grade students (Novak et al., 1983), in biology concepts (Lehman et al., 1985; Okebukalo and Jegede, 1989; Okebukalo, 1990; Soyibo, 1991) in science and mathematics (Malone and Dekkers, 1984) and in earth science concepts (Ault 1985).

Ring and Novak (1971) found a moderately strong correlation between students' learning in particular subject areas and the number of "subsuming" concepts known to the learners prior to exposure to the learning task. Kempa and Nicholls (1983) supported the theory of Ausubel in the contribution of prior knowledge subsumers to the learning process. They found evidence (by using word association tests) that the more branched and networked the knowledge and understanding in a student's mind, the more accessible it is and the more effective it is for problem solving. Where the concepts are only weakly linked, access to one concept via another is not readily achieved and problem solving, in which the linking is essential, does not occur. Cognitive structures of good problem solvers are more complex and contain more associations than those of poor problem solvers for given levels of relationships between concepts. Johnstone and Moynihan's (1985) findings in their research also support Kempa and Nicholls (1983). They found (by using word association tests) that there were significant differences between the emerging cognitive structures of 'good' and 'poor' pupils in terms of the complexity of the networks. In addition it was seen that few 'poor' pupils were able to get the correct answer in chemistry tests. This is further evidence that if a pupil possesses an unstable cognitive structure in a particular area of subject matter, then problem solving will be inhibited in that area. This also supports the idea of Novak et al. (1971) that the primary determinant of learning success is the availability of relevant subsumers in the cognitive structure of the learner.

Amir and Tamir (1995) state that measuring the meaningful organisation of concepts in a cognitive framework, which is the product of conscious and explicit linking of recently acquired knowledge to relevant concepts already existing in the student's cognitive structure, is not an easy task. They (1995) indicated that the clinical interview (Nussbaum and Novak, 1976) is one way of eliciting cognitive structure. However it is time consuming and not easily implemented with a large group of students. Alternatively, they introduced the proposition generating task in which students are required to consider just two concepts at a time, and construct a full sentence to explain the nature of the links between them. The results showed that a proposition generating task uncovers students' understanding of the relationship between the concepts of photosynthesis and respiration.

The most important factor in Ausubel's theory that prior knowledge as a factor influencing learning, is also very important in terms of the Information Processing Model. Because the perceptive filter uses prior knowledge in long term memory in order to select important information or stimuli before admitting it into working memory, it is important what concepts or misconceptions the learner already has, in other words what is available in long term memory. Also the contents of working memory interact with information from long term memory in order to find linkages to "make sense" of the new material. If this necessary long term memory information cannot be found or activated, it is not available to the working memory for its processing. Any processing which takes place will be faulty (leading to misconceptions) or be so poor as to result in rote, unconnected, boxed learning.

CHAPTER 2

Cognitive Styles

2.1 Introduction

After the increasing interest in Psychology (especially cognitive psychology) in Science Education, learner characteristics have had a wide effect among science educators. This is based on the notion that instructional procedures in science education should be matched to learner characteristics in order to maximise the effectiveness of the teaching and learning process (Kempa, 1992). According to Johnstone (1991) individual differences in learning and teaching of any subject matter, is one of the most striking phenomena. Among the learner characteristics that have been considered, the cognitive styles of the students have been studied largely in science and mathematics.

As pointed out at the beginning of the thesis (in Introduction, page 3), one of the questions which have been addressed in this study was to explore the effect of some psychological factors (i.e. Field Dependence/Field Independence and Convergence/Divergence and Working Memory Capacity) on the pattern of relationship between ideas in pupils/students' Long Term Memory. In this chapter the literature review about two of the most influential cognitive styles in science education i.e. field dependence - field independence and convergence - divergence will be considered. The information about working memory capacity has been given in a previous chapter (in Chapter 1).

2.2 What is a Cognitive Style?

When individuals are confronted with new information, they have different ways of selecting, perceiving and processing that information. This is related to what they already know, and their style of learning.

The concept of cognitive style is very closely connected with the idea of psychological differentiation. This means, in a broad sense, that differences exist between different individuals in relation to their cognitive structure and psychological functioning or as Witkin (1974) called it, "psychological individuality". Cross (1976) pointed out that each individual has his own style for collecting and organising information into beneficial knowledge. What is more, some students approach to learning is analytical and systematic while others are intuitive and global. Some students will perform best in groups, while others will do better learning alone. Some students prefer abstract materials and formal discussions, while others prefer concrete material and intuitive argument.

Witkin et al. (1981) indicated that cognitive styles are ways of moving towards goals rather than goal attainment, and they are stable over time. He noted that this stability extends not only over weeks and months, but over years. Therefore it can be deduced that, any educational implications of cognitive styles may have long term validity. Yet it does not mean that they are totally unchangeable. Harmon (1984) suggested that cognitive styles are relatively independent of abilities and aptitudes. Ability and aptitude represent a power to do, however cognitive styles refer to the way the power is used.

Saracko (1997) said that cognitive styles identify the ways individuals react to different situations and they include stable attitudes, preferences, or habitual strategies that distinguish the individual styles of perceiving, remembering, thinking and problem solving.

2.2.1 Field Dependent - Field Independent Cognitive Styles

2.2.1.1 Background

Students respond in various ways when they approach a mass of information, or stimulus complex, with a view to making sense of it. Some of the signs within this stimulus complex are essential to this process and some of them are not important or may even be disturbing. It is necessary to mention that clearer or noticeable signs are not necessarily the most valuable when it comes to making sense of the stimulus complex. On the contrary, obvious signs may often obscure the presence of more essential, vital signs. The ability to select the most important signs, regardless of whether or not they are the most obvious, is related of student's field-dependence/field-independence cognitive styles.

The Field-dependence/Field-independence dimension of cognitive styles originated in Witkin's work (Witkin, 1974, 1977; Witkin et al., 1977; Witkin and Goodenough, 1981). They were extensively studied by several researchers and have had wide application to educational problems (Rollock, 1992; Tinajero and Paramo, 1997). Witkin and Goodenough (1981) describe an individual as **field-dependent** (FD), who has difficulty in separating an item from its context. And an individual is **field-independent** (FI), who can easily break up an organised field and separate relevant material from its context or discern *signal* (what matters) from *noise* (the incidental and peripheral) in a confusing background (Johnstone and Al-Naeme, 1991).

To determine an individual's level of field dependency, the group embedded figures test (GEFT), (or it is called Field Dependent/Field Independent tests) which is a paper-and-pencil test developed by Witkin et al. (1971) can be used. In this test, subjects are asked to recognise and identify a target figure within a complex pattern. The more target figures correctly found, the better the subject is at this process of separation and is said to be field independent, and vice versa for field dependent. There is, of course, a continuum between these two extremes and those of intermediate ability are classed as field intermediate. Field independent subjects are good at the GEFT and other tasks requiring perceptual restructuring because they are autonomous, impersonal, task-oriented people. However, field dependent subjects who have stronger interpersonal orientation and greater sensitivity to social stimulation are worse on restructuring tasks because of their reliance on other people and a less task-oriented approach (Meadows, 1993).

2.2.1.2 FD/FI and Global/Analytical Way of Approach

According to Witkin et al. (1977) a learner with an analytical style is more likely to analyse a field when the field is organised or to organise a field that lacks it. On the other hand, a learner with a global style is more likely to perceive a field as it is, without analysing and structuring it. The capacity for analysis and structuring of experiences is the core of the field dependence-independence cognitive style (Witkin 1974). Therefore it is necessary to mention that an analytical/global way of thinking may be the best criterion to differentiate the interests of field-dependent/field independent learners. Basically, field independent learners perceive and process information analytically, while field dependent learners do it in a global, holistic and passive way.

Frank and Keene (1993) signified that the theory of field-dependence/field-independence is related to the performance of individuals in analytical and global information processing. Witkin and Goodenough (1981) indicated that field independent learners show evidence of greater skills in their cognitive analysis and restructuring than field dependants. They also point out that individual differences can be thought of as an analytical field approach at one extreme and a global field approach at the other.

Actually, the capacity for analysis and structuring of experiences is the heart of field-dependence/field-independence cognitive style (Witkin, 1974). They suggested that "a tendency towards an analytical or global way of experiencing characterises a person's problem solving activities as well as his perception." It was also found by Witkin et al. (1977) that in problem solving tasks, when the solution depends on using an object in an unfamiliar way, field independent students are more likely to give a good performance than field dependent students.

2.2.1.3 FD/FI and Working Memory Capacity

Several researchers (e.g., Pascual-Leone, 1970; Case, 1974; Case and Globerson, 1974) suggested that field dependent/field independent subjects vary in the effective use of their working memory (*M-Space, working space or short term memory*). They are unanimous in the belief that the efficiency of performance of tasks in working memory is related to field dependence/field independence and they showed that field independent subjects are better in the recall of information stored in working memory than field dependent subjects.

In the literature there are a number of studies (e.g., Pascual Leone, 1970; Berger, 1977; El-Banna, 1987; Al-Naeme, 1988, 1991 and Ziane, 1990) which were done to investigate the relationship between working memory capacity and field-dependence/field independence in secondary school and tertiary levels. The results suggest that the larger the working memory capacity of a student, the more likely he/she is to be field independent. Berger (1977) applied to students the digit span test and two measures of field independence to shed light on whether there is any relationship between the variables. The results showed that field independent students perform better in working memory tests involving interference, than field dependents. He assumed that field independents are superior to field-dependents in the recall of information stored in the short term memory when interference is possible and when the load of information is high. According to Pascual-Leone (1970) cognitive processing takes place in M-Space. He express that field-independent ability is a developmental characteristic and learners with this ability may possess at the same time a high working space, in which case they may be described as high processors. El-Banna (1987) looked at the relationship between field-dependency and performance in chemistry exams for those of low, medium, and high working memory capacity. He found an obvious relationship between field dependency and performance among the low working memory capacity students, with performance declining when the student is more field dependent. The same relationship was observed for students who had medium working memory capacity, but students who had high working memory capacity showed no correlation between the two factors. A possible interpretation of these results is that students who have low working memory capacity cannot afford to devote any working space to the irrelevant, therefore field independent low working memory capacity would naturally succeed better than their field dependent counterparts. For students who had high working memory capacity, if the demand of the problem under consideration was within their capacity, then spare capacity existed to deal with excess, unimportant material so that no real drop in performance was observed because of field dependence (Johnstone and Al-Naeme, 1991).

Johnstone et al. (1993) suggested that field dependent students need more working space to compensate for their field-dependence characteristic. Nevertheless, it was seen in research done by Al-Naeme (1988) that there is little difference in performance between low working memory capacity-field independent students and high working memory capacity-field dependent students (Table 2.1).

Working Memory Capacity	*Mean scores %*		
	FD	FINT	FI
Low (N=77)	36.3	38.2	45.2
Middle (N=62)	42.1	44.8	47.4
High (N=90)	45.6	47.0	49.1

FD (Field Dependent)
FINT (Field Intermediate)
FI (Field Independent)

Table 2.1 The Overall performance for students of different capacities and different degrees of FD/FI in a chemistry examination (Adapted from Al-Naeme, 1988)

A possible explanation for this is that, when individuals are faced with a real problem solving situation in which both *signal* (what matters) and *noise* (the incidental and peripheral) information are present, the working space of high capacity students will be occupied with noise as well as signal because of their field-dependency characteristic. However, field independent individuals will take only the signal and ignore the noise and they can use all their limited low working space for useful processing. Therefore, high capacity-field dependent individuals cannot gain full benefit of their larger working memory, because it is reduced by the presence of useless information.

2.2.1.4 FD/FI, Concept Attainment and Cue Salience

In many research studies (e.g., Dickstein, 1968; Goodenough, 1976; Witkin et al., 1977) the performance of the field dependent and field independent individuals was compared in concept attainment tasks. In concept attainment problems the subject is presented with a series of stimuli, some of which are exemplars and others nonexamplars of the concept to be learned. For each stimulus the subject guesses whether it is an exemplar and then they are told whether his guesses are correct or not. This procedure lasts until the subject reaches some criterion of success in his guesses.

Goodenough (1976) stated that in concept attainment tasks the performances of field independent subjects are better than field dependent subjects. Dickstein (1968) suggested that the field dependency dimension plays a more important role than general intelligence in concept attainment. He found out that field independent subjects showed significantly greater readiness in concept attainment.

Concepts which are defined in terms of more salient (i.e. noticeable) cues are generally easier to learn than the concepts with defined non-salient (i.e. indistinct) cues. Because field dependent individuals are particularly responsive to the dominant arrangement of the field as given and are dominated by the most salient cues, cue salience has more effect on field dependent than field independent individuals (Witkin et al., 1977). Goodenough (1976) stated that concepts defined in terms of more salient cues have more effect on field-dependent than field independent individuals in conceptual learning. He argued that field independent students would learn concepts more rapidly when the salient cue is irrelevant to the definition of the concept. While field independent students tend to ignore the irrelevant attributes and non-salient cues in concept definition, field dependent students may demonstrate greater readiness when relevant cues and attributes are salient.

2.2.1.5 FD/FI and Academic Achievement in Science

In many studies (Witkin et al., 1977; MacDonald, 1984; Tinajero and Paramo, 1997) especially in Centre for Science Education in Glasgow University (El-Banna, 1987; Ziane, 1990; Johnstone and Al-Naeme, 1991; Alamolhodaei, 1996; Uz-Zaman, 1996; and Gray, 1997), the correlation between field-dependence/field independence and academic performance has been studied. The results indicate that field-independents score significantly higher than field-dependents in most of the academic fields of science.

Witkin et al. (1977) suggested that mathematicians, biologists, chemists, physicists, engineers and artists are analytical-impersonal people and field independents choose to specialise in such fields. On the other hand, field dependants show interest in global-interpersonal fields in particular, require social skills and may choose sociology, humanities, languages, clinical psychology, and nursing. Besides shifts out of science and mathematics were particularly common among field dependent students. They (1977) found a positive correlation between science courses and mathematics and measures of field dependence/field independence and they indicated that field independent students were significantly better than field dependent students.

El-Banna (1987) reported that there is a significant positive correlation between students' degree of field-dependence/independence and their scores in chemistry examinations. He also indicated that students who are field independent perform better than the students who are field dependent in all groups of different working space. Ziane (1990) pointed out that field dependency was found to play an essential role in students' success; field independent physics students obtained higher scores in solving physics problems than the students who have field dependent cognitive style. Al-Naeme (1991) also indicated that field dependent/field-independent cognitive style is very important and may play a crucial role in chemistry mini-project laboratory problem solving procedures. In addition he reported that field-independent students perform better than field-dependent students in conventional chemistry examinations. In the field of mathematics, Alamolhodaei (1996) suggested that field dependent/field independent cognitive styles have an effect in calculus learning and problem solving; field-independent students tend to perform better than field dependent students. In another study Tinajero and Paramo (1997) also found that field-dependence/field independence is related to the overall academic achievement and results indicated that field-independent boys and girls in secondary school level performed better than field-dependent ones in all of the subjects considered.

2.2.1.6 Teachers' and Students' Cognitive Styles

Witkin and Goodenough (1981) suggested that the interpersonal behaviour of field-dependent and field-independent students is different. Field independent students have an impersonal orientation. They tend to be not interested in others and ignore psychological and physical closeness to people. On the other hand field dependent students have stronger interpersonal orientation and greater sensitivity to social stimulation. They show strong interest in others and like to be physically close to people.

The studies of the results by Witkin et al. (1977) indicated that there was a difference in the approach of teachers who were different in cognitive style. Field dependent teachers favour teaching situations that allow interaction with students. They are more student-centred in their behaviour and teaching approach. In contrast field-independent teachers emphasise teachers' standards. In addition field independent teachers tend to use questions as instructional tools more frequently than the field dependent teachers. Field independent teachers tend to use questions primarily to check on student learning following instruction.

Some research studies suggested that a match between students' and teachers' cognitive styles plays a positive role in the teaching and learning behaviour. For example, Witkin et al. (1977) indicated that teachers may do better with the students with the same cognitive styles and students may learn effectively when taught by teachers who have the same cognitive style.

Jolly and Strawitz (1984) designed a study to determine whether biology students who were matched with their teachers in cognitive style (field dependence-field independence) gained significantly higher mean scores on a cognitive test in biology than did biology students who were mismatched with their teachers in cognitive style. The result showed that field independent students achieved equally well with field independent or field dependent teachers. However, field dependent students taught by field independent teachers achieved significantly higher mean scores than did field dependent students taught by field dependent teachers. Because field independent teachers structured information and this appeared to help field dependent students who had difficulty in doing this for themselves. They concluded that the match between teacher and student cognitive style may not bring about the highest achievement in students. Henderson (1981) also found that there was no correlation between science achievement and mismatch between the cognitive styles of black students and instructor.

The results of the studies would seem to suggest that the match between students' and teachers' cognitive styles does not bring positive results for everyone. However, if the differences in teaching approaches in the classroom related to differences in teachers' cognitive styles, then the question arises as to whether teachers are able to adopt teaching approaches, other than those fostered by their cognitive styles in order to meet the needs of the students in the classroom, each one of them having different cognitive styles.

2.2.2 Convergent - Divergent Cognitive Styles

The idea of convergers and divergers originated in Hudson's (1966, 1968) work. However, the studies of Getzels and Jackson formed a background for him. Getzels and Jackson (1962) did a study on intelligence. They differentiated two groups of learners. The first group was called "High IQ" learners, who obtained high scores in intelligence tests, but were relatively weak on the test of creativity. The second group was called "High creative" learners who were good at the creativity tests but had relatively low scores in intelligence tests. Hudson (1966) called a high IQ learner a *converger* and a high creative learner a *diverger* and two styles of reasoning, convergent and divergent, respectively. Then he created two new *open-ended* tests. The first concerned the meaning of words (How many meanings can you think of for each following words?) and the second concerned the uses of objects (How many uses can you think of for each of the following objects?). He defined a converger as one who scores better in intelligence tests than open-ended tests; the diverger is the reverse. In addition there are *all rounders* who are more or less equally good (or bad) on both types of tests.

Hudson (1966, 1968) indicated that the convergence/divergence dimension is a measure of bias, not a level of ability as it is possible for a converger to have higher score in open-ended tests than a diverger as a result of having a quite exceptionally high IQ score, or as a result of the diverger's IQ being exceptionally low.

Convergent thinkers have been defined and distinguished by their comparatively high scores in problems requiring one conventionally accepted solution clearly obtainable from the information available (as in intelligence tests), whilst at the same time obtaining low scores in problems requiring the generation of several equally acceptable solutions (typified in divergent thinking tests). The reverse arrangement defines divergent thinkers (Child and Smithers, 1973). To put it more simply, divergers can find a greater variety of answers to a problem. Convergers can see information leading to a restricted answer or solution.

In the research literature, tests of divergent thinking tended to become synonymous with tests of creativity. However several researchers (e.g., Nuttall, 1972; Bennett, 1973; Runco, 1986) do not agree with that. Runco (1986) suggested that divergent thinking style is of course not absolutely synonymous with creative ability. It is just one component of creativity in spite of the fact that divergent thinking tests are psychometrically reliable and widely employed as estimates of creative potential. Runco found in his study that divergent thinking and creative performance were moderately related in gifted school children, but unrelated in the non-gifted sample.

According to the studies in the literature (mainly the studies of Hudson 1966, 1968) the general characteristics of convergent and divergent thinkers can be outlined as in Table 2.2.

Cognitive styles	Characteristics
Convergers	* higher performance in intelligence tests * good at the practical application of ideas * specialised in physical science and classics * prefer formal materials and logical arguments * ability to focus hypothetical-deductive reasoning on specific problems * better in abstract conceptualisation * hold conventional attitudes * like unambiguity * emotionally inhibited
Divergers	* higher performance in open-ended tests * fine at generating ideas and seeing things from different perspectives * specialised in the arts * better in concrete experience * interested in people * hold unconventional attitudes * strong in imaginative ability * more likely to be witty

Table 2.2 General characteristics of convergent and divergent thinkers

2.2.2.1 Convergence - Divergence Dimension and Arts, Science Choice

The central result in Hudson's (1966) study was that most arts specialists, weak in the IQ tests, were much better at the open-ended ones; most scientists were the reverse. Arts specialists are on the whole divergers, physical scientists convergers. Between three and four divergers go into arts subjects such as history, English literature and modern languages for everyone that goes into physical science. And, vice versa, between three and four convergers do mathematics, physics and chemistry for every one that goes into arts. Several research studies (e.g., Mackay and Cameron, 1968; Field and Poole, 1970; Child and Smithers, 1973; Lloyd-Bostock, 1979; Webster and Walker, 1981; Runco, 1986) in the literature would seem to support these findings of Hudson.
Hudson (1968) clearly sees convergence and divergence as a cause rather than an effect of subject choices and he suggests that its origin may be found in early childhood. On the other hand, Butcher (1968) indicated that this study of Hudson in the upper forms of English schools should be replicated in other types of schools and at other ability levels. There is evidence to support the opinion that educational experience is a reinforcing factor in the development of cognitive style, rather than the prime cause (Povey, 1970).

Teachers may play a part in shaping the thinking style of students. When pupils come to school they already have many things in their heads from their family, but they also have started to learn new things around them and the teacher as a model, may have an effect on many students. For instance, in teaching situations of biology, teachers may encourage students to recognise that there can be only one correct answer to some questions in biology (convergent thinking) in other situations there cannot be only one answer to particular questions, for instance in evolution where there can be variety of answers (divergent thinking). The best recommendation of the teachers in biology might be to encourage students to start with a divergent way of thinking (thinking in a flexible way about several answers and evaluate them) and then converge to find the best answer.

Field and Poole's (1970) results showed that even though the majority of science specialists entering university were convergent thinkers, it is mainly the divergent thinkers among them who finally achieved the better results. Runco (1986) pointed out that there were particular domains of performance, for instance art and writing, that were more strongly related to divergent thinking than other areas such as music and science.

Hudson's view on convergence, divergence and academic choice received only partial support in the study of Lloyd-Bostock (1979). In her study a significant relationship was seen between arts orientation and divergent cognitive style as distinct from a convergent one, before any specialisation occurred. However, Hartlet and Greggs (1997) found in their study that arts students do not differ significantly from science students regarding the score they gained in divergent thinking tests.

Someone may question if there is any discipline which does not fall into just one dimension of the cognitive styles of divergent and convergent thinking. It was seen earlier in Hudson's study (1966) that biology, geography, economics and general arts courses and later in Orton's (1992) study that biology, geography, economics attract convergers and divergers in approximately equal proportions.

2.2.2.2 Convergent - Divergent Cognitive Styles and Performance in Science

Convergence - Divergence dimensions have had an influence on the thinking of science educators, but not as much as Field dependence/Field independence dimension of cognitive styles. In the literature some research studies were reported mostly in particular branches of science, for example, in chemistry (not in biology or physics) and mathematics regarding the effect of students' performance and their convergent-divergent thinking styles.

It was seen in the study done by Field and Poole (1970) that senior Australian undergraduate students who were outstanding at the end of the science course were mainly the students who had divergent thinking styles. Furthermore they noted that while a convergent bias associated with high level students' passes in the first year of study, there was no difference in the relative success of convergent students in the second year.

Kempa (1992) has looked at the aspects in chemistry; (i) the students' perception of the ease or difficulty of learning from the discovery learning/expository teaching, (ii) their 'enjoyment' of learning from the two methods. The results showed that divergent thinkers clearly find the discovery learning mode more difficult than do their convergent counterparts. In terms of enjoyment the difference between two groups was not statistically significant.

The results of Al-Naeme's (1991) study in chemistry showed that convergent and divergent thinking styles play an important role in problem solving in mini projects, in which divergent students showed better performance and higher scores than convergent students. He looked at the convergence-divergence dimension along with the field dependence-independence dimension of cognitive styles. Although it was found that divergent students had higher scores than convergent students he emphasised that field dependent-field independent learning styles were better predictors of success than convergent-divergent learning styles in tackling the mini project problems in chemistry.

As mentioned earlier, most of the convergers tend to choose science subjects such as chemistry, physics, but this tends not to be the case for biology because it attracts both groups of students (Hudson, 1966; Orton, 1992). Biology might be one of the science branches in which students might cope equally well with a convergent or a divergent bias. Johnstone and Al-Naeme (1995) indicated that much science teaching is convergent and students are rewarded for convergent thinking leading to unique specific answers. However, the research results so far would seem to suggest that the divergent students have higher scores than convergent students in science. How can it be possible? The answer might be related with the assessment techniques. When one is looking at the relationship between students' performance in any topic and their cognitive styles, the type of assessment techniques used, such as multiple choice type of question, essay questions, projects and so forth should be reported because a particular type of assessment technique may favour a particular kind of cognitive style.

CHAPTER 3

Techniques to Reveal Cognitive Structure

3.1 Introduction

How is it possible to gain useful insights into the ideas lodged in a student's cognitive structure? How is it possible to explore the pattern of relationships among concepts in students' Long Term Memory? How can it be established whether they have good patterns of knowledge or have understood what they are taught? There are several techniques which have been reported in the literature to probe into the cognitive structure of the students. In this study, three methods, namely *word association tests, mind maps* and *structural communication grids* have been used to answer the questions above. Therefore, the focus of this chapter will be on the literature of these three educational tools and their importance for science education.

3.2 Word Association Tests

3.2.1 Background

There are several methods to externalise (or to derive a picture of the relations between concepts) and to measure the cognitive structure of students. A word association test (WAT) is one of the commonest and oldest methods for investigating cognitive structure and has been used by several researchers (e.g., Deese, 1965; Shavelson, 1972, 1973, 1974; Geeslin and Shavelson, 1975; Preece, 1976, 1978; Kempa and Nicholls, 1983; Carrie, 1984; Johnstone and Moynihan, 1985; Cachapuz and Maskill, 1987; Gussarsky and Gorodetsky, 1988).

Word *association* means that things are connected to each other in the mind. The underlying assumption in a word association test is that the order of the response retrieval from long term memory reflects at least a significant part of the structure within and between concepts (Shavelson, 1972). In a word association test, the degree of overlap of response hierarchies is a measure of the semantic proximity of the stimulus words (Deese, 1965). As stated in section 1.4.1.2 (in Chapter 4) the results of several research studies (Rips et al., 1973; Ashcraft, 1978; Kounios and Holcomb, 1992) suggested a great regularity in semantic memory structure. Concepts farther removed from one another in the hierarchy require more time for retrieval. Concepts closer together in the hierarchy require less time for retrieval and are more central to the meaning of the concepts or categories. This is the *semantic relatedness* or *semantic distance effect*, which defines a fundamental generalisation: if two concepts are close in semantic memory (distance) or the more related they are, the faster is the mental search process which retrieves information about the concepts. This can be used to explain the importance of the order of the students' responses to each stimulus word in the word association tests (The detail about network models of semantic memory is given in section 1.4).

3.2.2 Method of Analysis

In a word association test, a small number, typically about ten, key (stimulus) words from the topic are selected and subjects are asked to write, for each stimulus word (taken one at a time) as many related terms as possible in a minute (or in 30 seconds). The most common method of analysing the responses to the key (stimulus) words is to measure the number of common words between responses to pairs of key words and their rank order. This is attempted in the formula by Garskoff and Houston (1963) to generate a *relatedness coefficient*, which could range from a value of 1 (perfect relatedness; possibly a synonym) to a value of 0 (totally unrelated). The formula of Garskoff and Houston to generate a relatedness coefficient was also used by several other researchers (e.g., Shavelson, 1972, 1974; Moynihan, 1981; Carrie, 1984). The information about the formula is given in detail in section 5.3.2 (in Chapter 5). The calculated relatedness coefficient values between the stimulus words can also be used to draw a network map (or a cognitive map) that shows the closeness of relationships between stimulus words.

Apart from looking at the overlap between the responses of stimulus words, a number of different scores are commonly derived from the list of responses to each stimulus word in the WAT: (i) the number of responses to each stimulus word, and (ii) the nature of these responses (Shavelson 1974). According to White and Gunstone (1992), it is reasonable to assume that the greater the total number of responses listed the better the understanding. The number of different responses for a word is a significant and direct indication of the individual's understanding of the word, because meaning can be defined as being proportional to the number and complexity of the links the individual can make to the word. When the students study the topic, the stimulus words should increase in meaningfulness, and so the average number of responses to each concept should increase. In other words, the number of "meaningful and acceptable response words" to a stimulus word might be proportional to the meaningfulness of the key concept. Without any connections, as Schaefer (1979) noted, a word is relatively meaningless, and its meaning is enriched as more connections are formed.

3.2.3 Potential Use of Word Association Tests in Science Education

Results of several research studies in the literature in the field of science education suggest that the word association tests can be used as a tool to elicit the associations students have formed between concepts, i.e. as a diagnostic tool and to measure understanding of concepts and topics, i.e. as an assessment tool to detect changes between pre- and post instruction.

Kempa and Nicholls (1983) used the word association tests to look at the relationship between students' cognitive structure (it refers to the pattern of relationships between concepts within the memory) and their problem solving abilities in the context of chemistry. It was found that the more branched and networked the knowledge is in a student's mind, the more accessible it is and the more effective it is for problem solving. Where the concepts are only weakly linked, access to one concept via another is not readily achieved and problem solving, in which the link is essential, does not readily occur. Cognitive structures of good problem solvers are more complex and contain more associations than those of poor problem solvers for given levels of relationships between concepts.

In another research study, the word association test was used to map cognitive structure of areas of the Scottish Chemistry Syllabus for secondary schools (Johnstone and Moynihan, 1985). They measured the performance of pupils in the WAT by awarding one mark for each acceptable response. The pupils were then divided into 'good' and 'poor' on the ground of class tests in chemistry and the researchers calculated mean relatedness coefficient scores graphed using the technique of Waern (1972). The results showed that there were significant differences between the measured cognitive structure of 'good' and 'poor' pupils (in terms of the complexity of their networks) and responses in exams in favour of 'good' pupils. In addition it was seen that only a few of the 'poor' pupils were able to get the correct answer in chemistry tests. This is further evidence that if a pupil possesses an unstable cognitive structure in a particular subject area then problem solving will be inhibited in that area.

Word association tests were used by a number of researchers to detect changes between pre- and post instruction, in other words to see concept growth. For instance, in Cachapuz and Maskill's (1987) study, students were given the WAT before instruction (WAT pre-test) to expose the students' prior knowledge about the chemistry topic of reaction kinetics. Then they were given the WAT after instruction (WAT post-test) to detect the changes teaching made. The WAT pre-test results showed that students had some prior knowledge of reaction kinetics although they had not been exposed to formal teaching in this topic. In terms of complexity of the network and associations between key words and their responses, the most obvious feature of the WAT pre-test was the isolated clusters around the key words. The network obtained in the WAT post-test were more complex, that is with few isolated clusters, suggesting that, as a result of the learning period, conceptual learning had taken place. Shavelson (1972) also found that (i) the achievement of students in the physics instruction group increased significantly from the WAT pre-test to the WAT post-test, (ii) cognitive structures of the students (the word association data) changed considerably during instruction, (iii) key concepts were interrelated more closely at the end of the instruction than at the beginning, and (iv) cognitive structure corresponded more closely to content structure at the end of instruction than at the beginning. However, similar changes for the control group (no instruction was given) were not observed.

As mentioned earlier, in order to measure the performance of students in the word association tests, one mark is given for each acceptable response. The relationships between performances in the word association tests and achievement in particular science topics were also reported. For example, Johnson (1967), reported that high achievers in physics on average gave a greater number of associations to all of the stimulus words than did the low achievers. Johnstone and Moynihan (1985), Cachapuz and Maskill's (1987) found in chemistry that there was a statistically significant positive correlation between performance of the students in the word association tests and in the objective chemistry test. On the other hand, Shavelson (1973) found no relation between number of responses on a word association test and achievement.

3.2.4 Criticism About Word Association Tests

In some responses for the key words, it may be seen that successive words show a chain of thought. However, in order to minimise the chaining effect, in which each response rather than the key word becomes the stimulus for the next response, each stimulus word can be written at the top of the page and 10 times down the side of the page so that subjects are encouraged to return to the key word after each association.

Sutton (1980) argues that when a child is presented with a key word and then responds with the first word he thinks of, or with a succession of words, going back to the stimulus word each time, there is empirical evidence for some connection in the child's awareness. However, in the generation of free associations there is almost an infinite number of possibilities. The responses may be adjectives or nouns, words which are associated just because they sound similar, or paired opposites, words that are similar in meaning or ones that are used together but the child does not know *why*, for instance acid/alkali or atom/molecule. The response word may be a superordinate class label, or a subordinate example, or neither. There is a randomness therefore in the products of word association tests.

Stewart (1979) criticised the word association tests as an assessment tool and as a representation of cognitive structure in the minds of the learner. His main attack was on the use of semantic proximity techniques for such assessment and he stated that "if semantic proximity (per se) is not the research interest, then these methods are useless". His reasoning is based on the statement of Shavelson (1972) that is, the underlying assumption in the WAT, that the order of the response retrieval from long term memory reflects at least a significant part of the structure within and between concepts. According to Stewart, this assumption of Shavelson is not reasonable and because of this position he claims that the interpretation of data made by researchers in the field require tremendous leaps of inference. On the other hand, Nagy (1983) opposes Stewart's criticism and he states that the inference required to interpret semantic proximity data as having a bearing on cognitive structure is no greater than the types of inference made on a routine basis by educational researchers and teachers. The second objection of Stewart is that proximity data could just as easily be interpreted as evidence of temporal contiguity rather than real learning. That is, a student may properly associate concepts not from any accurate understanding of their relationships, but simply from having heard or read them in the same sentence, paragraph, or class. It is true that a student may learn an association at nothing beyond the verbal level, for instance some stimulus-response pairs are common enough in popular culture, e.g. acid-rain, atomic-fusion etc. that one would have difficulty arguing for true understanding of the concepts on the basis of word association data alone. However, Nagy (1983) argues that if we were willing to infer that changes in achievement after instruction resulted from real learning, then in the light of such an acceptance of the achievement data, we ought to be willing to accept changes in the cognitive structuring (that can be seen in the word association data) as evidence of the same real learning.

Stewart (1979) also criticises the ability of "cognitive maps" produced from the word association test responses to reveal nature and quantity of the corresponding conceptual relationship which are used in problem solving. But the findings of two studies help to weaken this criticism. Because it was clearly seen that, where students did not relate a particular key word to other key words in the word association tests, they tended to be unable to solve the achievement test items requiring this conceptual relation (Cachapuz and Maskill, 1987). Also where existing concepts are firmly linked in the cognitive structure, facility values for questions testing these concepts are high (Johnstone and Moynihan, 1985).

White and Gunstone (1992) suggest that, in word association tests, inferences about understanding that are made from the response list are subjective and that a simple test of knowledge, that took about as much time as a word association test, could check more directly whether information had been acquired. Because it may be seen as less subjective it may remove the need for a word association test. But they (1992) argue that such a test would not, however, yield the same information nor have the same effect on learning. The key difference is that the word association test is open, allowing students to reveal links that they have made between the topic being assessed and other knowledge, while the knowledge test is closed, requiring specific responses. The word association emphasises links between concepts, while the knowledge tests may treat all items as separate. And the word association may bring students to appreciate the need to reflect on interlinking of topics, and so can promote superior habits of learning.

3.3 Mind Maps

Mind maps (or mind mapping) were developed in the 1970's by Tony Buzan. Then different versions of mind maps were developed by several researchers, but most of the essential characteristics in all versions are more or less similar.

In this research study mind maps were introduced to students to help in the planning of their essay writing as well as to gain an insight into ideas lodged in a student's cognitive structure, because mind maps, like concept maps, can serve as a vehicle for obtaining a graphic representation of information held in memory. However, it is important to mention that, in this study, the mind maps which were introduced to students were not exactly in the form of mind maps that Buzan (1995) suggested. In fact, the maps which were used in this study had some characteristics of concept maps (as in Figure 3.1) as well as mind maps (as in Figure 3.2). Furthermore a scoring key was developed to allow the quality of the maps to be graded. The detail will be given in section 5.4.3 (in Chapter 5).

3.3.1 Mind Maps and Concept Maps: Differences and Similarities

Sometimes the notion mind maps and concept maps are used interchangeably. However, there are some important differences between concepts maps and mind maps. These are differences with regard to; (i) the primary purpose of using the maps and, (ii) the layout. These differences and some similarities between the two techniques are given in Table 3.1.

Mind Maps	**Concept Maps**
Primary purpose	
A note taking technique for: * meetings and in lectures etc. * brainstorming and idea generation * making summaries from a book or a lecture	An educational tool: * to explore prior knowledge and misconceptions * to encourage meaningful learning to improve students' * to measure understanding of the knowledge
The Layout	
* Centre out hierarchy (i.e. most inclusive concept in the middle and more specific radiate out from centre * Branching of ideas, and examples * Cross links are not emphasised or shown. * Use of pictures, colourful pencils. * Words should be on the linking lines.	*Top down hierarchy (from most inclusive at the top to less inclusive the bottom) * Branching of ideas and examples * Crosslinks, which indicate creative ability between ideas are * Words should be at the end of the linking lines.

Table 3.1 The differences between mind maps and concept maps in terms of primary purpose of using the maps and the layout

It is also important to mention that **concept maps** developed as an outgrowth of Ausubel's theory of learning, therefore they concentrate mainly in the importance of prior knowledge and meaningful learning. Concept maps are also used as a testing device and when they are used in summative assessment (i.e. assessment aimed at measuring learning outcomes on completion of a course or topic) they can be scored. Various scoring keys or schemes of concept maps have been reported in the literature (e.g., Novak and Gowin, 1984; Stuart, 1985; Vargas and Alvarez, 1992; Wallace and Mintzes, 1990; Markham et al., 1994). These scoring keys differ in the attributes of concept maps which are included and the scoring weight assigned to each of the attributes. Novak and Gowin (1984), for example, suggest scoring on a number of criteria: the number and meaningfulness of links between ideas; the extent to which the map reveals appropriate hierarchy among the concepts; the existence of the cross links between different parts of the concepts hierarchy; the provision of appropriate examples. For each criterion different points are awarded.

Mind maps are based on associations in which proximity and connections between the words are strongly emphasised. But theory of learning is not implied explicitly. Furthermore, they have never been used as testing devices and have never been scored to measure the performance of the students in mind mapping.

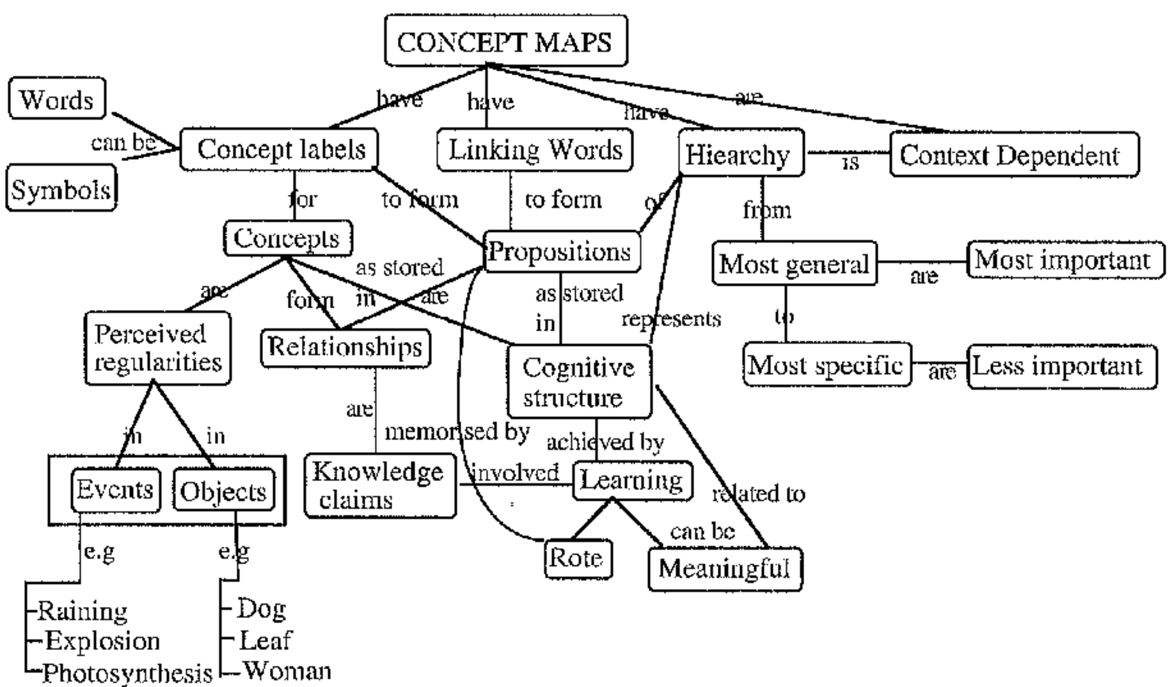


Figure 3.1 A concept map showing the key figures and ideas that underlie concept maps (Adapted from Novak and Gowin, 1984)

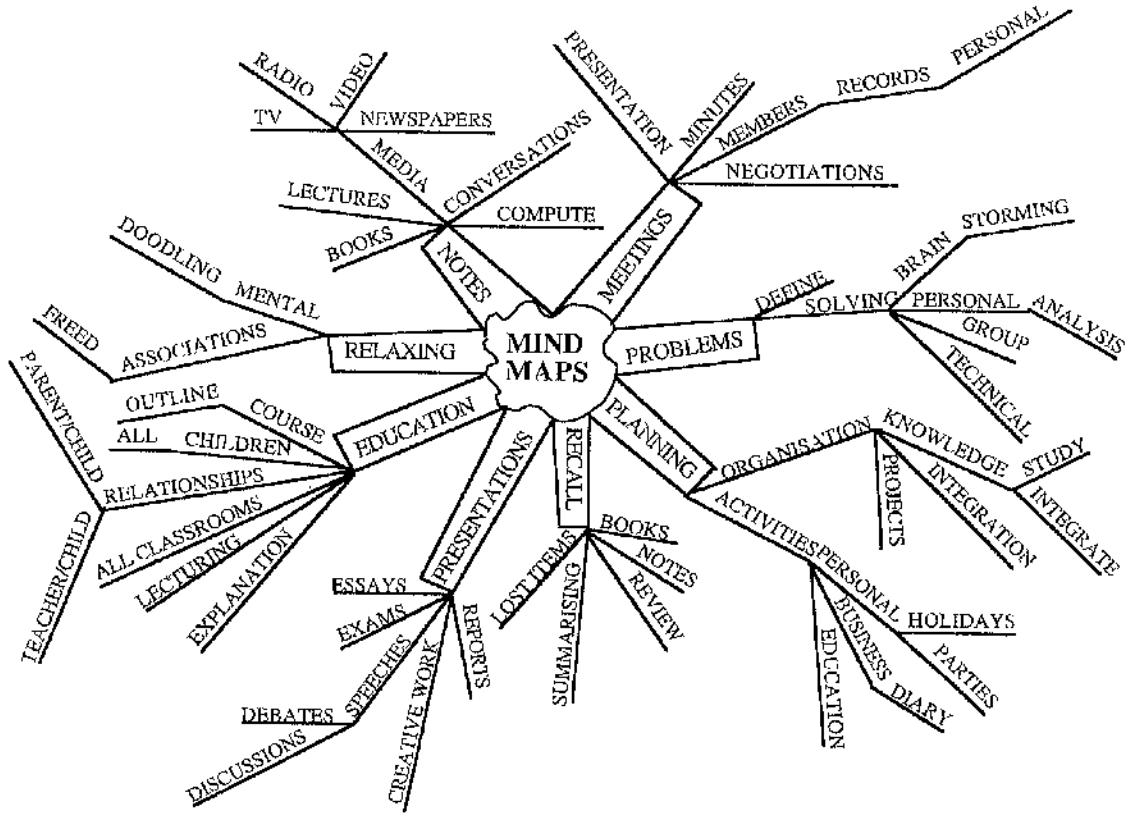


Figure 3.2 A mind map on the uses of mind maps (Adapted from Buzan, 1995)

3.3.2 Key words

The notion of "Key words" (or the most inclusive concept in concept maps) is very important for mind maps and also for word associations. If someone wants to remember the essential information in a text or anything read, it should be possible to pick the key words from it. They are the words that help to recall the text.

Buzan (1995) states that "the main body of a person's recalling, is of this Key Concept nature. It is not, as is often assumed, a word-for-word verbatim process. When people describe books they have read or places they have been to, they do not start to re-read from memory. They give Key Concept overviews outlining the main characters, settings, events and add descriptive detail. Similarly a single key word or phrase will bring back whole ranges of experience and sensation". In Buzan's "Bur model" (1995) every word is multi-ordinate, which means that each word is like a little centre on which there are many "hooks". Each hook, when it attaches to another word changes the meaning of the word. Because each person has a different kind of experience, each association between the words may be unique.

As was mentioned in the network models (in Chapter 1, in section 1.4.1) and in the word association tests (in section 3.2.1, in Chapter 3), there is great regularity in the semantic memory structure. Concepts further removed from one another in the hierarchy require more time for retrieval. Concepts closer together in the hierarchy require less time for retrieval and are more central to the meaning of the concepts or categories. In terms of mind maps, it may be that the key words locate in the middle of any hierarchical level in this conceptual network in semantic memory and may have the greatest links with other concepts (mainly strong and less weak) and therefore key concepts may aid easy access to its related concepts and to remembering.

3.4 Structural Communication Grids

Structural communication grids (SCG) are powerful assessment techniques, but it can be said that they have not been given enough attention in the assessment field, which they deserve. The earliest work was done by Egan (1972) and since then this technique has been developed in Glasgow University by several researchers (e.g., Duncan, 1974; Johnstone and Mughol, 1978, 1979; Johnstone, 1981; Johnstone et al., 1981, 1983; MacGuire, 1981; Carrie, 1984; MacGuire and Johnstone, 1987; Southern Exam Board, 1988; Scottish Exam Board, 1997). They used structural grid tests as an alternative method of diagnostic and summative testing.

3.4.1 Layout and Importance of SCG

In the SCG the data is presented in the form of a numbered grid (Figure 3.3). In order to construct the grids, the teacher asks himself a question, writes an answer and then breaks the answer into component parts, and scatters these randomly across the grid. He then asks a second <u>related</u> question and does the same, but some of the answer to question 2 may be common with question 1. He does this for a third or fourth question till the grid is full. Now he presents the grid and the questions to the students to (i) select the pieces (box numbers) needed to answer the grid question and (ii) to present these numbers in a logical sequence to show their reasoning. The student does this for each question. He thus communicates with the teacher through the structures he has imposed on the random grid, hence Structural Communication. This response shows the degree of completeness and interconnectedness in the student's knowledge in a given topic.

In terms of selecting the boxes, there are four possibilities.

(i) The student includes all the relevant information and omits all the irrelevant information. He gives a correct and complete sequence and gets full marks.
(ii) The student includes most, but not all the relevant information and includes no irrelevant information. This leads to a lesser score.
(iii) The student includes some or all relevant information along with some irrelevant information. Then he gets an even smaller score.
(iv) The student omits all relevant information and includes irrelevant information only and so gets a negative score.

The score for the selection can be obtained

$$\frac{\text{The number of relevant pieces choosen}}{\text{The number of relevant pieces}} - \frac{\text{The number of irrelevant pieces choosen}}{\text{The number of irrelevant pieces}}$$

According to this formula students' scores range from +1 through 0 to -1 and they can be handled easily by computer or manually from a table. This can then be multiplied by some factor to give the student a recognisable score. For example, add 1 to raw score (to get rid of the negative) and multiply by 5. The score would then range from 10 to zero.

In a 9 box grid, suppose that an answer needed four boxes. The pupil chooses three of these plus one irrelevant box (out of five). The score would be given by,

$$\text{Score} = \frac{3}{4} - \frac{1}{5} = 0.75 - 0.20$$
$$= 0.55$$

Now add 1 and multiply by 5

Final score = 5*(1.55)

= 7.75 or rounded to 8

At the second level of assessing the performance of the students (for the sequencing), a separate score is given. For instance, let us assume that after the student has selected the right boxes from the grids (grid contains 9 boxes), the correct sequence to answer a question is 2, 1, 3, 5 and 4. An exact match of the students' answer, results in full marks, and a complete mismatch results in zero marks. If a proportion of the sequence is correct in the student's answer, a rank order correlation can be applied to find out the degree of relationships between exact correct sequence and the student's responses and a proportion of the full score can be given. For example,

Ideal sequence= 2, 1, 3, 5, 4

A student's answer sequence= 2, 1, 4, 3, 5 scores 0.7 (i.e. rank order correlation value)

This can then be made a recognisable score by multiplying it by a factor which reflects the importance of the logical sequencing e.g. multiply by 10.

By using a computer, an alternative scoring method can be used. For instance, the computer checks the student's response by asking paired questions as follows:

Q1- Does 2 come before 1 and are they adjacent? *Yes or No/Yes or No*

Q2- Does 1 come before 3 and are they adjacent? *Yes or No/Yes or No*

Q3- Does 3 come before 5 and are they adjacent? *Yes or No/Yes or No*

Q4- Does 5 come before 4 and are they adjacent? *Yes or No/Yes or No*

If all answers are *No*, no score is given. If all answers are *Yes*, maximum score is given. If any of the answers is *No*, a reduced mark is given. For instance,

Ideal sequence= 2, 1, 3, 5, 4

A student's answer sequence= 2, 1, 4, 3, 5. For student's answer:

Q1- *Yes/Yes*

Q2- *Yes/No*

Q3- *Yes/Yes*

Q4- *No/No*

This student would obtain 5 out of 8.

It is necessary to mention that if a student includes an irrelevant response in the sequence, this is ignored in the sequence score because it has already been penalised in the first (selecting) score for including the wrong number of box i.e. in the selection of the right boxes.

The appropriate size of the grids can be arranged according to the age of the students using it. Twelve boxes (4*3 or 3*4) were found quite appropriate for pupils at the last stage of secondary school and for first year students in university.

1	2	3	4
5	6	7	8
9	10	11	12

Figure 3.3 The basic structure of the SCG

The contents of the boxes can be words, phrases, pictures, equations, definitions, numbers, formulas and so on. When the students are presented with data in one of the forms above, because they do not know how many boxes are required to answer the question they have to consider the contents of each box and have to decide which box or boxes are part of the answer to the question asked. Therefore, it is reasonable to say that, in the SCG, the ability to select relevant from irrelevant is being tested. Also in addition to selecting information, students can be asked to place these responses in particular order (logical order). Because students do not know how many boxes they have to select and in which logical order they have to present the information in the boxes, guessing does not exist in SCG. This is unlike multiple choice questions in which guessing can play an important role.

Structural communication grids have been used successfully in various schools and disciplines by Johnstone and his co-workers. The Scottish Qualification Authority also uses them in national exams. The grid questions can be used to test:

(i) sequence information to give a coherent procedure,

(ii) recognise examples of a concept from non-examples,

(iii) select information which gives a description,

(iv) make deductions and inferences from information given.

The grids can be suitable for motivating students in self assessment. Students need to check themselves as to how the concepts are growing in their mind and they need feed-back that will send them back to their learning where they are weak. The grids can aid students to test relationships within the structure of the concepts in their cognitive structure, enable them to see where their linkages are strong and where they are weak or as isolated islands not connected to the main network.

Also structural communication grids can give to the teacher an opportunity to gain insight into student's thinking and to see where the misconceptions or mislinkages lie in a student's mind. Because selecting each piece of information in the boxes and judging which of these boxes are necessary to answer the question and putting them in logical order require a deep level of understanding and therefore ideas correctly chosen, ideas wrongly chosen, or correct ideas which have been omitted can give information to the teacher about the level of understanding and misconceptions which students have had in their mind.

CHAPTER 4

Methodology 1

4.1 Introduction

In this chapter the focus will be on the methodology which has been employed in the present research study to measure some psychological factors. The psychological factors which were used in this research study are Field Dependence/Field Independence, Convergence/Divergence dimensions of Cognitive Styles, and Working Memory Capacity. Several methods are used in cognitive psychology to measure these psychological factors. The researcher, however, applied some methods that have been developed and modified by other researchers at the Centre for Science Education in the University of Glasgow.

4.2 Student Samples for the Tests of the Psychological Factors

In the first year of the research study, in Autumn 1996, an attempt was made to select a sample from first year biology students in the University of Glasgow. Unfortunately, this attempt failed. However, the Department of Biology recommended another option, that is a "Volunteer group". In order to find volunteers we advertised the aims of the research in the laboratories and lecture theatres and a prize was offered. The advertisement sheet is given in Appendix 1. After much effort, 71 (37 Female and 34 Male) students turned out to be volunteers and they sat the tests for measuring Field-dependence/Field independence, Convergence/Divergence and Working Memory Capacity. However, it is important to mention that not all students sat the tests simultaneously. Because of the students' time constraints, several tests sessions were arranged for students and they sat these tests in this pre-arranged time.

In the second year of research study, in Spring 1998, a sample was chosen from first year biology students in the same university. 298 students took the Convergent/Divergent Tests along with other test that will be mentioned in the second part of the methodology.

In addition to the University sample, in the second year of the research study, 101 pupils, studying Higher Grade Biology, from 4 different schools in the Central Belt of Scotland were involved with the research. They were given the tests for Field dependence/Field independence (all of them) and Convergence/Divergence (Only 88 pupils). Table 4.1 shows the distribution of the sample for each school involved.

Selected schools	Number of Pupils
Linlithgow Academy	42
Bishopbriggs High School	32
Whitburn Academy	20
Bathgate Academy	7
Total	101

Table 4.1 The schools selected as the sample in the second year of the study

4.3 The Description of the Field Dependent/Field Independent Tests

As stated in section 2.2.1.1 (in Chapter 2) to determine an individual's level of field dependency a paper-and-pencil test, Field Dependent/Field Independent Tests (FD/FI tests) developed by Witkin et al. (1977) can be used. The version of FD/FI tests used in this research study, which had been used in the Centre for Science Education at Glasgow University by several researchers, includes 20 complex figures, apart from another 2 figures used as examples. Simple shapes are located in the last page of the FD/FI tests booklet as a specimen of the type to be found. Students are required to recognise and identify a hidden simple shape in each of the set of complex figures and outline it in pen or pencil on the lines of the complex figure. Students were given 15 minutes to complete the test. The version of FD/FI tests which was used in this research study is given in Appendix 2.

4.3.1 The Measurement of Field Dependence/Field Independence (FD/FI)

The main scoring scheme which is used for the FD/FI tests is to give one point for finding a correct simple shape embedded in a complex figure. The overall sum of these scores is the total mark which a student can gain. The possible maximum score that can be obtained is 20 because there are 20 complex patterns in total in the FD/FI tests.

In the FD/FI tests, students are asked to recognise and identify a sample figure within a complex pattern. The more sample figures correctly found, the better the subject is at this process of separation of a figure from a confusing background and is said to be field independent (FI), and vice versa for field dependent (FD). There is, of course, a continuum between these two extremes and those of intermediate ability are classified as field intermediate (FINT). A formula, which was taken from Alamolhodaei (1996) was used by the researcher to create these three categories. The same formula was also used by several researchers (e.g., Scardamalia, 1977 and Case, 1974). According to this pupils who scored more than a quarter of a standard deviation above the mean score were classified as field independent, while pupils who scored under a quarter of a standard deviation below the mean score were classified as field dependent and between a score of -0.25SD and +0.25SD were considered as field intermediate. These criteria were used both for the secondary schools and for the volunteer students sample. The classifications of the sample of first year biology students (volunteers group) and the secondary school pupils are given in Table 4.2. (Note: data for students' and pupils' scores in FD/FI tests are given in Appendix 3)

	FD	FINT	FI	Total
No. of Students	28 39.4%	9 12.7%	34 47.9%	71
No. of Pupils	40 39.6%	26 25.7%	35 34.7%	101

Table 4.2 Classification of the university and the school sample

4.4 The Measurement of Convergent /Divergent Thinking

The second psychological factor to be measured in this research study is the convergent/divergent thinking style. The main intention of such an assignment is to classify students/pupils into those who are divergent thinkers or convergent thinkers in their bias. Divergent thinkers are likely to find a greater variety of answers to a problem while convergent thinkers are likely to see information leading to a restricted answer or solution.

Based on Hudson's (1966,1968) and Child and Smither's (1973) research studies, a convergent thinker is defined as a learner whose performance on IQ tests (intelligence tests) would be better than on open-ended tests (divergent thinking tests). The reverse arrangement defines divergent thinker. In addition there are all rounders who are more or less equally good (or bad) on both types of tests.

4.4.1 Description of Convergent/Divergent Tests

This research study is based on Hudson's (1966) original work in this dimension of cognitive style. The researcher used a version of convergent/divergent tests (CON/DIV tests) which were modified from Al-Naeme's (1991) research study. The tests consist of six mini tests in which a limited time for completion for each is allowed. The students/pupils were instructed to write as many answers as possible for every question they were given. The descriptions of the six tests are as follows:

Test 1

This test was designed in order to find out the subjects' ability to generate words of the same or similar meaning to those given. Furthermore, at the beginning of the test in order to clarify what the student was required to do, an example was provided. For example, if the word was short was given a set words such as "abbreviated, limited, brief, concise, momentary, little, abrupt, petite, crisp and compact" might be expected. This test included three questions and the total time were given for this test was 4 minutes.

Test 2

In this test the subjects were asked to construct as many sentences as possible including four given specific words in each sentence and the words must be used in the form as given. But the sentences which did not make sense were not credited. An example was provided at the beginning and 4 minutes was given for this test.

Test 3

Most of the divergent tests are in verbal form. However, it is a fact that there are some students who perceive ideas more easily by pictures and diagrams. They are pictorial learners and thinkers. In order to give an opportunity to this type of student, a pictorial test was included. In this test the students were required to draw up to five different pictures to relate to the idea of the given word. Five minutes was set as the time limit and one example was also provided at the beginning of the test.

Test 4

The purpose of this test was to see how many things the subjects could think of that are alike in some way. They were asked to write all the things that are round or that are round more often than any other shape. An example was given at the beginning and 2 minutes was allowed for this test.

Test 5

The objective of this test was to measure the subjects' ability to think of as many words as they could that begin with one letter and end with another. For example, students were asked about the words which begin with the letter "G" and end with the letter "N". Names of the people or places were not allowed and the time limit was 2 minutes.

Test 6

This was a test to find how many ideas the subjects could think of about a given topic. They had to list all the ideas they could about a topic whether or not they seemed important to them. An example was given at the beginning of the test and 3 minutes were allowed to complete this test.

The total time allocated for these six mini tests was 20 minutes. The time limit for each test was controlled by the researcher during the session.

In order to measure the performance of the students/pupils one mark was given for every single correct response (Hudson, 1966). The highest possible score that could be gained in this test was 100. All tests are given in full in Appendix 4.

4.4.2 The Division of the Samples into Convergent/Divergent Thinkers

In his original study, Hudson (1966) divided his sample of school pupils (according to their performance in open-ended tests and IQ tests) into divergers (30%), who were predominantly better in the open-ended tests, and the convergers (30%), who were substantially superior at the IQ tests. There were also what can be classified the all-rounder (40%), who were more or less equally good (or bad) at both kinds of test. Furthermore, Hudson (1966) divided his sample again as extreme convergers (10%) and moderate convergers (20%), all rounder (40%), extreme divergers (10%) and moderate divergers (20%). But, Hudson neglected the all-rounder groups from his study because he thought that comparisons between contrasting groups (convergers versus divergers) are a convenient way of describing complex results.

In Al-Naeme's (1991) research study the mean score was regarded as a crucial point between moving from convergent thinking into divergent thinking styles or vice versa. Students who had scores below the mean were classified as convergent thinkers and the students who had scores above the mean were classified as divergent thinkers.

The divisions of Hudson or Al-Naeme were not used in this study. For the "volunteer university sample" (N=71) in the first year of research, the *Mean score±0.25SD* will be considered as a crucial point between moving from convergent thinking style into divergent thinking style or vice versa. Accordingly, a student who had a score above the Mean score+0.25SD would be classified as a divergent thinker (DIV), while a student who had a score below the Mean score-0.25SD would be classified as a convergent thinker (CON). Also any student who had a score between Mean score+0.25SD and Mean Score-0.25SD was classified as an all rounder (ALL R). Table 4.3 shows the number of students in these three categories in the volunteer sample.

	Group	CON	All R	DIV
Total	71	31 43.7%	16 22.5%	24 33.8%

Table 4.3 The Classification of the volunteer sample in terms of Convergence/Divergence

In the second year, for the first year university biology student sample and the secondary school sample, instead of the Mean score±0.25SD, the *Mean score±0.5SD* was considered as a crucial point between moving from convergent thinking style into divergent thinking style or vice versa. In the first year, for the volunteer sample, Mean score±0.25SD were used for classification because the total number of the students in the sample was not large (only 71 students). If Mean score±0.5SD had been used, a large number of students would have been classified as all rounders rather than convergers or divergers. However, in the second year, Mean score±0.5SD was used because the size of the samples was large. Therefore, a student who had a score above the Mean score+0.5SD would be classified as divergent thinker, while a student who had a score below the Mean score-0.5SD would be classified as convergent thinker. Thus any student who had a score between a score of +0.5SD and -0.5SD would be classified as all rounders. Table 4.4 shows the number of students and pupils in these three categories.

(Note: data for pupils' scores in CON/DIV tests are given in Appendix 3 and for University sample they are given in Appendix 5)

	Group Total	CON	All R	DIV
Schools sample	88	31 35.2%	31 35.2%	26 29.6%
University sample	298	90 30.2%	113 37.9%	95 31.9%

Table 4.4 The classification of the sample in the second year of the research in terms of CON/DIV

4.5 The Working Memory Capacity (WMC)

The capacity of the Working Memory (working space) is the third psychological factor which was used in this research study. As noted in section 1.2.2 (in Chapter 1), the most important characteristics of the working memory is that "it is a limited, shared space in which there is a trade-off between what has to be held in conscious memory and the processing activities required to handle it, transform it, manipulate it, and get it ready for storage in long term memory store. If there is too much to hold there is not enough space for processing; if a lot of processing required, we can not store much" (Johnstone, 1997).

4.5.1 The Measurement of Working Memory Capacity

There are a number of techniques in cognitive psychology to measure the capacity of working memory (e.g., digit-span backwards test, figure intersection test). In this study, the researcher used a test which involved holding, translating and rearranging. This test was developed and modified at the Centre for Science Education in the University of Glasgow and has been used by several researchers (e.g., Johnstone and El-Banna, 1986; Su, 1993; Selepeng, 1995).

In this test, students were given a date in words, for example "Twenty third October" and were asked to convert the date into digits (2 3 1 0) and arrange them in numerical order from the smallest to the largest (0 1 2 3). This had to be done entirely in the head. Then students were given a slightly longer date. In order to give students another chance two examples were provided for each level of complexity. A total of 12 dates were included in this test and each date was shown on the overhead projector. The smallest date in the test consisted of 3 digits and the largest date consisted of 8 digits. The time given (for looking at the date on the overhead projector and for writing in correct order on the sheet) was proportional to the number of digits in each date, for example for the date "Thirty first December" students were given 4 seconds, because there are four digits (1 1 2 3). The example of the test and the correct order of the digits are given in Appendix 6.

4.5.2 The Scoring Scheme and Classification of the Sample

In the test, the highest number of digits that a student was able to recall correctly in order was considered to be the size of his working memory space. If the student fails to give the correct order of digits for the two attempts at a given level, then the previous level is taken as the size of his working memory space. An example is given below in Table 4.5: (The capital letters stand for the date shown on the overhead projector)

A 1 4 5 √	D 1 1 4 3 2 9 √
A 1 3 7 √	D 1 1 2 2 7 9 X
B 0 1 2 3 √	E 1 2 6 7 8 9 9 X
B 1 1 2 3 √	E 0 1 5 1 6 7 8 X
C 1 4 5 8 9 √	F 1 2 1 2 1 8 4 9
C 1 1 2 7 9 X	F 2 3 7 6 5 8 8 9

Table 4.5 An example of scoring a student's responses in the tests to measure working memory capacity

The student above was therefore considered to have a working memory space equal to 6 because he failed in both attempts at giving the correct order of digits in section-E. If a student fails in both attempts at giving the correct order of digits, the more complex digits will not be considered (e.g., in section-F above) because the student would be unlikely to give the correct order of digits in section-F without having given at least one correct order of digits in section-E.

After making all responses, three groups of the students were classified: those giving the correct order of 3, 4 or 5 digits were considered as Low Working Memory Capacity (LWM), while those giving correct order of 7 or 8 digits as High Working Memory Capacity (HWM) and giving the correct order of 6 digits as Medium Working Memory Capacity (MWM). Only the first year biology students (volunteers group) in the first year of the research study were given the test to measure the working memory capacity. Table 4.6 shows the number of students in these three categories.

	Group	LWM	MWM	HWM
Total	71	29 40.8%	19 26.8%	23 32.4%

Table 4.6 The classification of the volunteer sample in terms of working memory capacity

In this research (as were the field intermediate and all rounders) the group of medium working memory capacity students was not considered.

4.6 Relationship between Psychological Factors

One of the purposes of this research study was to look at the relationship between some psychological factors (i.e. FD/FI, CON/DIV and WMC) and students' cognitive structure and also to find out if there was any connection between these psychological factors and to examine the overlap of them if any. An understanding of the psychological factors involved in this study could lead to an understanding of the laying down and interconnecting processes in the students' long term memory and to an understanding of students' performance and achievement in biology.

It is known from previous research studies that:

* Field dependence/field independence and convergence/divergence cognitive styles correlated positively but this correlation is quite, but not very significant (10% or 5% Level). In other words, these two factors are fairly independent. However, field independent students tended to be divergent thinkers and field dependent students tended to be convergent thinkers (Alamolhodaei, 1996; Johnstone and Al-Naeme, 1995).

* There is a significant positive correlation between field dependent/field independent cognitive styles and the size of working memory capacity. That is, field independent students tend to have high working memory capacity, field dependent students tend to have low working memory capacity (Pascual Leone, 1970; Berger, 1977; El-Banna, 1987; Al-Naeme, 1988; Ziane, 1990).

* The relationship between convergence/divergence cognitive styles and the size of working memory capacity is not known.

In this research study, in the light of previous research findings which were mentioned earlier, the following predictions are made concerning the correlations between these psychological factors:

1- A positive but not very significant correlation is expected between field-dependence/field-independence and convergence/divergence cognitive styles.

2- A significant positive correlation is expected between field-dependence/field independence cognitive style and the size of working memory capacity. Accordingly, more field independents are expected to fall in the category of high working memory space and more field dependants are expected to fall in the category of low working memory space.

4.6.1 Hypotheses

In the written literature, there have not been any studies that looked at the relationship between convergence/divergence cognitive styles and the size of working memory capacity. Therefore, the relationship between these two factors are not known. On this basis, for this research study, the following hypotheses are made;

Hypothesis 4.1- Divergent thinkers are expected to have high working memory capacity in order to generate ideas and see things from different perspectives.

Hypothesis 4.2- Most of the convergent thinkers might fall in the category of low working memory space, because they are not good at problems requiring the generation of severally equally acceptable solutions which may require high working memory capacity to juggle with them.

It is also known from previous research studies that the overall performance of the field independent student are better than field dependent students in conventional exams. Thus, overall performance of students who have high working memory capacity are better than the performance of the students who have low working memory capacity. In the same way, for this study, the performance of the field independent students is expected to be better than field dependent students and the performance of the students having high working memory capacity is expected to be better than low working memory capacity students in conventional biology exams. In terms of the performance of convergent and divergent students the following hypothesis is made;

Hypothesis 4.3- "The overall performance of convergent students are expected to be better than divergent students in the multiple choice questions (MCQ), because, in the MCQ, they are rewarded for convergent thinking leading to unique specific answers."

CHAPTER 5

Methodology 2

5.1 Introduction

In this chapter attention will be paid to the methodology of the three techniques, namely Word Association Tests (WAT), Mind Maps and Structural Communication Grids (SCG).

5.2 The Sample

The word association tests were applied in the first year (in Spring 1997) and in the second year (Spring 1998) of the research study to 280 first year biology students. Also, Mind Maps were applied in the second year (in Autumn 1997) of the present research study to the first year biology students in the same university. 400 students were involved with mind mapping. For the third technique, Structural Communication Grids, in the second year of the study, in Spring 1998, another attempt was made to select a sample of pupils from secondary schools in Scotland. 101 pupils, studying Higher Grade Biology, from 4 different school in the central belt of Scotland were involved in this research. They sat the Structural Communication Grids Tests with the tests for Field dependence/Field independence and Convergence/Divergence. Table 4.1 in section 4.2 (in Chapter 4) shows the distribution of the sample for each school which was involved with these three tests. All of this is set out in Table 5.1.

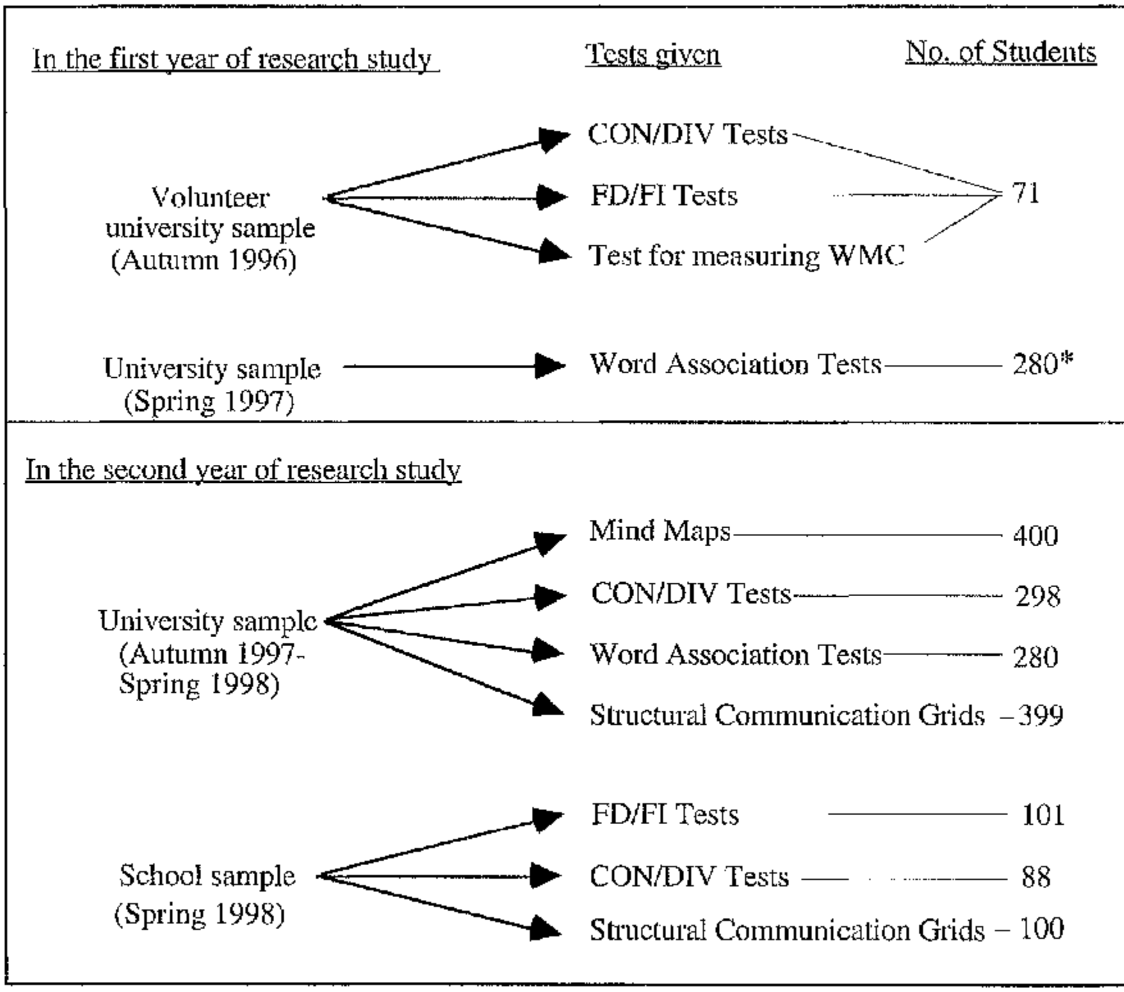


Table 5.1 The sample size of the each test and the time when they were applied

* This sample included the majority of the 71 volunteer students.

5.3 Word Association Tests

As stated in the literature review (in section 3.2, in Chapter 3), a word association test is one of the commonest and oldest methods for investigating cognitive structure and can be used as a tool to elicit the associations students have formed between concepts, i.e. as a diagnostic tool and to measure understanding of concepts and topics and also to detect changes between pre- and post instruction.

5.3.1 Description of the Word Association Tests and Procedure

In the first page of the word association tests students were given the instruction as follows: *When you hear or see a word, it often makes you think of other words. In this study we would like to find out what other words are brought to your mind by some words used in Genetics. On each page you will find a key word written many times. Say the word to yourself, and then as quickly as possible write the first word to come to mind in space Number 1. And then continue to write in the other spaces other associated words which come to mind. Continue in this way until you are told to turn the next page. There are no right answers. Write as quickly as possible since you are allowed only 30 sec. for each page.*

The second and third pages of the test contain examples of responses to the stimulus (key) words "Eagle" and "Photosynthesis".

To construct the word association test, the lecturer teaching genetics was asked to provide ten key words to act as stimuli. The stimulus words selected by the lecturer were the most important key ideas on which he had built his course. The stimulus words were *Mutation, Gene, Pedigree, Gamete, Chromosome, Phenotype, Cell Division, Genetic Engineering, Haemophilia and Backcross.* For each stimulus word, students were required to list ten words which they considered to be most closely associated with that stimulus word. For each stimulus word, students were given thirty seconds, like other researchers did. For instance, Kempa and Nicholls (1983) (Cachapuz and Maskill (1987) also gave thirty seconds for each stimulus word) allowed a response time of thirty seconds which had been established as an *optimum* time span during pretests. On the basis of these studies, in this study students were also given 30 seconds for each stimulus word. Students did the word association test in laboratory time and the total test time (5 min.) was controlled by the experimenter. The subjects were 280 first year biology students (roughly equal numbers of males and females) and they took the word association test at the end of the genetics course in Spring 1997 and 1998. The full word association tests are given in Appendix 7.

In the word association tests, each stimulus word was written at the top of the response form and ten times down the side of the page so that subjects were encouraged to return to the stimulus word after each association in order to minimise the chaining effect, in which each response, rather than the key word becomes the stimulus for the next response. An example of chaining, obtained from a student who ignored the instructions, was seen for the single stimulus word "mutation" when he formed the chain: DNA, ribose, sugar, glucose, sweets, chocolate, fat, obese.

5.3.2 Method of Analysis

The responses that are given to each stimulus word in a fixed time may be analysed in several ways. The most common analysis of the responses to the stimulus words works as follows. If stimulus word A generated a series of responses P, Q, R, S and another stimulus word B generated the same responses in the same order, we might be safe in assuming that words A and B are very closely associated with each other because they had so much in common. At the other extreme, if the responses to A and B shared no commonality, then A and B would be deemed to be unassociated. Between these two extremes one could visualise the responses to A and B to have some words (but not all) in common and the rank order of common words could be different. A measure of commonality would therefore have to take into account the *number* of common words and their *rank order*. This is attempted in the formula by Garskoff and Houston (1963) to generate a *relatedness coefficient,* which could range from a value of 1 (perfect relatedness; possibly a synonym) to a value of 0 (totally unrelated). The formula and a specimen calculation are given in Appendix 19. In this research study a computer program was written in c-programming language in order to calculate a set of relatedness coefficient values for each student, or for a set of mean relatedness coefficients for the whole class (N=280) or for a set of mean relatedness coefficients for a particular subgroup. The particular group was mentioned in here because, within this sample, there were some students from the groups who have taken psychological tests and the responses of these students who had a particular thinking style were compared. In order to present this set of calculated mean relatedness coefficients for the whole class or for a particular group in visualisable form, a network map (or cognitive map) was drawn. The details about the drawing of the map are given in Chapter 7. The computer program which was written to calculate relatedness coefficient values is given in Appendix 12.

In order to feed the computer program with the data, the researcher had to look at each student's responses for the stimulus words and had to count how many kinds of different valid words were used as a response. The words used in the count were taken to be "valid" if they are meaningful and acceptable in terms of genetics. Then a numerical code had to be given to each different response word. After that, responses were written in numerical codes for each student. One example of a student's responses is given below (Table 5.2):

1 0 0 0
1 111 116 0 0 0 0 0 0 0 0
2 90 136 162 12 66 13 65 273 0 0
3 52 51 63 83 173 0 0 0 0 0
4 179 62 36 67 116 0 0 0 0 0
5 156 59 66 0 0 0 0 0 0 0
6 20 77 80 0 0 0 0 0 0 0
7 165 150 253 99 225 12 0 0 0 0
8 136 143 0 125 144 2 44 0 0 0
9 48 217 119 80 58 50 139 0 0 0
10 70 15 75 127 132 1 16 11 0 0

Table 5.2 One example of a student's WAT responses in numerical codes

In the first line, 1 means first student and 0 0 0 stands for the psychological factors. A student was able to take a maximum of three tests, but not all students were given the whole set. There is a flag in the programme for each psychological factor. These flags are 1- Convergent, 2- Divergent and 3- All Rounder 4-Low working memory capacity 5-Medium working memory capacity and 6- High working memory capacity, 7- Field dependent 8- Field intermediate and 9- Field independent and 0 indicates no data available. Therefore, this student has not taken these tests and is indicated as 0 0 0. In the second line 1 indicates the first key word "Mutation", 111 stands for the response word "Defect", 116 stands for the response word "Down syndrome" in the frequency table is given in Appendix 8. This student has given only two responses for the first key word and the rest of the responses are therefore indicated as 0. In the third line 2 indicates the second key word and the numbers stand for the response words as above and so on. In the last line 10 stands for the tenth key word.

Appendix 8 shows the frequency table and the numerical code for the responses in the word association tests which were applied in 1997 and the frequency table and the numerical codes for the responses in the word association tests which were applied in 1998 is given in Appendix 9. The list of students' invalid WAT responses to the stimulus words are given in Appendix 10.

As mentioned in section 3.2.2 (in Chapter 3), in addition to looking at the overlap between the responses of stimulus words, a number of different scores can be derived from the list of responses to each stimulus word in the word association tests: (i) the number of responses to each stimulus word, and (ii) the nature of these responses (Shavelson, 1974). In this research study *the number of different "valid"* (meaningful, and acceptable in terms of genetics) *responses* to each stimulus word, and *the total number of different valid response words* for the whole sample or for any group in particular was also counted. What is more, as was done for the mean relatedness coefficient values, another network map was drawn in order to present the response frequencies in the word association test in visualisable form. All details are given about the maps in Chapter 7 (Results 2 and Discussions).

To allow a correlation to be sought between the conventional exams and the word association tests, each "valid" response in the word association tests was given a score of 1. The sum of these was then correlated with the score in the conventional exam tests. In addition, the mean scores of different psychological groups were compared.

5.3.3. Hypotheses

The following hypotheses were proposed in this research study with regard to WAT;

Hypothesis 5.1- Divergent thinkers are expected to have a higher number of different response words as well as average response words in the WAT than convergent thinkers. Thinking in a versatile way, producing ideas and seeing things from different perspectives requires a large store of different words in the long term memory.

Hypothesis 5.2- In terms of high number of responses and high number of different responses in the WAT, a substantial difference between field dependent - and field independent students is not expected. In the WAT, students did not have to break up an organised field and separate relevant material from its context or discern the "signal" (what matters) from the "noise" (the incidental and peripheral) against a confusing background.

Hypothesis 5.3- High working memory capacity students are expected to show higher performance in the WAT (in terms of total number of different response words and average different response words) than low working memory capacity students. The total number of different response words includes all the different responses to all key words.

Average number of different response words is calculated by dividing the total number of different responses to the total number of students in the group.

5.4 Mind Maps

In section 3.3.1 (in Chapter 3) the differences and similarities have been given between concept maps and mind maps. Mind maps are used primarily for note taking and for brain storming. On the other hand, concept maps are used as an educational tool for different purposes, such as an assessment tool to measure the understanding, or to reveal prior knowledge or misconceptions which students have in their mind or to aid meaningful learning.

In this study mind maps were not introduced to students in the form of the mind maps which are proposed by Buzan (1995). In fact, the maps which were used in this study had some characteristics of concept maps as well as mind maps. Furthermore a key was developed to allow the maps of the students to be scored.

5.4.1 The Purpose of Using Mind Maps

Students are often diffident about essay writing. In an essay, they are expected to present their ideas in the form of a logical argument and this argument should be supported by evidence coming from different sources. These ideas should be written in a structured way so that the reader can see the beginning, middle and the end of the argument. However, it is often the case that students produce the facts about the topic without considering the importance of the relationships between ideas. They may be able to recall the necessary facts about the topic but they often fail to present and relate them to each other. This problem can be even worse when writing an essay in an exam against the clock.

In traditional methods of essay writing, students are sometimes required to write a plan in the first page of their essay. This plan includes the most important elements of the essay subject and helps students to marshal the major points which should be mentioned and extended in the essay. Most of the time their plans are in a linear form. One example of the linear plan of a student who did not draw a mind map is given below (Note: Essay topic was "Seed Germination").

Introduction: Seed dormancy, The needs to be broken. Light, O_2, Warmth. Why cell needs the ideal condition to grow?

Middle: 4 Factors, - Light, Chemical inhibition (Abscisic acid), Chill factor, Impermeable coat. Phytochrome system P_R & P_{FR}

Gibberelin in the embryo --- aleurone layer -- alpha amylase--- starch --- glucose (also proteins -- embryo (GROWTH!) Diagram of cell (and removal of embryo)

Conclusion: Ideal conditions, germination -- photosynthesis. Industrial importance.

Mind maps have the advantages over a linear way of writing a plan and in this study it was thought that students could use these advantages of the mind maps for better planning and for a better essay writing. Buzan (1995) summarises the advantages of mind maps compared to linear way of writing as:

1- *The centre with the main idea is more clearly defined.*

2- *The relative importance of each idea is clearly indicated. More important ideas will be nearer the centre and less important ideas will be near the edge.*

3- *The links between the key words will be immediately recognisable due to their proximity and connection.*

4- *As a result of the above, recall and review will be both more effective and more rapid.*

5- *The nature of the structure allows for the easy addition of new information without messy scratching out or squeezing in, etc.*

6- *The shape and contents of each map will be different from each other map and this will assist recall.*

7- *In the creative area of note making the open-ended nature of the map will enable the mind to make new connections far more readily.*

In mind maps also, putting the key concept in the middle of the page (rather than putting the most inclusive idea at the top of the page as in concept mapping) can give more freedom to the student in terms of writing their ideas and they can feel less restricted. Broody (1994) states that the top down hierarchy of concept maps as described by Novak and Gowin (1984) typically does not give evidence of the centrality of the concept that is the basis of the map. This centrality is better communicated when the most inclusive concept is located in the middle of the map. This arrangement also gives a better opportunity for the concept mapper to balance different areas of the map in relation to each other. During the formation of the map, the order of essay presentation is implied and can be left till a later stage in the planning.

The use of mind maps was planned to aid students towards better essay writing as well as to gain an insight into students' ideas lodged in cognitive structure. Because mind maps, like concept maps, can serve as a vehicle for obtaining a graphic representation of information held in memory, then students can realise that the ideas or concepts in their minds are interrelated (like a network) as well as being hierarchical. This power of mind maps should also enable us to look at the associations between ideas which students formed in their minds and to see the effect of particular thinking styles, such as convergence and divergence, over these associations between ideas which formed.

In addition of using mind maps for better planning (and for better essay writing) as an alternative to linear writing plan and to see the effect of particular thinking styles over the associations between ideas, mind maps also were used in this study to reveal the missing ideas and misconceptions (i.e. ideas which are scientifically not true) in students' essays on Seed Germination.

5.4.2 Procedure of Mind Mapping

In the second year of the study (in Autumn 1997), the first year biology students in the university were shown how to use mind mapping in a short tutorial. 400 students were given instructions about mind mapping while the rest of students (361) were not given this tutorial instruction.

For the mind mapping exercise students were given information about the purpose and the advantages of the technique. Then they were given an example how to construct a mind map step by step. Students were encouraged to participate in the construction of the mind map and they were allowed to see how each main idea radiating from key concept was developed and further branched. The first example which was given on the blackboard was about a general topic: "Visiting Glasgow." However, the second example which was based on a biological concept was given as a handout to the students. This example is given below in order to explain how the mind maps were constructed and what the most important characteristics were. Here is the example:

"*For most students, writing an essay is not easy. They may not be able to get their ideas together when they sit down to write. Mind mapping is one way to ease you over this* *hurdle. It serves as a vehicle for obtaining a graphic representation of information held in your memory.*

Let's use this idea to prepare an essay on "The Food Chain". Rather than starting from the top and working down, you can start from the centre with the Key concept (Food Chain) and branch out from the key concept with the main ideas (as in Figure 5.1).

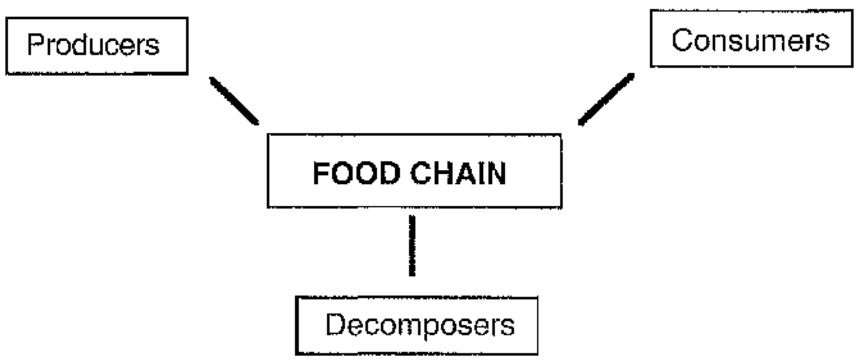


Figure 5.1 Main ideas which are branching out from the key concept

Now, take each of the main ideas and allow them to branch and interconnect as in the main idea (Consumers) shown below (Figure 5.2). Consumers can be branched into; carnivores, herbivores, and omnivores. These subconcepts can be further interconnected, i.e. omnivores can eat herbivores and carnivores, carnivores can eat herbivores. As seen, the main ideas are interconnected; for example, consumers can eat producers and both producers and consumers are broken down by decomposers.

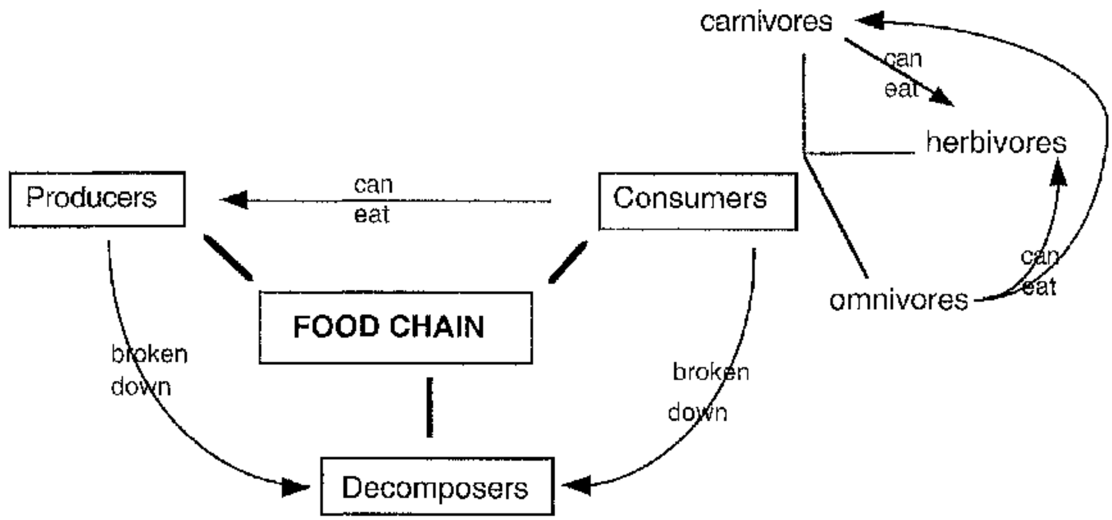


Figure 5.2 Branching out one of the main ideas

Once each main idea has been expanded and all interconnections made, the visual image of the completed mind map is more apparent.

The centre with the main idea is more clearly defined.

The relative importance of each idea is clearly indicated. More important ideas will be nearer the centre and less important ideas nearer the edge.

The links between the key concept and the main ideas will be immediately recognisable.

This will allow you to sequence your main ideas (1 Producers, 2 Consumers, 3 Decomposers) into a logical order (as in Figure 5.3).

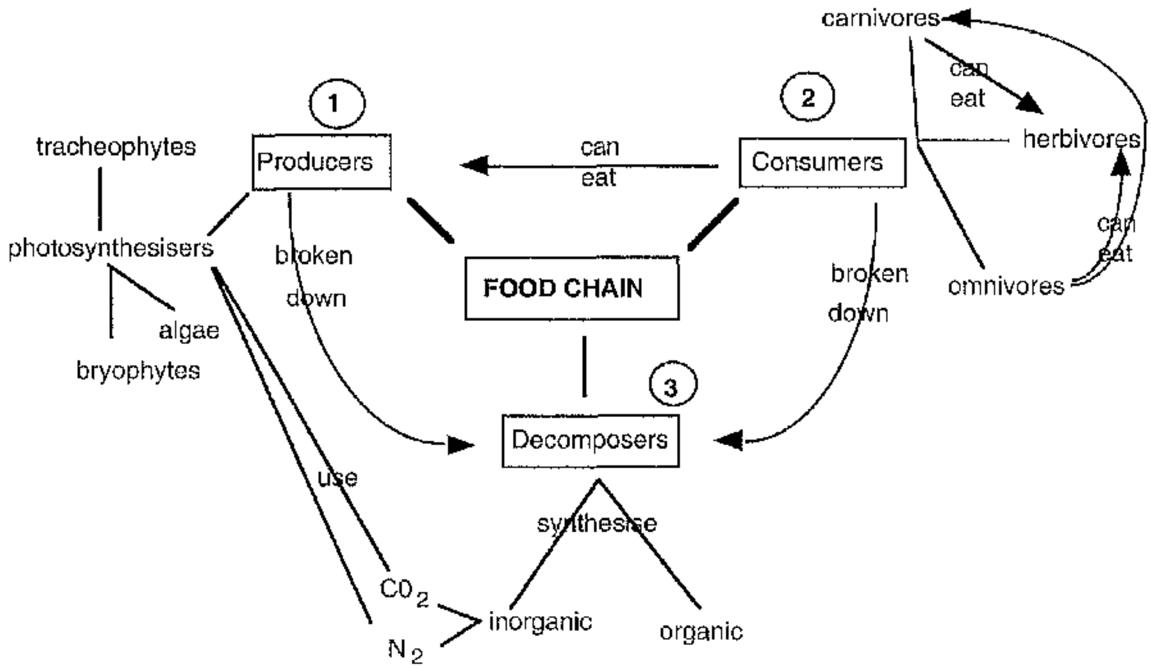


Figure 5.3 The whole mind map showing the connections between ideas and logical order

You should remember the points below for mind mapping.

* *Put the key concept in the middle of the page.*

* *Branch out with main ideas.*

* *Look at each of the main ideas for further branching.*

* *Look for interconnections between concepts.*

* *Sequence your main ideas for presentation.*

It is also very important that the mind should be left as free as possible. Any thinking about where things should go, or if they should go, will simply slow down the process!".

After these exercises, students (400) were asked to draw a mind map in preparation and planning their essay writing which was to be graded as a part of their continuous assessment. They were not given a particular time for mind mapping but they were told not to spend more than 10 or 15 minutes, because they had to have enough time to write the essay. As mentioned earlier, the topic of the essay was "Seed Germination."

5.4.3 Method of Analysis

5.4.3.1 Qualitative Approach

Firstly, a qualitative approach was attempted before using a quantitative approach (i.e. developing a scoring key) on mind mapping. In qualitative approach, without consideration of students' essay marks, their mind maps, which were drawn at the first page of their essay as a plan, were classified as *good*, *moderate* and *poor*. In fact, this was purely by *impression marking* of the overall structure of each map. The three groups (i.e. good, moderate and poor) were then checked using the criteria set out in Table 5.3 and, if necessary, reallocated. This classification was done in order to see whether there was any significant difference between the essay marks of good mind mappers and poor mind mappers.

Criteria	**Groups**		
	Good	**Moderate**	**Poor**
Structure Hierarchy	Generally, more than 2 level of hierarchy	Mostly 2 level of hierarchy	Mostly one level of hierarchy
Branching	More than 5	Between 4 and 5	Few (mostly between 1 and 3)
Number of Concepts	Many (more than 20)	Between 13 and 18	Few (around 10)
Cross links	Generally more than 2	Few (1 and 2)	Mostly None

Table 5.3 Mind map scoring criteria (qualitative approach)

Although these criteria were used to judge which category the students were in, the results were, at best, qualitative. After the students were classified as good, moderate, and poor mind mappers, the mean essay scores of these three groups were calculated and compared. Details are given in Chapter 7 (Results 2 and Discussions).

5.4.3.2 Quantitative Approach

In this study a scoring key was developed to measure the students' performance in mind mapping. The performance of a student in mind mapping has not been scored and measured quantitatively before. But concept maps have been used by several researchers for assessment (e.g., Novak et al., 1983; Mason, 1992; Morine-Dershimer et al., 1992; Markham et al., 1994; Rice et al., 1998; Bolte, 1999).

In a scoring scheme for mind maps, some important ideas of Ausubel's theory of learning have been used. In particular the three ideas of hierarchical structure, progressive differentiation and integrative reconciliation have been used. *Hierarchical structure* includes Ausubel's concept of subsumption, namely that new information often is relatable to and subsumable under more general, more inclusive concepts. Connections between the concepts are shown by the hierarchical structure which begins with broad, inclusive concepts and then leads to more specific, less inclusive concepts. However, it is important to mention that this hierarchical structure in the mind map is not in the shape of the concept map. As mentioned before, in mind maps each main idea radiating from the key concept, which is in the middle of the page rather than at the top, shows a hierarchy on its own. *Progressive differentiation* refers to the learning process in which the concepts held by the learner are being constantly modified, elaborated, and made more precise. Progressive differentiation is obvious in mind maps through a more clearly determined conceptual and propositional hierarchy. When two or more concepts are seen to relate to each other in a new propositional meaning or when conflicting meanings of concepts are resolved *integrative reconciliation* occurs. In mind maps, connections or cross-links between concepts, which may be on different levels of the hierarchy, or at the same level, illustrate integrative reconciliation.

This scoring key produces separate quantitative scores for relationships at each level of the hierarchy and for cross links. The total score for each map is calculated by combining these sub-scores.

L1 Each node at Level 1 will score 10 points. If there are more than six nodes at this level do not score nodes beyond six and subtract 5 points for each additional one.

For example four nodes $= 4 * 10 = 40$
seven nodes $= (6 * 10) - (1*5)= 55$

The subtraction (5 points) for each additional node beyond six is because, for this particular essay topic (i.e. Seed Germination), the researcher thought that there should not be more than six main ideas in the first level.

In this scoring key the term "node" stands for any concept or idea in students' mind maps. The term "level" indicates the hierarchical position or organisation of the ideas in the map.

L2 Each node at level 2 will score 5 points,

L3 Each node at level 3 will score 4 points,

L4 Each node at level 4 will score 3 points,

L5 Each node at level 5 will score 2 points,

L6 Each node at level 6 (or level 7) will score 1 point.

Each valid cross link at any level of hierarchy will score 10 points.

As discussed in the section on network models of semantic memory (in section 1.4.1.2, in Chapter 1), there is a great regularity and a hierarchical structure in the semantic memory structure. Concepts closer together in the hierarchy require less time for retrieval and are more central to the meaning of the concepts or categories (i.e. semantic distance effect). Therefore, in this scoring key, more points are awarded to the relationships at the first level of the hierarchy. The superordinate ideas around the key concept are more important than the subordinate ideas that are far from the core. Accordingly, any problem (or misconception or mislinkage) at the level which is nearer the centre may indicate a more serious defect in the learning than any problem at a level far from the centre of meaning.

In this method of scoring, each cross link is given as great importance as in the concept maps, because connections or cross-links between concepts, which may be on the same or on different levels of the hierarchy illustrate integrative reconciliation. Cross links are the sign of relating two or more concepts in a new way, which can make the learning deeper and more meaningful. As is the case in the word association tests, cross links may also aid in remembering the ideas which are in the form of a network. Connections make ideas into an interconnected network, but without connections each idea at any level of the hierarchy, can exist as unconnected, isolated islands which is the evidence of rote learning.

In the handout as well as in the practice session of the mind mapping, students were told to sequence the main ideas (i.e. putting them in the logical order) for presentation. However, during scoring the mind maps logical order was not considered, in other words it was not scored.

The researcher also prepared a model mind map as a guide from the model answer sheet for the question (i.e. Seed Germination) and this model answer sheet was used during marking. The model mind map and the positioning of the concepts hierarchically are shown in Appendix 13. However, this model mind map could not be used strictly, because sometimes students wrote information on the mind map which was not included in the model answer but which was biologically true. In other words, in some few cases the researcher had to use his own judgement.

One of the original examples and its scoring, according to the scoring key, are given in Figure 5.4:

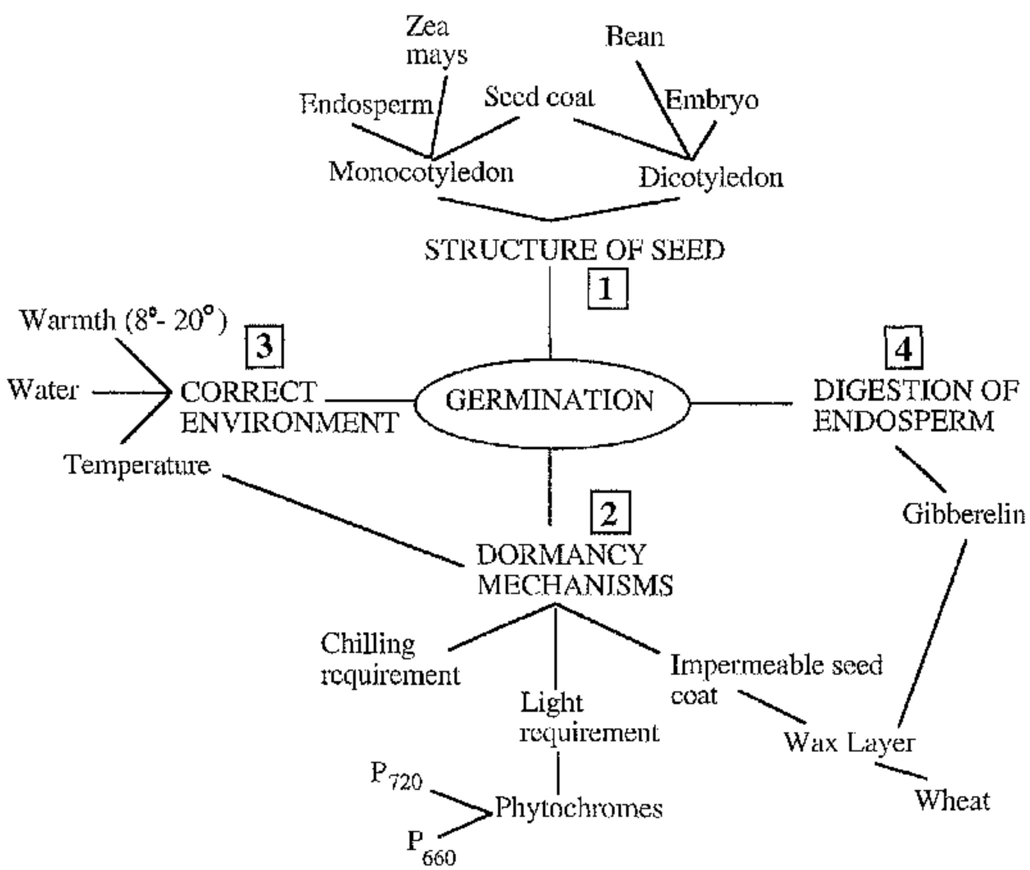


Figure 5.4 One of the original examples of the students' mind maps

Scoring of this map:

Level 1: There are four main ideas (i.e. Structure of seed, Dormancy Mechanisms, Correct environment and Digestion of endosperm) around the key concept in the first level of hierarchy. Because each node at Level 1 of hierarchy scores 10 points, four nodes score **(4*10) = 40 points**.

Level 2: There are nine ideas in the second level of hierarchy (i.e. Monocotyledon-Dicotyledon, Gibberelin, Chilling requirement-Light requirement-Impermeable seed coat, Warmth-Water-Temperature) radiating out from four main ideas. Because each node at Level 2 of hierarchy scores 5 points, nine nodes score **(9*5) = 45 points.**

Level 3: There are five ideas in the third level of hierarchy (i.e. Endosperm-Seed coat-Embryo, Wax layer, Phytochromes). Zea Mays and Bean, which are the examples for Monocotyledon and Dicotyledon seeds are thought, according to the model mind map of seed structure, to be in the fourth level of hierarchy and therefore they are not scored as ideas in Level 3. Each node at Level 3 of hierarchy scores 4 points, five nodes score **(5*4) = 20 points.**

Level 4: There are five ideas in the fourth level of hierarchy (i.e. Zea Mays -Bean, P_{720}-P_{660}, Wheat). Because each node at Level 4 scores 3 points, five nodes score **(5*3) = 15 points**.

There are no ideas beyond level 4.

There are three crosslinks in this map. These crosslinks or connections are (i) between "Temperature" which is in the second level of hierarchy and "Dormancy Mechanism", which is in the first level of hierarchy, (ii) between "Monocotyledon" and "Dicotyledon" seed through Seed Coat and, (iii) between "Gibberelin" which is in the second level of hierarchy and "Wax Layer" which is in the third level of hierarchy. However, the connection between "Gibberelin" and "Wax Layer" is not a valid one (it may indicate a misconception) and therefore it is not scored. According to scoring key, each crosslink or connection scores 10 points, two valid crosslinks in this map score **(2*10) = 20 points**.

Total score for this map is **140 points**.

Two original examples of mind maps of each grade good, moderate and poor, and their scoring are given in Appendix 14.

It is necessary to mention that these scoring criteria apply only to hierarchical mind maps. However, there were also some students who drew a mind map in which there was not a hierarchical structure. But the total numbers of these students in this study were not significant and therefore their maps were not scored. In addition to that, because the essay marking was primarily based on the existence of key facts and on the way these were placed in the text, the mind map scoring included credit for this particular content. However, sometimes students wrote these important ideas in the first level of the hierarchy as main ideas around the key word although they should have been second or third level of ideas in terms of the content. Therefore, these ideas which were wrongly placed at the hierarchy were scored according to the criteria of the scoring key. That is, if the idea, which is written at the first level of hierarchy should have been in the second level of hierarchy it scored 5 points rather than 10 points.

Like any other scoring keys for concept maps this method of scoring, which was developed for mind maps, has considerable subjectivity in it. Depending on the purpose, this scoring key can be changed, different attributes can be used or different weight can be assigned to each of these attributes.

As stated earlier (in section 5.4.1), the first aim of using a mind map was to aid students in better essay writing and consequently to help them to gain higher marks. It is necessary to mention that the essays were marked independently of the researcher. The mean essay scores of the two groups were compared to find out whether or not the essay marks of the students who drew mind maps before the essay were higher than the essay marks of the students who did not use the mind maps and preferred to have a linear form of essay plan. A t-test was applied to find out whether the difference between mean scores was statistically significant.

The second aim of using this technique was to gain an insight into how students' ideas were lodged in cognitive structure. Because mind maps as concept maps can serve as a vehicle for obtaining a graphic representation of information held in memory, it should be possible, by using mind maps, to look at the relations between ideas students formed in their minds. In this study the majority of the students who did mind mapping were also given another test later in the same year which measured the convergence-divergence dimension of their cognitive styles. To see the effect of these particular thinking styles on the quality of mind mapping, correlation was sought between the mind map scores, the total number of concepts which were used in the maps and the students' scores on the convergent/divergent tests. The details are given in section 7.2.6 (in Chapter 7).

In addition to these two aims, to reveal missing ideas and misconceptions about the topic of seed germination, students' mind maps and their essays were also examined in detail to look for correspondence between them.

5.4.4 Hypotheses

The following hypotheses are proposed in this research study in terms of Mind Maps;

Hypothesis 5.4- Overall performance in the essays of the students who used mind maps for planning their essay writing is expected to be better than students who did not use mind maps.

Hypothesis 5.5- The mind maps of divergent students are expected to be more complex and branched than convergent students. Consequently, divergent students may benefit more than convergent students in terms of getting higher scores in their essay.

5.5 Structural Communication Grids

As mentioned in section 3.4.1 (in Chapter 3), the tool of structural communication grids can be used to test:

(i) sequence information to give a coherent procedure,

(ii) recognise examples of a concept from non-examples,

(iii) select information which gives a description,

(iv) make deductions and inferences from information given.

In this study, the grids (SCG) were used as a technique to gain insight into students' thinking, and as a tool to reveal the effect of some cognitive styles (e.g., field-dependence/field-independence and convergence/divergence) in the performance of the grids type of questions of a particular concept area in biology.

5.5.1 Description of the SCG

5.5.1.1 SCG for Secondary Schools

To prepare the grid questions for secondary school pupils, the syllabuses, text books and exam papers of Higher Grade Biology were investigated. Two topics, namely the chemistry of respiration and food digestion were chosen which were already taught in the schools. Figure 5.5 shows the first grid questions on food digestion.

For secondary school level grids with 9 boxes and for first year university students grids with 12 boxes have been used successfully before by several researchers (e.g., Johnstone et al., 1983; Johnstone, 1988). Accordingly, in this study the grids with 9 boxes for pupils and the grids with 12 boxes for students were used. Prior to administering the grids, pupils were given information about the basic structure and the purpose of the tests. They were told that these tests were not part of their exam and would not affect their performance on the course. Total test time for both grids, which was around 10 minutes, was controlled by the researcher.

Topic: Food Digestion

The grid below contains the names of digestive enzymes, fluid and breakdown products.

Use the numbers from the boxes to answer the following questions. Each number can be used once or more than once.

1 glucose	2 pepsin	3 maltase
4 lipase	5 amino acids	6 glycerol and fatty acids
7 amylase	8 bile	9 trypsin

Q1. Which box contains the digestive enzyme which is present in both saliva and pancreatic juice?

Number ....

Q2. Which boxes contain the enzymes which are active in the small intestine?

Numbers ....

Q3. Which boxes contain the enzymes which are protease?

Numbers ....

Q4. Which boxes contain the enzyme and fluid that play a role in fat digestion?

Numbers ....

Q5. Which boxes contain the end products of digestion?

Numbers ....

Q6. Which box contains the enzyme which is active only in the stomach?

Figure 5.5 First grid questions on food digestion

5.5.1.2 SCG for University Students

In the second year of the study, another grid question was administered to first year biology students (N= 399) in the university. It is important to mention that these grids were not prepared and administered by the researcher but by a co-operative lecturer. The students' scores which they gained in the grids were part of their official exam and the total weight of grids was about 8% of their total exam mark.

The layout of the grids which were administered was slightly different from the grids which were administered to pupils in schools. The original version of the grid question which was part of exam is given below:

GRID Question on HAEMOPHILIA

The following statements have been arranged in random order in the grid below. You should select the statements which are relevant to haemophilia, and place them in order that leads logically from genotype to phenotype.

Statements

1. Mutation

2. Altered primary structure of polypeptide

3. Defective function of factor VIII

4. Prolonged clotting time

5. Reduced wound healing

6. Infection

7. Premature death

8. X chromosome

9. Red cells lyse in blood vessels

10. Red cells sickle

11. Autosome

12. Haemoglobin S

1. EXCLUDED STATEMENTS

Identify those statements that are irrelevant or inappropriate. Circle the corresponding number for each of these statements in the box below and transfer the marks to the top section of the OMR (Optical Mark Reader) form provided.

EXCLUDED STATEMENTS

1	2	3	4	5	6	7	8	9	10	11	12

2. Place the remaining statements in the most logical order, starting with genotype and leading through to effects on phenotype. Write the number for each statement in the following box, placing the numbers in the order you have selected.

ORDER OF INCLUDED STATEMENTS

Finally, to get your answer marked, transfer your "included order" to the grid boxes on the OMR form (An example of OMR form is given in Appendix 15). *Start at the box marked "First" and mark the check box for the statement number you choose to be first. Proceed through to the second, third etc. boxes. If you have excluded one or more of the 12 statements, then one or more of the OMR grid boxes will not receive an entry.*

5.5.2 Method of Analysis

In general, students/pupils' responses to grids questions can be scored in two steps: i) to measure their success in separating relevant from irrelevant, and ii) to arrange their choice in a logical order. In this research, students who were in the first year of biology courses in the University were asked to select relevant statements to the question and place them in an order. On the other hand, pupils in the secondary schools were asked only to choose the right answers in the boxes to the questions and they were not asked to arrange their responses in a logical order. Therefore, for this group the second step of scoring was not considered.

5.5.2.1 Marking of Grid Question on Haemophilia

The grid question on Haemophilia was marked out of 5 marks. Students were informed on the grid question sheet that there is more than one possible answer and some errors will result in the award of 3-4 marks. Errors of a fundamental nature will result in the award of no marks for the question.

Correct answers for the grid question on Haemophilia:
Students should exclude the statements of 9, 10, 11, 12
correct orders of included statements can be: 8,1,2,3,4,5,6,7. or 1,8,2,3,4,5,6,7. or 1,8,2,3,4,6,5,7. or 8,1,2,3,4,6,5,7.

Four issues were considered for marking of the grids. These were:

(i) If they confuse sickle cell and haemophilia they get zero.
(ii) Statements 5 and 6 may be in either order.
(iii) Students must make the link between 2-5/6 to get any marks for correct sequencing.
(iv) A mark is deducted for those who think the gene for factor VIII is autosomal.

Marking scheme:
Inclusion of either of the following, results in zero marks for the question: 10, 12.
Marks = 0

exclude: 9, 10, 11, 12
correct orders: 8,1,2,3,4,5,6,7. or 1,8,2,3,4,5,6,7. or 8,1,2,3,4,5,6,7. or 1,8,2,3,4,6,5,7.
Marks = 5

Partially correct answers:
11,1,2,3,4,5,6,7. 1,11,2,3,4,5,6,7. or 11,1,2,3,4,6,5,7. or 1,11,2,3,4,6,5,7.
8,1,2,3,4,5,6. or 1,8,2,3,4,5,6. or 8,1,2,3,4,6,5. or 1,8,2,3,4,6,5.
Marks = 4

1,2,3,4,5,6. or 1,2,3,4,6,5
Marks = 3

"Fail" marks because they do not start with genotype as requested in question:
2,3,4,5,6,7. or 2,3,4,6,5,7
Marks = 2

2,3,4, (plus any of 5-7)
Marks = 1

5.5.2.2 Scoring Key for Grid Question on Food Digestion

There were six questions in the grid on Food Digestion. Correct answers for six questions:

Q1= 7 Q2= 3,4,7,9 Q3= 2,9 Q4= 4,8 Q5= 1,5,6 Q6= 2

Total Marks: **60** Full Mark for each answer: **10**

For Q1 and Q6

Inclusion of two numbers as an answer for Q1 and Q6 (one is correct) results 7 Marks (3 marks will be subtracted). Answers beyond 2 numbers for each question result in zero marks even though one of these numbers is the right answer. Because these two questions require only one number and beyond two numbers indicate guessing.

For Q2, Q3 and Q4

Inclusion of all of the right numbers with one wrong number results in full marks.

Inclusion of half of the right numbers as answer results in half marks i.e. **5** Marks.

Q2 = 3,4 or 7,9 or 3,7 or 3,9 or 4,7 or 4,9

Q3 = 2 or 9

Q4 = 4 or 8

Inclusion of half of the right numbers with one wrong number results in **4** Marks.

Inclusion of half or total right numbers with two or more wrong numbers results in zero marks.

For Q5

Inclusion of 1,5 or 1,6 or 5,6 results in 7 Marks. Inclusion of only one of these right number results in 4 Marks.

Inclusion of one wrong number with one of these right numbers results 3 Marks. However, inclusion of more than one wrong number results in zero marks (This is also valid for inclusion of two or all right numbers with more than one wrong numbers)

There are four questions in the second grid test which is about Chemistry of Respiration. In this grid test, each question was marked out of 25 and total mark was 100. Appendix 15 shows this second grid question and its scoring scheme.

5.5.3 Hypotheses

As stated in section 5.2, in addition to structural communication grids, pupils in secondary school were given Field Dependent/Field Independent and Convergent/Divergent tests. Also students in the university were given both grid tests and Convergent/Divergent tests. Some hypotheses are proposed below in terms of the influence of these two psychological factors on the performance of structural communication grids.

Hypothesis 5.6- Overall performance of the field independent pupils should be better than field dependent pupils, because by definition field independents are better than field dependents in selecting relevant from irrelevant.

Hypothesis 5.7- Overall performance of the convergent pupils is expected to be better than that of divergent pupils, because convergent pupils have higher ability in solving problems requiring one acceptable solution clearly obtainable from the information available. They can focus on the content of each box and can decide which box or boxes are required to answer the question.

CHAPTER 6

Results-1 and Discussions

6.1 Relationships Between Psychological Factors

As mentioned in section Introduction, one purpose of this research study was to look at the relationship between some psychological factors (i.e. Field Dependence/Field Independence (FD/FI), Convergence/Divergence (CON/DIV) and Working Memory Capacity (WMC)) and relate the findings to students' cognitive structure. An understanding of the psychological factors involved in this study may lead to an understanding of the laying down and interconnecting process in the students' long term memory and to an understanding of students' performance and achievement in biology.

All the university students in the volunteer sample were participants in the Field Dependent/Field Independent tests, Convergent/Divergent tests and also in the test to measure Working Memory Capacity. As stated in section 4.2 (in Chapter 4), in the second year of study in the secondary school, pupils were given the Field Dependent/Field Independent tests and Convergent/Divergent tests. However only 88 of those school pupils were full participants in both tests.

The results of students/pupils' achievements in each sample in these tests were set out against each other. The results which are given below show the relationships and the significance of correlation (Pearson Product-Moment Correlation) between these psychological factors. In this research study, as several researchers have done before, the all rounder students/pupils (All R) in the Convergent/Divergent tests, the field intermediate (FINT) students/pupils in the Field Dependent/Field Independent tests and the students who had medium working memory capacity (MWM) were neglected so as to expose the extremes.

6.1.1 Pearson P.M. Correlation Between FD/FI And CON/DIV

As the students' scores in the Field Dependent/Field Independent tests (FD/FI tests) and in the Convergent/Divergent tests (CON/DIV tests) were plotted against each other (for the volunteer sample), a low positive correlation emerged as the Correlation Coefficient was **0.20** (degrees of freedom= 69/two tailed tests). *The null hypothesis* (Clegg, 1990; Zar, 1996), that there is no relationship between students' degree of divergency and FD/FI cognitive style, could only be rejected at the 10% level. Also, for the secondary schools sample, a low positive correlation emerged as the Correlation Coefficient was **0.19** (degrees of freedom = 86/two tailed tests). Similarly, *the null hypothesis*, that there is no relationship between students' degree of divergency and FD/FI cognitive style, could only be rejected at the 10% level. Although the trends are interesting, usually 5% level of significance is required.

From this correlation it may be concluded that divergent students/pupils tend to perform better in the FD/FI tests than did convergers.

6.1.1.1 The Distribution Of Convergers/Divergers Over FD/FI Tests

In order to clarify the conclusion above between CON/DIV and FD/FI, the distribution of convergent/divergent students/pupils over FD/FI was required. Tables 6.1 and 6.2 show the distribution of the number of convergent/divergent students over the FD/FI tests.

Cognitive Style	FD	FINT	FI
Convergers N= 31	12	7	12
All Rounders N=16	10	1	5
Divergers N=24	6	1	17

Table 6.1 The distribution of convergent/divergent students over FD/FI in the university volunteer sample

<u>Note</u>: For the purpose of this comparison All Rounders, FINT and MWM were included in all tables.

It can be seen from Table 6.1 that divergent students tend to be rather more field independent than field dependent. The distribution of convergent students over FD/FI tests was equal.

Cognitive Style	FD	FINT	FI
Convergers N= 31	14	9	8
All Rounders N=31	12	11	8
Divergers N=26	8	5	13

Table 6.2 The distribution of convergent/divergent pupils over FD/FI in secondary school sample

Table 6.2 (for pupils) also indicates that divergent pupils tend to be rather more field independent and convergent students tend to be slightly more field dependent.

From all the results above it can be concluded that these two dimensions of cognitive style correlated positively but this correlation was not significant (10% Level) as was predicted (in section 4.6). These two factors are fairly independent but, divergent students/pupils showed a small tendency to be field independent and convergent students/pupils tended to be slightly more field dependent.

6.1.2 Pearson P.M. Correlation Between FD/FI and The Size of WMC

As the students' scores in the FD/FI tests and in the Tests to measure working memory capacity were plotted against each other (in the university volunteer sample), a significant positive correlation emerged as the Correlation Coefficient was **0.47** (degrees of freedom = 69/two tailed tests). *The null hypothesis*, that there is no relationship between students' degree of field dependency and the size of working memory capacity, could be rejected at the 0.1% level. On this basis, it can be concluded that field independent students had higher scores in the tests for measuring working memory capacity than field dependent students. And so, field dependents tend to have low working memory capacity and field independents tend to have high working memory capacity.

6.1.2.1 The Distribution Of Field Dependents/Field-Independents Over The Tests To Measure WMC

The distribution of field-dependent/field independent students over LWM/HWM is given below in Table 6.3 to make more obvious the relationship between FD/FI and the Working Memory Capacity.

Cognitive Style	LWM	MWM	HWM
F.Dependent N=28	17	9	1
F.Intermediate N=9	4	2	3
F.Independent N=34	8	7	19

Table 6.3 The distribution of F.Dependent/F.Independent students over LWM/HWM in the university volunteer sample

As can be seen from Table 6.3, the majority of field dependent students have low working memory capacity and field independent students tend to have high working memory capacity.

The prediction which was made in earlier in section 4.6. (in Chapter 4) was "a significant positive correlation is expected between field-dependence/field independence cognitive style and the size of working memory capacity. Accordingly, more field independents are expected to fall in the category of high working memory space and more field dependents are expected to fall in the category of low working memory space". On the whole, the results support this prediction.

6.1.3 The Relationship Between CON/DIV and The Size of WMC and Testing the Hypotheses

As mentioned in the previous section, the relationship between convergence/divergence cognitive styles and the size of working memory capacity is not known. The hypotheses which were made in section 4.6.1 (in Chapter 4) are; **Hypothesis 4.1**- Divergent thinkers are expected to have high working memory capacity in order to generate ideas and to see things from different perspectives. **Hypothesis 4.2**- Most of the convergent thinkers might fall in the category of low working memory capacity, because they are not good at problems requiring the generation of several equally acceptable solutions which may require high working memory capacity to juggle with them.

The scores of students in both CON/DIV tests and the test for measuring WMC were set out against each other. A significant positive correlation emerged as the Correlation Coefficient was **0.29** (degrees of freedom = 69/two tailed tests). *The null hypothesis*, that there is no relationship between students' degree of convergence/divergence and the size of working memory capacity, could be rejected at the 2% level. On this basis, it can be inferred that divergent students tended to perform better in the tests for measuring WMC and tended to have high working memory capacity rather than low working memory capacity. Whilst convergent students tended to have low working memory capacity rather than high working memory capacity in accordance with their lower performance in the test for measuring WMC.

To illuminate the conclusion above between convergence/divergence and the working memory capacity, distribution of convergent/divergent students in relation to low working memory capacity and high working memory capacity is given in Table 6.4.

Cognitive Style	LWM	MWM	HWM
Convergers N= 31	15	8	8
All Rounders N=16	8	4	4
Divergers N=24	6	7	11

Table 6.4 The Distribution of convergent/divergent students over LWM/HWM in the university volunteer sample

From Table 6.4 it can be seen that convergent students tend to have low working memory capacity and divergent students tend to have high working memory capacity.

In conclusion, it can be said that all the results support the hypotheses 4.1 and 4.2. In other words, divergent thinkers tend to have high working memory capacity which may have advantage in generating ideas and seeing things from different perspectives. Most of the convergent thinkers tend to have low working memory capacity which would tend to make them converge rather than juggle with many ideas.

6.1.4 The Overlap Between These Three Psychological Factors

From the results between the tests of psychological factors it can be said that there is an overlap between field dependent/independent and convergent/divergent thinking styles, but the overlap between convergent/divergent thinking styles and working memory capacity is higher than overlap between field dependent/independent and convergent/divergent thinking styles. However the overlap between field dependent/independent dimension of cognitive styles and working memory capacity is the highest (Figure 6.1)

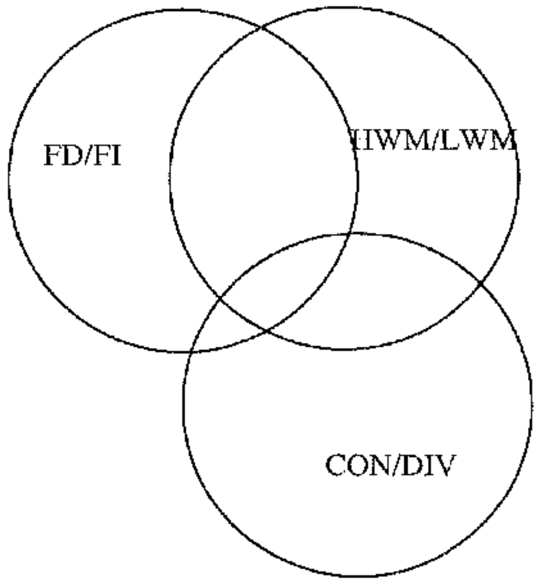


Figure 6.1 Overlapping between psychological factors

Field dependents tend to be convergers and have low working memory capacity. By contrast field independents tend to be divergers with high working memory capacity. Similarly, divergers tend to be field independent and have high working memory capacity. High working memory capacity students tend to be field independent, divergers. Students who have low working memory capacity tend to be field dependent and convergent.

6.2 The Relationship Between Psychological Factors And Students' Performance In Conventional Biology Exams (For The Volunteer Sample)

Students took four different courses (or modules) and one study project during the year. Their total exam scores consisted of;

<u>For Module A (Plant and Microbes):</u>
30% Continuous assessment
70% Multiple choice questions (MCQ) (Total 40 questions).

<u>For Module B (Molecules, Cells and Genes):</u>
30% Continuous assessment,
70% MCQ (Total 40 questions) and structural communication grids questions.

For Module C (How Animals Function)
30% Continuous assessment,
40% MCQ (Total 40 questions),
20% Short definitions,
10% Problem solving questions.

For Module D (Evolution and Ecology)
30% Continuous assessment,
40% MCQ (Total 40 questions)
30% Short notes (Total 100)

To find out if is there any correlation between psychological factors (i.e. Field dependence/Field independence, Convergence/Divergence and Working Memory Capacity) and students' performance in their exam at the end of the year, students' marks in exams (for four modules indicated above) and their scores in the psychological tests were set out against each other. Pearson P.M. Correlation Coefficient values (for all correlations: degrees of freedom 69/two tailed tests) between psychological factors and students total scores in four different modules were very low and the results revealed no significance correlation (Table 6.5) As mentioned in section 4.6.1 (in Chapter 4), field independent - and high working memory capacity students were expected to be better in the conventional biology exams than field dependent - and low working memory capacity students. However, the results revealed no significant difference between field dependent and field independent as well as between low - and high working memory capacity students and the predictions were not supported.

P. Factors	COURSES			
	Mod. A	Mod B	Mod C	Mod D
CON/DIV	-0.08	-0.03	0.01	0.00
FD/FI	-0.06	-0.05	-0.13	-0.01
WMC	0.08	0.04	0.03	0.06

Table 6.5 Pearson P.M.correlation coefficient values between psychological factors and students' scores in the courses

Note: For all correlations: degree of freedom 69/two tailed tests

Moreover, when the correlation was calculated between students' scores in the MCQ (instead of students' overall scores) in the exam and their scores in psychological tests, (similarly, like the correlation between students' scores in psychological tests and their overall scores including MCQ and C. Assessment) almost no significant correlation emerged. In the light of this lack of correlation, the hypothesis 4.3 regarding the performance of convergent and divergent students in the MCQ, which was made in section 4.6.1 "The overall performance of convergent students are expected to be better than divergent students in the multiple choice questions, because, in the MCQ, they are rewarded for convergent thinking leading to unique specific answers" is also rejected.

These results (i.e. no significant difference in terms of the exam performance between field dependent and field independent students, between convergent and divergent students as well as between low and high working memory capacity students) may be explained by considering the following ideas: as El-Banna (1987) and Johnstone and Al-Naeme (1991) found out in their studies which were mentioned in section 2.2.1.3 (in Chapter 2), the questions in the exams did not exceed anybody's working memory capacity (in other words, the demand of the questions were so well within the working space), and so FD/FI did not come into play, nor did CON/DIV. It is only beyond a certain point that the effect of these psychological factors will show and will correlate with exam scores. The lack of correlations for this sample between students' psychological factors and exam scores may be not a bad thing, because an exam is meant to measure learning and <u>not</u> psychological factors.

6.2.1 The Relationship Between Convergence/Divergence and Students' Performance in Conventional Biology Exams (For University Sample)

As noted previously in section 4.2 (in Chapter 4), in the second year of the study (for the university sample), only Convergent/Divergent tests were applied to 298 first year biology students. In order to find out if is there any correlation between convergent/divergent thinking styles and students' performance in their exam at the end of the year, students' marks in exams and their scores in the Convergent/Divergent tests were set out against each other. Table 6.6 shows the results. As in the Volunteer Sample, total exam scores consist of continuous assessment scores and multiple choice questions.

P. Factor	COURSES				
	Mod A	Mod B	Mod C	Mod D	Study project
CON/DIV	**0.13** df=294 Significant at 0.05 level	**0.17** df=295 Significant at 0.005 level	**0.13** df=294 Significant at 0.05 level	**0.18** df=293 Significant at 0.005 level	**0.01** df=181 No Significance

Table 6.6 Pearson P.M.Correlation coefficient values between CON/DIV tests and students' overall scores in biology courses

Note: For all tables which show correlations "df" stands for the term "degrees of freedom"

It can be seen from Table 6.6 that statistically significant, positive correlations appeared between students' CON/DIV tests scores and their scores in four different modules. According to the correlation coefficient values in the table (except r value between CON/DIV Tests scores and Study Project scores of the students) the *null hypothesis*, that there is no relationship between students' degree of divergency and students' overall exam marks, could be rejected at the 5% level (for Mod A and Mod C), 0.5% level (for Mod B and Mod D). From this correlation it can be concluded that divergent students gained higher overall scores than convergent students in biology exams. In questions involving an extend answer and other questions, there is a possibility for students to write irrelevant answers, or to be wide ranging in their answers. This could favour the divergent students.

As pointed out in section 6.2, for the volunteer sample, no significant correlation appeared between psychological factors and students' overall scores (as well as their scores in multiple choice questions). For first year university students in the second year of the study, in order to look at the relationship between students' degree of divergency and their performance in the MCQ, students scores in the Convergent/Divergent tests and their scores in the MCQ were set out against each other. Table 6.7 shows the results.

P. Factor	COURSES				
	Mod A	Mod B	Mod C	Mod D	Study project
CON/DIV Tests Scores	**0.11** df=294 Not Significant	**0.12** df=295 Not Significant	**0.11** df=294 Not Significant	**0.14** df=293 Significant at 0.02 level	**0.10** df=168 Not Significant

Table 6.7 Pearson P.M.Correlation coefficient values between CON/DIV tests scores and students' scores in the MCQ

As can be seen from Table 6.7, the Correlation Coefficient Values between convergent divergent test scores and students' scores in the MCQ were low. The *null hypothesis*, that there is no relationship between students' degree of divergency and their performance in the MCQ could be rejected at the 2% level only for Module D. But for other modules, the null hypothesis can be rejected only at the 10% level (which is regarded as not significant) and the null hypothesis is accepted for Study Project. In the light of these correlations the following hypothesis 4.3, regarding the performance of convergent and divergent students in the MCQ, was made in the section 4.6.1 (in Chapter 4) "The overall performance of convergent students is expected to be better than divergent students in the multiple choice questions, because, in the MCQ, they are rewarded for convergent thinking leading to unique specific answers" is rejected. However, it is important to mention that Correlation Coefficient Values between convergent divergent test scores and students' scores in multiple choice have fallen considerably, if they are compared with the "r" values between CON/DIV tests scores and students' overall scores in Table 6.6. Also the correlation coefficient values were low and not significant (mostly 10% level) or less (as in Study project).

6.2.2 The Relationship Between Psychological Factors and Pupils' Performance in Higher Grade Biology Exam (For Secondary School Sample)

As mentioned in section 4.2 (in Chapter 4), in the second year of the study, Convergent/Divergent tests and Field Dependent/Field Independent tests were applied to secondary school pupils who were studying Higher Grade Biology. In order to find out if is there any correlation between these two psychological factors and pupils' performance in their exam at the end of the year, pupils' marks in exams and their scores in the psychological tests were set out against each other. Exam questions include problem solving, grid questions and essay questions. Table 6.8 shows the Correlation Coefficient Values between pupils' scores in psychological tests and total scores of the pupils in the Higher Grade Biology exam.

	CON/DIV Tests Scores	FD/FI Tests Scores
Exam Scores	**r= 0.15** df= 83 No Significance two tailed tests	**r= 0.27** df= 94 Significance 0.01 Level two tailed tests

Table 6.8 Pearson P. M. Correlation coefficients between pupils' exam scores and their scores in psychological tests

As can be seen from Table 6.8, the correlation coefficient value between CON/DIV tests scores and exam scores of pupils was not statistically significant. Therefore the *null hypothesis*, that there is no relationship between pupils' degree of divergency and pupils' exam marks, is accepted. In terms of the performance of convergent and divergent students the following hypothesis 4.3 "The overall performance of convergent students is expected to be better than divergent students in the multiple choice questions, because, in the MCQ, they are rewarded for convergent thinking leading to unique specific answers" cannot be tested, because the exam did not include MCQ.

On the other hand, a statistically significant positive correlation emerged between field dependence/field independence and pupils' exam marks as the Correlation Coefficient was **0.27**. *The null hypothesis*, that there is no relationship between pupils' degree of field dependency and pupils' exam marks, could be rejected at the 1% level. As stated in section 4.6.1 (Chapter 4) the prediction was made "the overall performance of the field independent students/pupils is expected to be better than the overall performance of field dependent students/pupils". For secondary school sample, the statistically significant positive correlation (at the 1% level) supports our prediction. Because from this correlation it can be concluded that field independent pupils showed a better performance and consequently had higher marks in the exam than field dependent pupils.

CHAPTER 7

Results-2 and Discussions

In this chapter the results of the three techniques (i.e. Word Association Tests, Mind Maps and Structural Communication Grids) and discussion of them will be given.

7.1 Results for Word Association Tests

As mentioned in section 5.3.2 (in Chapter 5), to get a measure of how each student relates a given stimulus to another, Garskoff and Houston relatedness coefficients were calculated for each student. Table 7.1 shows an example of a single student's relatedness coefficients between ten key words.

	2	3	4	5	6	7	8	9	10
1	0.493	0.333	0.182	0.323	0.069	0.099	0.206	0.218	0.178
2	-	0.410	0.343	0.515	0.281	0.190	0.051	0.051	0.026
3	-	-	0.463	0.149	0.331	0.020	0.089	0.303	0.182
4	-	-	-	0.281	0.491	0.036	0.218	0.325	0.453
5	-	-	-	-	0.139	0.196	0.139	0.182	0.200
6	-	-	-	-	-	0.089	0.186	0.253	0.218
7	-	-	-	-	-	-	0.057	0.036	0.018
8	-	-	-	-	-	-	-	0.323	0.275
9	-	-	-	-	-	-	-	-	0.335

KEY

1- Mutation 2- Gene 3- Pedigree 4- Gamete 5- Chromosome

6- Phenotype 7- Cell Division 8- Genetic Engineering 9- Haemophilia

10- Backcross

Table 7.1 An example of a student's relatedness coefficients

When these calculations were done for each student, a mean relatedness coefficient was calculated for the whole class (N=280) for each stimulus word pair. In this part of the study the aim was to reveal the group's cognitive structure rather than the each student's cognitive structure. Table 7.2 shows mean relatedness coefficient values for the group of first year biology students (N=280) for 1997 (first rows) and for 1998 (second rows italic numbers)

Mean Scores

Showing Mean Relatedness Coefficient for 280 Students

	2	3	4	5	6	7	8	9	10
1	0.266	0.103	0.101	0.220	0.115	0.109	0.131	0.141	0.075
	0.333	*0.113*	*0.105*	*0.248*	*0.124*	*0.114*	*0.144*	*0.144*	*0.086*
2	-	0.136	0.127	0.387	0.184	0.125	0.152	0.101	0.100
		0.143	*0.128*	*0.397*	*0.161*	*0.115*	*0.160*	*0.101*	*0.098*
3	-	-	0.119	0.105	0.140	0.089	0.092	0.125	0.133
			0.132	*0.123*	*0.160*	*0.091*	*0.099*	*0.122*	*0.152*
4	-	-	-	0.147	0.096	0.153	0.082	0.084	0.065
				0.156	*0.104*	*0.127*	*0.084*	*0.086*	*0.070*
5	-	-	-	-	0.115	0.222	0.105	0.072	0.071
					0.124	*0.193*	*0.112*	*0.084*	*0.074*
6	-	-	-	-	-	0.111	0.104	0.108	0.135
						0.123	*0.110*	*0.112*	*0.138*
7	-	-	-	-	-	-	0.085	0.055	0.041
							0.105	*0.078*	*0.048*
8	-	-	-	-	-	-	-	0.117	0.062
								0.119	*0.062*
9	-	-	-	-	-	-	-	-	0.081
									0.079

KEY 1- Mutation 2- Gene 3- Pedigree 4- Gamete 5- Chromosome 6- Phenotype 7- Cell Division 8- Genetic Engineering 9- Haemophilia 10- Backcross

Table 7.2 The mean relatedness coefficient scores for the groups (N=280)

To present results (for 1997) in a visualisable form, the strongest relatedness coefficient greater than (0.300) between Chromosome and Gene is shown in the first cell in Figure 7.1.

The coefficient was now "relaxed" to 0.250 and the word Mutation joined Chromosome and Gene, but was attached more strongly to Gene. A further relaxation of the coefficient to 0.200 now showed linkages between Mutation and Chromosome (weaker than between Mutation and Gene) and a new word joins the picture with Cell Division linking to Chromosome. Two further relaxations of the coefficient values are necessary before all ten stimulus words join the picture and the line thicknesses indicate the relative strengths of the associations.

Figure 7.2 shows the map of the results of the second word association test in the second year of the study. The same criteria were used as in Figure 7.1 in order to map the relatedness coefficients. However, the first cut-off point was chosen at 0.350 rather than 0.300, because the relatedness coefficient value between the key words Chromosome and Gene was slightly higher in the second WAT results.

As can be seen from Figures 7.1 and 7.2, because similar responses were made to the stimulus words Chromosome and Gene, these two stimulus words are most closely related. The relatedness between these two stimulus words and the stimulus word Mutation is also high. A possible interpretation of this is that the students have strong connections between these concepts. However, one may argue that, because the relatedness coefficient is a measure of the number of identical words given as responses to two stimulus words, the higher relatedness coefficient value can be obtained with a small, but similar number of responses for two stimulus words. But this was not the case in this study since it was seen that the total number of different response words for the stimulus words Mutation, Chromosome and Gene was very high (Table 7.3 shows the total number of different response words to each of the stimulus words). However, the highest relatedness coefficient value which was between Chromosome and Gene is 0.387 (for 1997) and 0.397 (for 1998) out of a possible of 1 and only at the 0.135 relatedness level are all these key words linked as a complete network. This may suggest that students may not be able to see all the key words (and their related words) as a connected network at this stage of their learning.

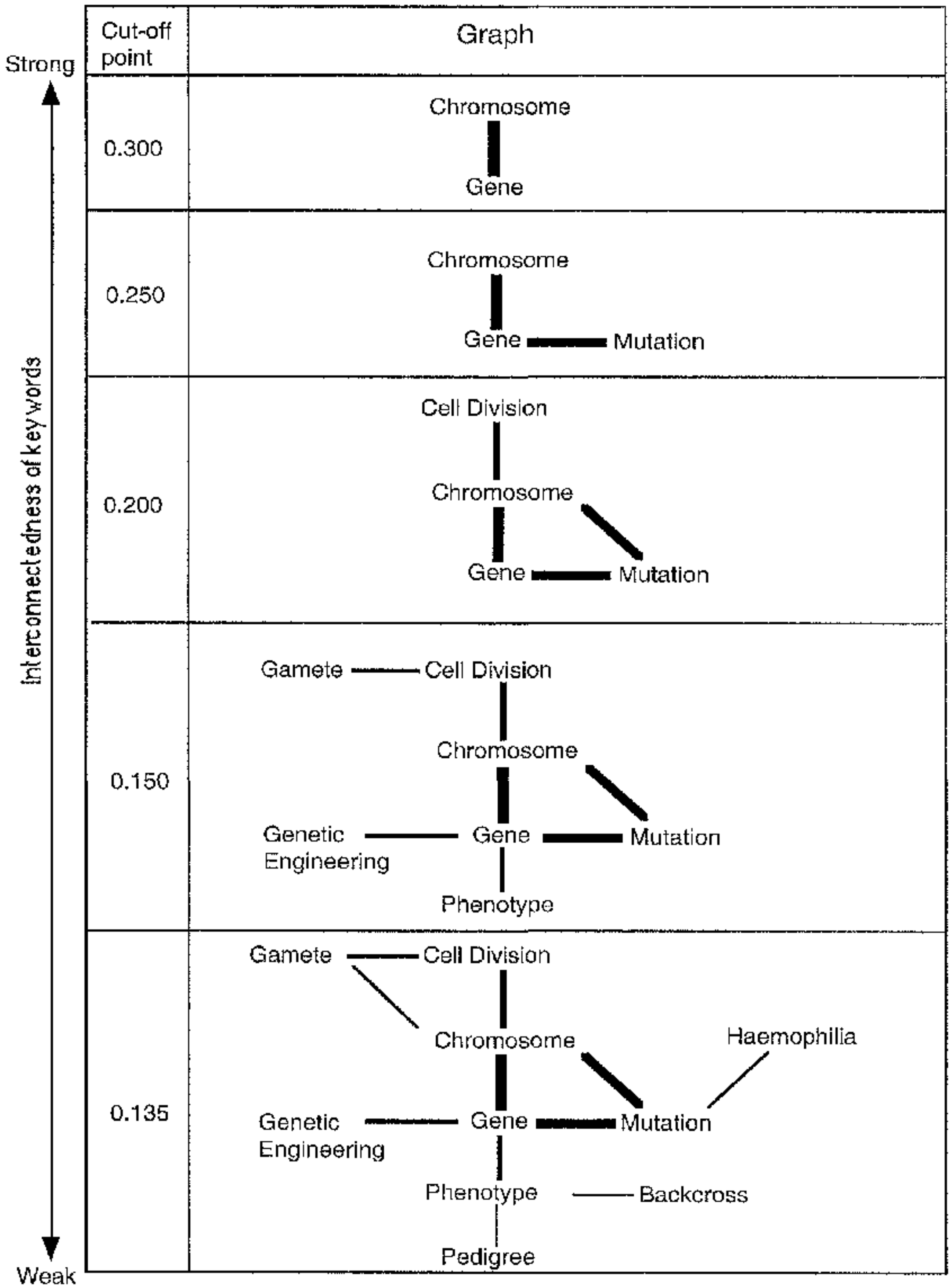


Fig 7.1 The cognitive structure of 280 students using relatedness coefficient (for 1997)

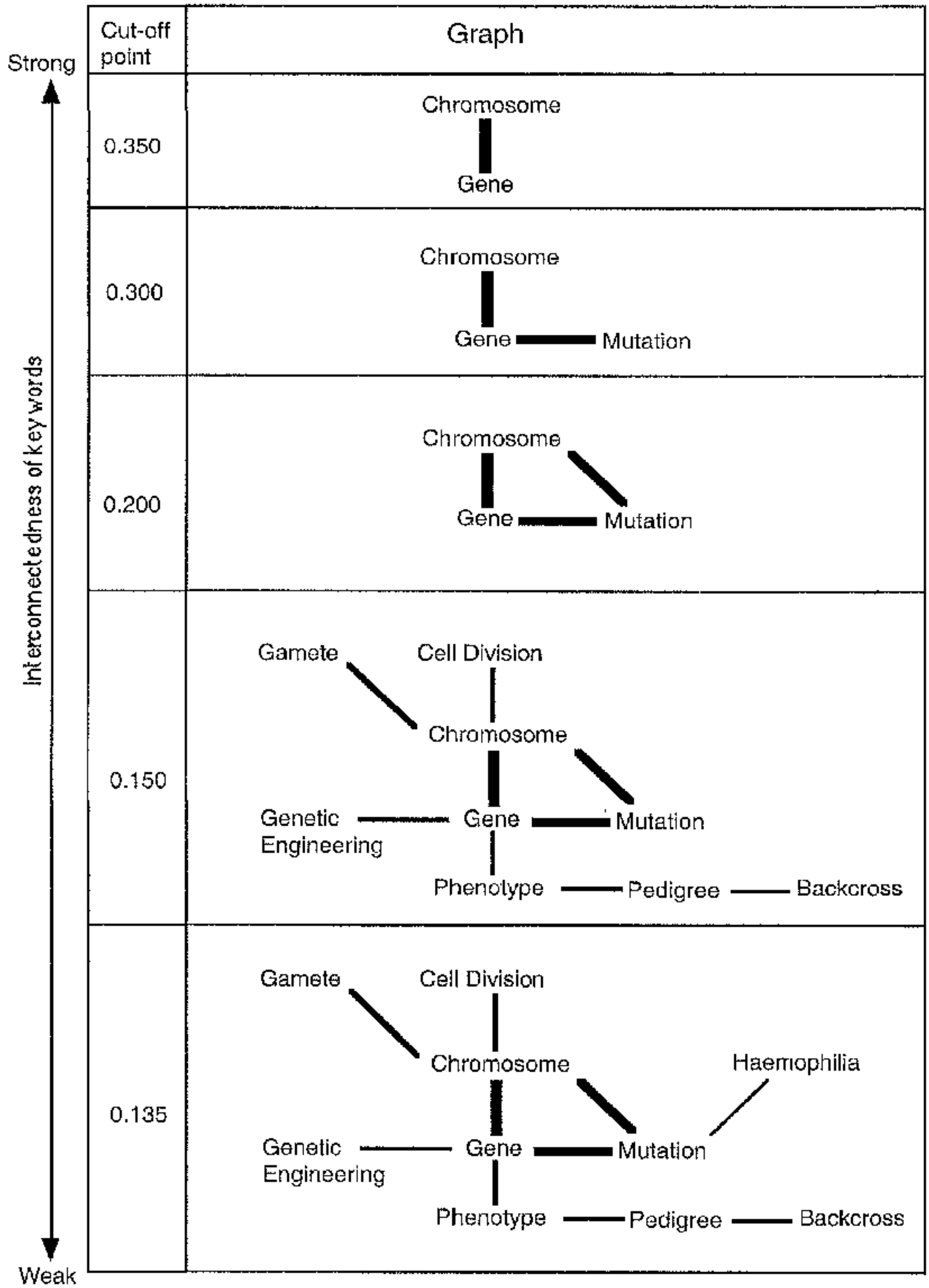


Fig 7.2 The cognitive structure of 280 students using relatedness coefficient (for 1998)

Another way of looking for relations is similar to that used by Waern (1972). A count was made, for the class as a whole, of which valid words (the words used in the count were taken to be "valid" if they were meaningful and acceptable in terms of genetics) were mentioned more than 150 times in response to a key word. For example, "Meiosis and Mitosis" were used as responses to the key word Cell Division more than 150 times. Also the word "Genotype" was used as a response to the key word Phenotype more than 150 times. This gave the picture shown in Figure 7.3, cell one. The criterion was now lowered to a frequency of mention of 125 and this yielded the pattern shown in cell two. This procedure was continued until the frequency dropped to 40, at which point all the key words had joined the picture. This procedure yields a more complex diagram than the relatedness coefficient method, but it is very informative. Figure 7.3 shows the "map" which was drawn by using the frequency of the response words (for 1997) to each stimulus word. This revealed the richness of the response words which students had in mind. Although there are a few connections between the key words Chromosome and Gene at the beginning (and later Mutation and Cell division joined this core) this map suggests that students are not likely to see all the key words as linked even remotely to each other. The ideas cluster as only a few isolated islands and only very slowly begin to come together to form the reasonable networks that the teacher might desire. Three out of ten key words have become part of the whole network only at the weakest level of association, that was 40. It is also necessary to mention that a complete network of the key words at the cut-off point 40 does not mean that 40 students out of 280 have this network of the concepts. Each student of the 40 may have some part of the connections in the map but not necessarily all. This is a class picture.

Figure 7.4 show the "map" which was drawn by using the frequency of the response words in the word association test in the second year of the study. In spite of the fact that there are a few connections between the key words Mutation and Gene at the beginning (and later Chromosome and Cell division joined this core) this map also suggests that students are not likely to see all the key words as linked even remotely to each other. The ideas cluster as only a few isolated islands and only very slowly begin to come together to form the reasonable networks that the teacher desires. As in the first map (for 1997), five out of ten key words have become part of the whole network only at the weakest level of association, that was 40.

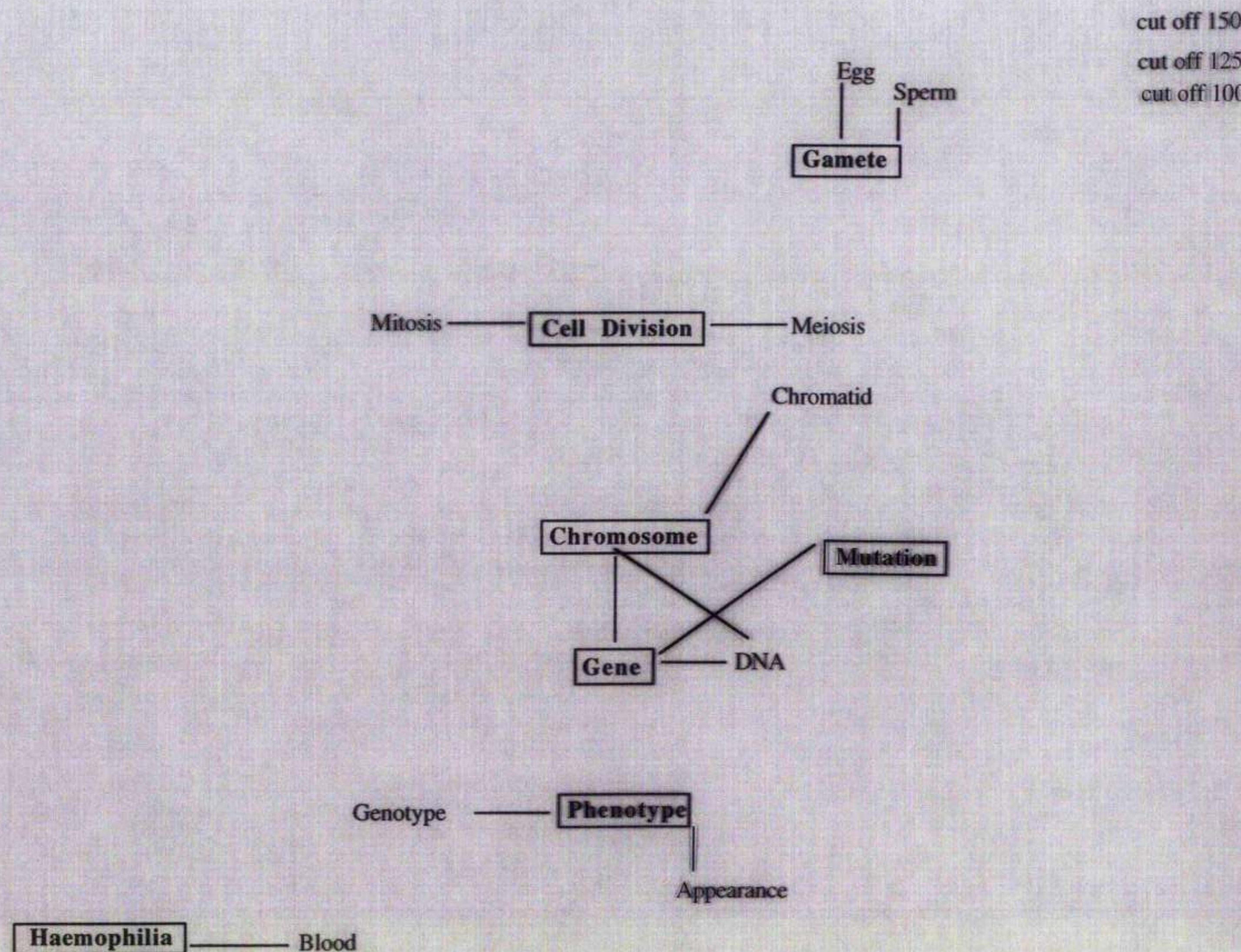


Figure 7.3 Frequency map of the WAT responses (for 1997)

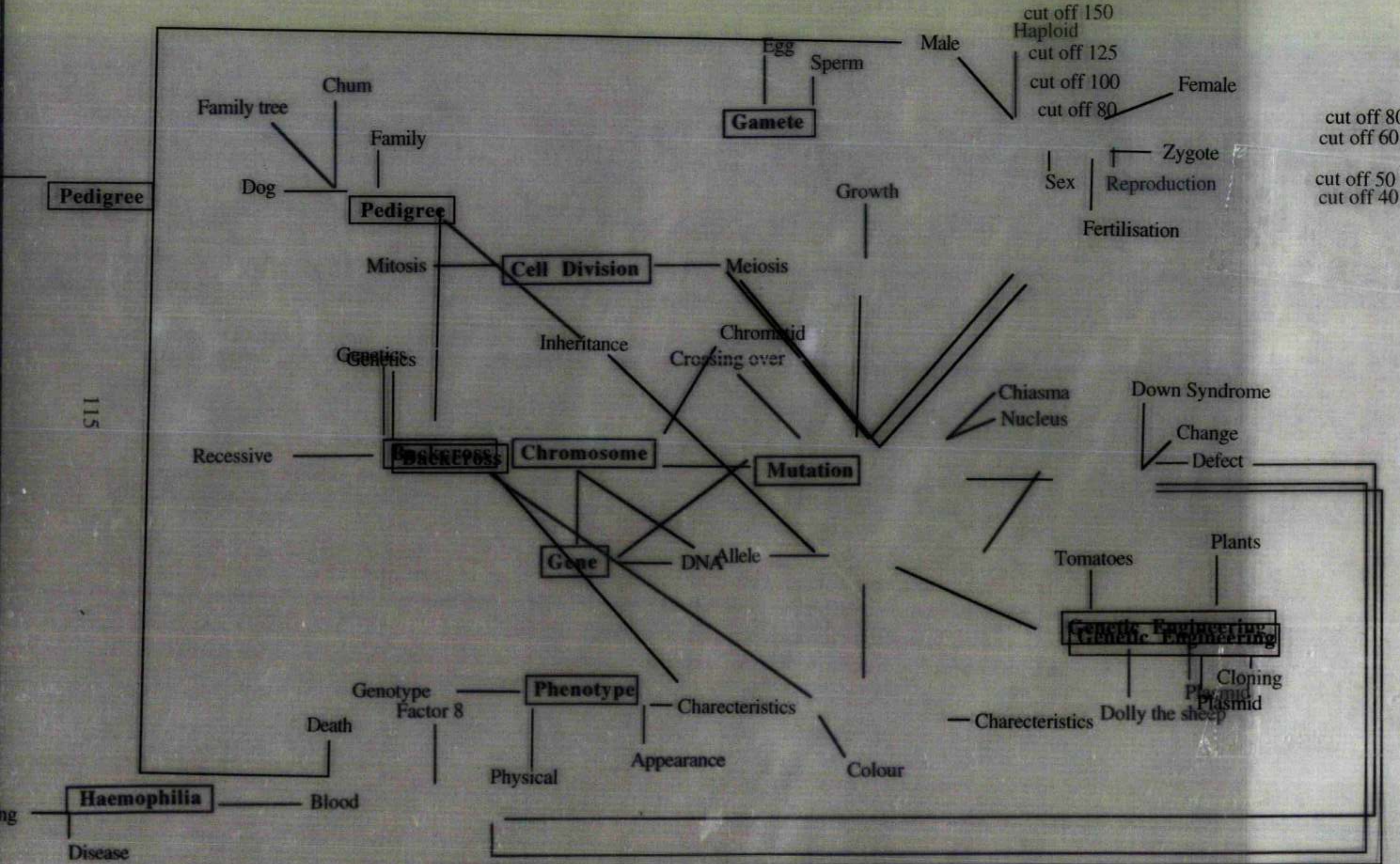


Figure 7.4 Frequency map of the WAT responses (for 1998)

These two maps show a substantial number of similarities, but there are some differences in terms of response words which attached to the key words and connections between the response words or between key words and response words. The overlapping map (Figure 7.5) shows these similarities and differences.

The total number of response words is slightly higher in the first year map (N=49) than in the second year map (N= 44). As can be seen from this overlapping map, a considerable number of connections are the same in both maps, especially in the core of both maps, between the key words Chromosome, Gene, Mutation and Cell division. However, two new connections appeared between the key words Mutation and Haemophilia in the second year map. This might be explained by the fact that during the year the lecturer emphasised more connections between these two key words. In the second year map the key words Pedigree and Haemophilia lost their connection through the response word Recessive. Similarly, the connections between the key words Gamete with Cell Division through the response word Meiosis and the connection between the key words Backcross with Gene through the response word Allele disappeared.

In terms of response words which attached to the key words, Cell Division, Backcross and Genetic Engineering, both maps differ. In the first year map, the Phases of Cell division, that is, Prophase, Anaphase, Metaphase and Telophase were replaced by the response word Growth in the second year map. Also, the response words which were Homozygous, Test, Test cross and F1 generation to the key word Backcross did not appear in the second year map. In terms of the key word Genetic Engineering the response words Bacteria and Ligase did not come out in the second year map. Instead the response words Dolly the sheep and Cloning appeared. This may be accounted for as follows. In the first year most of the examples about Genetic Engineering were given by referring to Bacteria, however during the second year there was a public debate about Cloning and Dolly the sheep. This could have had an effect on the course and on the perception and information of the students about Genetic Engineering. These results reveal that a word association test may be a reasonable reflection of the ideas which students have in mind.

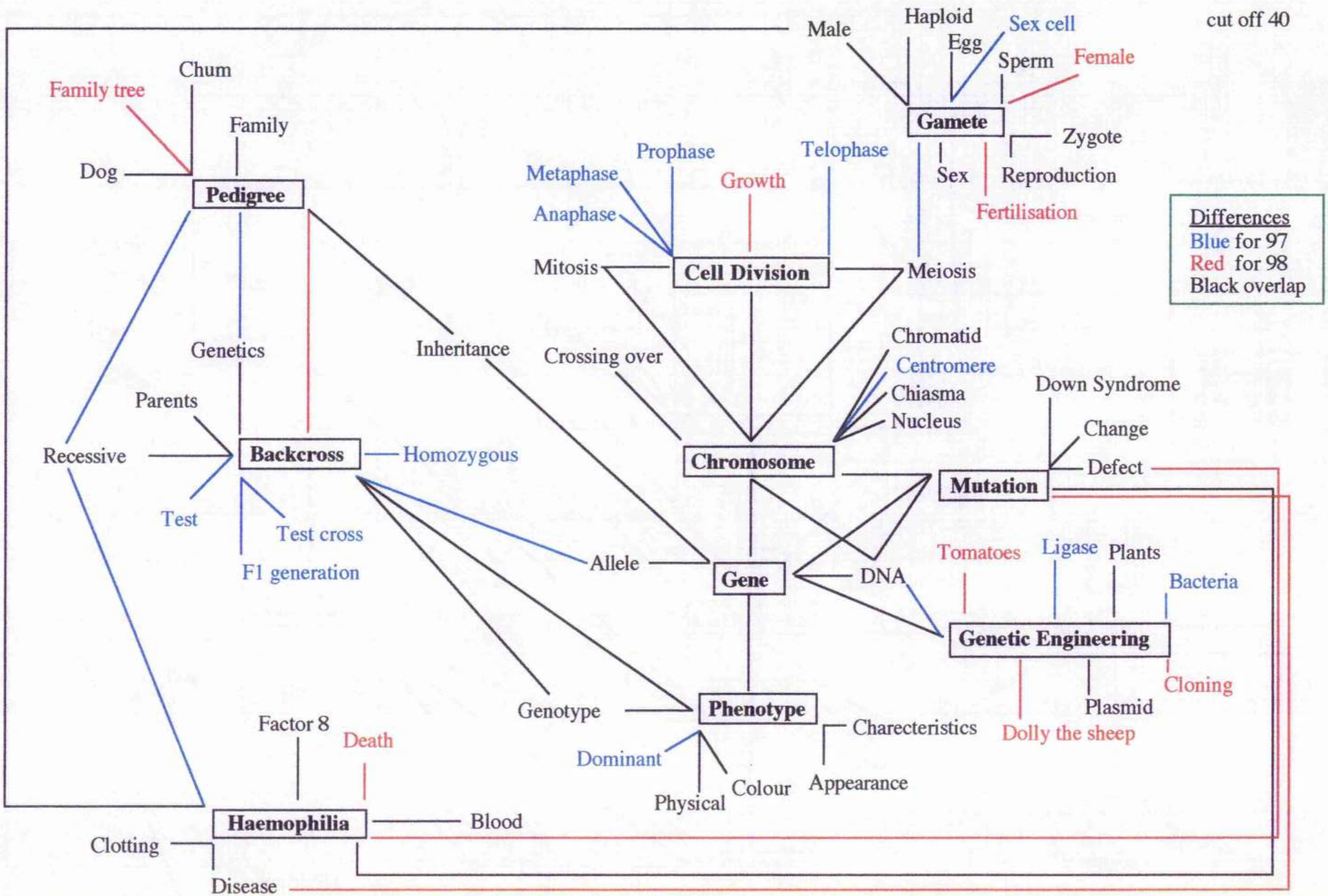


Figure 7.5 Overlap Between Frequency Maps

As mentioned in previous paragraphs, students were not likely to see all the ideas as a linked, interconnected network. In this context a network is not thought of as something like a fishing net, in which the intersections must be equidistant. A network may simply mean 'an interconnected system' in which the strength of the links (associations) between words (and concepts) are not necessarily equal. That is if the distance between two words in the network is very short, they have a strong association and if they are far from each other, they have either no association or the association is very weak. Also in this network one word may have several associations with other words, and the strengths of these associations may vary. For example in Figures 7.1, 7.2 there are associations between Gene, Chromosome, Mutation, Phenotype and so on. However, the strengths of the associations are not equal between these words, (e.g. Chromosome and Gene has the strongest link) and some words do not have a direct association. They are linked through other words, for instance (in Figure 7.3), Chromosome is linked to Gamete through Meiosis, Haemophilia to Pedigree through the word Recessive.

In this study it is not expected that every word should have a link (either strong or weak) to every other word like Haemophilia to Cell Division. Nevertheless we would expect links such as those between Chromosome and Gene, Gamete and Cell Division, Haemophilia and Mutation, Haemophilia and Pedigree, Phenotype and Backcross, Gene and Genetic Engineering and so on. However some of these expected associations in both Figures 7.1 and 7.2 appeared only at the weakest level.

We now have a picture of the associations between the key ideas which the students have in mind and this can be compared with the intentions which the teacher had in mind for this course. In an informal meeting, when the teacher saw the map (in Figure 7.3) he was happy to see some important connections which appeared at the highest levels of cut off point, such as the connections between the stimulus words Chromosome, Gene and Mutation, which were fundamental to the course. Similarly he was pleased to see the connections between Gamete and Cell Division through Meiosis, between Chromosome and Cell Division through Meiosis and Mitosis. On the other hand, he emphasised the missing connections between Haemophilia and Mutation, Haemophilia and Gamete, Pedigree and Backcross Backcross and Phenotype, all of which appeared only at the weakest level.

As stated in section 1.5.1, there is research evidence that the more branched and networked the knowledge and understanding in a student's mind, the more accessible it is and the more effective it is for non-routine problem solving (Kempa and Nicholls, 1983). Where the concepts are only weakly linked, access to one concept via another is not readily achieved and problem solving, in which the link is essential, does not occur. Cognitive structures of good problem solvers are more complex and contain more associations than those of poor problem solvers for given levels of relationships between concepts.

7.1.1 Total Number Of Different Responses in the WAT

Table 7.3 shows the total number of different responses to each of the stimulus words in the WAT.

Stimulus words	Total no of different responses **1997**	**1998**
Mutation	173	154
Genetic engineering	161	145
Chromosome	159	140
Gene	151	152
Cell Division	129	122
Pedigree	125	120
Backcross	123	105
Gamete	121	106
Haemophilia	114	92
Phenotype	108	95
Total no of different words	432	470

Table 7.3 Total number of different response words to each stimulus word in the WAT

Note: For 1997 the different response words are in rank order but not the response words for 1998.

It can be seen from the Table that the highest number of different responses to the key words in both word association test responses (for 1997 and 1998) are similar. In order to examine the relationship between these two different responses for both years statistically, Spearman's *rho* rank order correlation coefficient were calculated. A significant positive correlation emerged as the Spearman's *rho* correlation coefficient was **0.94** (N= 10 and two tailed test). The *null hypothesis*, that there is no similarity between the total number of different responses to the key words, could be rejected at least at the 1% level.

Counting the number of responses to each stimulus word is one method of summarising the word association test (WAT) data (Shavelson, 1974). The number of different responses for a word is a significant and direct indication of the individual's understanding of the word, because meaning can be defined as being proportional to the number and complexity of the links the individual can make to the word. When students study the topic of genetics, the stimulus words should increase in meaningfulness, and so the average number of responses to each concept should increase. In other words, the number of "valid response" words to a stimulus word might be proportional to the meaningfulness of the key concept. Without any connections, a word is relatively meaningless, and its meaning is enriched as more connections are formed (Schaefer, 1979). The total number of different responses to the stimulus word "Mutation" are the highest, "Genetic Engineering," "Chromosome" and "Gene" are higher than others in both results of the word association tests. The higher number of different responses to the stimulus words "Mutation" and "Genetic Engineering" may be the result of recent problems about a nuclear station or political and ethical debates about cloning (especially of the human embryo and of sheep), particularly as presented in television and current science fiction films. This was supported by students' responses using words like Alien, Chernobyl, HIV (for Mutation) Dr Moreau Island, Government, Controversy, Super race, Creation, Dolly the Sheep (for Genetic Engineering). The responses to the stimulus words "Chromosome" and "Gene" are also diverse. Chromosome and Gene are seen in almost any topic in biology, therefore students may be more familiar with the words associated with these two stimulus words than to the others.

7.1.2 Relationship Between the Word Association Test Scores and Students' Scores in Exam

As noted in section 5.3.2 (in Chapter 5) to allow a correlation to be sought between the exams and the word association tests, each "valid" (i.e. meaningful and acceptable in terms of genetics) response in the word association tests was given a score of 1 (Note: students' WAT scores (for 1997-98) are given in Appendix 11). The sum of these was then correlated with the score in the conventional exam tests. Table 7.4 shows the significance of correlations (Pearson P. M. Correlation) between students' exam scores and their word association tests (WAT) scores for the years 1997 and 1998.

		Students' Scores on the Courses				
		Mod. A	Mod. B	Mod. C	Mod. D	S. project
WAT Scores	1997	**r = 0.32** significance 0.001 level df 272	**r = 0.30** significance 0.001 level df 271	**r = 0.22** significance 0.001 level df 264	**r = 0.30** significance 0.001 level df 276	
	1998	**r = 0.27** significance 0.001 level df 278	**r = 0.34** significance 0.001 level df 278	**r = 0.26** significance 0.001 level df 278	**r = 0.21** significance 0.001 level df 278	**r = 0.27** significance 0.002 level df 168

Table 7.4 Pearson P.M. Correlation coefficients (and their significance) between students' WAT scores and their scores in the exams

Note: "df" stands for the term "degrees of freedom"

As can be seen from Table 7.4, there are very significant positive correlations between students' word association test scores and their scores in exams. For almost all values *the null hypothesis*, (i.e. there is no relationship between students' WAT scores and their scores in exams) can be rejected at the 0.1% level. For the course "study project" the null hypothesis can be rejected at the 0.2% level. On the basis of these very significant, positive correlations it can be said that students who gave a high number of responses to the key words in the WAT showed better performance in the exam than the students who gave a low number of responses to the key words in the WAT. It is important to mention that the WAT did not only show a positive correlation with the course (Mod B= Molecules & Cells and Genes) from which the key words were selected, but it also showed significant positive correlations with other modules on both occasions (for 1997 and 1998).

There is a possibility that students may have a good understanding of the particular topic and good scores in the exam although they show little overlap between their responses to the key words and therefore low relatedness coefficient values between the key words in their word association test. As can be seen from Table 7.4, there is a significant positive correlation between students' word association test scores and their scores in the exam which was based on the topic genetics (Module B). However, it was seen from the frequency maps (Figures 7.3 and 7.4) as well as from the relatedness coefficient maps (Figures 7.1 and 7.2), that students fail to see all the key words and their related subwords as a network. Most of the students see the key words in small clusters as isolated islands and do not appear to be as good at seeing the links between all the key words. Therefore, it is possible that the questions in the exam required answers to specific questions which dealt with isolated islands in the frequency map, and did not emphasise the links between the topics being assessed. As a result of this, students still can get a good score although they cannot see all the information as the complete network which the teacher may have had in mind.

7.1.3 The Effect of Psychological Factors in WAT's Performance and Testing the Hypotheses

In this section an attempt is made to link the performance of group of students in the WAT and their thinking styles as exposed by the psychological tests for Field Dependence/Field Independence, Convergence/Divergence and Working Memory Capacity. Table 7.5 shows cross connections between key words in each group of students in the volunteer sample in the first year of study.

Relatedness Coefficients ➡ / Psychological Factors	**0.3 and over**	**0.299-0.2**	**0.19-0.10**	**0.099-0.01**	**Number of Students**	**Chi-square Values**
CON	2	1	26	16	29	9.42 Sig.L 0.01
DIV	1	2	12	30	21	
FD	1	3	18	23	26	0.31 No Sig.
FI	1	2	21	21	30	
LWM	1	1	26	17	27	6.98 Sig.L 0.01
HWM	1	3	13	28	20	

Table 7.5 The strength of cross connections between key words for each group of students (university volunteer sample)

Note: The last column in the table shows the Chi-square values for four values in the columns of 0.19-0.10 and 0.099-0.01 for each pair of thinking style. For example, the first Chi-square value (9.42) was measured by using the values of 26 -16 (for convergents) and 12-30 (for divergents). For all Chi-square values degrees of freedom is 1.

It can be seen from Table 7.5 that most of the cross connections of convergent students fall between the cut-off points 0.19 and 0.10, on the other hand divergent students show many more cross connections in the lower point between 0.099 and 0.01. However, as is shown in Table 7.6, if these two groups are compared in terms of the total number of different responses as well as average number of different responses (Number 1 and 2), it can be clearly seen that the divergers were higher than convergers. In addition, the average of responses of divergers was significantly higher than convergers. But someone may ask why are the cross connections for divergers weaker than convergers although the number of different responses to the key words are higher for them? Because, the relatedness coefficient is a measure of the overlap of two individual continuous word association hierarchies and therefore the programme that calculates the relatedness coefficient looks at the overlap between the responses for the stimulus words. Divergent students have given <u>more</u> and <u>different</u> responses for the stimulus words and therefore the overlap between the responses for each stimulus word was reduced. On the basis of these results (as can be seen from Table 7.5 and Table 7.6) the proposed **hypothesis 5.1** (in section 5.3.3, in Chapter 5) is accepted. It was *divergent thinkers are expected to have higher number of different response words as well as average response words in the WAT than convergent thinkers. Thinking in a versatile way, producing ideas and seeing things from different perspectives requires a large store of different words in the long term memory.*

As can be seen from Table 7.5, for field dependent and field independent students, the number of cross connections that fall in each cut-off point column was similar. There were no significant differences. This is also supported by the low, not significant Chi-square value which was 0.31. According to this value the *null hypothesis*, (i.e. there is no difference between the cross connection values for field dependents and field independents) is accepted. As can also be seen from Table 7.6 there was no significant difference between field dependent and field independent students regarding the average of different response words as well as average response words in the WAT. In terms of the performance of field dependents and field independents the following **hypothesis 5.2** (in section 5.3.3, in Chapter 5) was proposed: *In terms of high number of responses and high number of different responses in the WAT, a substantial difference between field dependent - and field independent students is not expected. In the WAT, students did not have to break up an organised field and separate relevant material from its context or discern the "signal" (what matters) from the "noise" (the incidental and peripheral) against a confusing background.* In the light of the evidence given above, this hypothesis is accepted.

Because of the nature of the WAT, field independent students who can easily break up an organised field and separate relevant material from its context or discern the "signal" (what matters) from the "noise" (the incidental and peripheral) against a confusing background, did not have any advantage over field dependent students who have difficulty in separating an item from its context.

Groups	Number of Students	* Total No. of Different Responses	** Average of Different Responses (per student)	*** Average of Responses (per student)
1- CON	29	245	8.4	45
2- DIV	21	280	**13.3**	**60.5**
3- FD	26	261	10	52.5
4- FI	30	278	9.2	52.1
5- LWM	27	225	8.3	48.9
6- HWM	20	262	13.1	48.7
7- CON + FD	10	155	11.5	48
8- DIV + FD	7	176	**25.1**	**63.1**
9- CON + FI	13	182	14	43.8
10-DIV+ FI	13	228	**17.5**	**60.5**
11- CON + LWM	15	197	13.1	45.1
12-DIV + LWM	6	142	**23.6**	**58.8**
13- CON + HWM	7	121	17.2	39
14- DIV + HWM	8	206	**25.7**	**56.3**

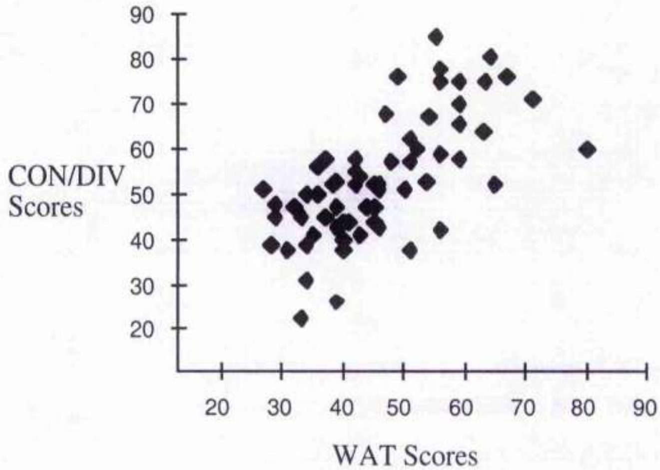
Table 7.6 Total and average different response words and average response words for each group of students in the WAT (university volunteer sample)

<u>**Note:**</u> *Total number of different responses was found by counting each different response to the key words. **Average of different response words was calculated by dividing the total number of different responses to the total number of students in the group.***Calculate average responses, all responses to the ten key words were counted and divided by the total number of students in the group.

As can be seen from Table 7.5, the cross connections between the stimulus words were stronger for the students who had low working memory capacity than the students who had high working memory capacity. Nevertheless, as is shown in Table 7.6, like divergent students, the total number of different responses and average different response words were higher for students who had high working memory capacity than had a low working memory capacity. In the light of this evidence the **hypothesis 5.3** (in section 5.3.3, Chapter 5) was accepted: The hypothesis was that *High working memory capacity students are expected to show higher performance in WAT (in terms of total number of different response words and average different response words) than low working memory capacity students.*

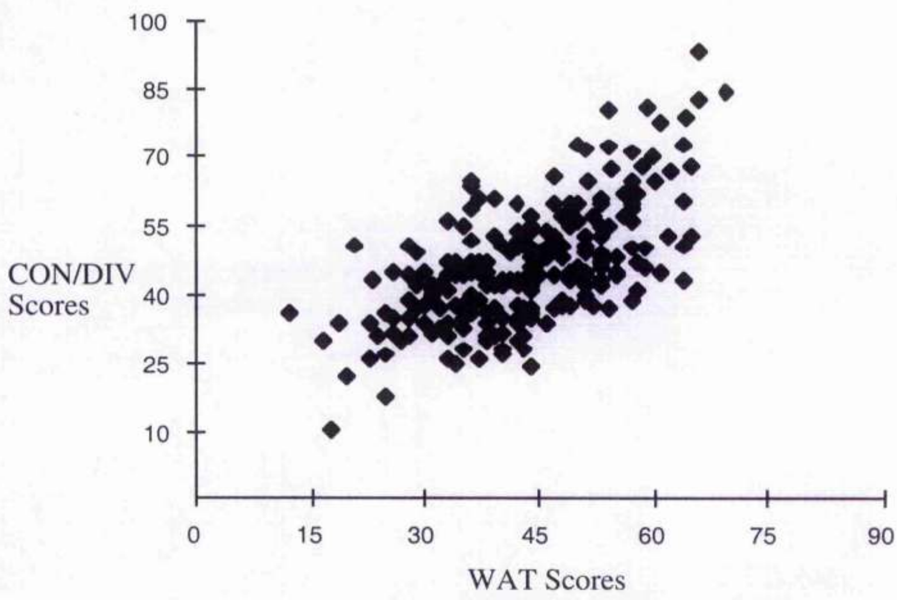
However, ability to give a large number of different response words for the stimulus words may not be related to having high or low working memory capacity. There may be several observations for this. (i) As can be seen from Table 7.6, there was almost no difference in terms of average response words (per student) between the students who had low - and high working memory capacity. (ii) If one compares the pairs in the average responses column in Table 7.6, differences only appear in pairs in which CON/DIV (written in bold in Table 7.6) is involved. In each case when the students were divergent, the total number of different responses and average different responses (per student) as well as average response words (per student) were higher.

Furthermore, as the students' word association test scores and their scores in the psychological tests were plotted against each other (in Figures 7.6, 7.7 and 7.8), a significant positive correlation appeared only between the CON/DIV tests and students' WAT scores (for Volunteer sample as well as university sample in the second year of the study). The *null hypothesis,* that there is no relationship between students' degree of divergence and their scores in the word association test, can be rejected at the 0.1% level. On the basis of this significant positive correlation it can be said that divergent students performed significantly better than convergent students in the WAT. On the other hand for field dependence/field independence and working memory capacity, the Pearson P.M. Correlation Coefficients were near zero and the *null hypothesis* was accepted.



Correlation Coefficient Value (r)= 0.5

Figure 7.6 A scatter plot between students' WAT scores and their CON/DIV tests scores (in the volunteer sample N= 65)



r = 0.45

Figure 7.7 A scatter plot between students' WAT scores and their CON/DIV test scores (in the university sample N= 225)

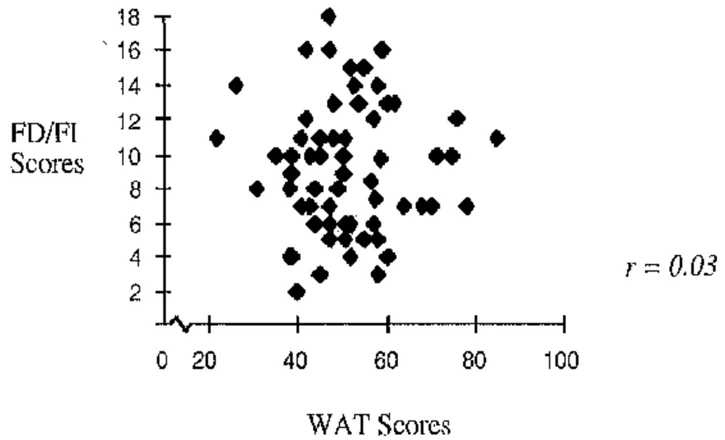


Figure 7.8 A scatter plot between students' WAT scores and their FD/FI tests scores (in the volunteer sample N= 65)

In conclusion, in the light of all these results it can be said that **only** convergence and divergence dimension of cognitive styles showed a significant relationship with the word association tests. The cognitive structure of the students who had divergent thinking style were rich in terms of their total number of words and total number of different words about genetics and consequently they might have a more complex and branched network structure of genetics concepts in mind than convergent students do.

7.2 Mind Mapping

As stated earlier in section 5.4.1 (in Chapter 5), the first aim of using mind maps in this research study was to aid students towards better essay writing because mind maps have advantages over a linear way of writing and it was thought that students could use these advantages for better planning and for better essay writing reflected in higher marks.

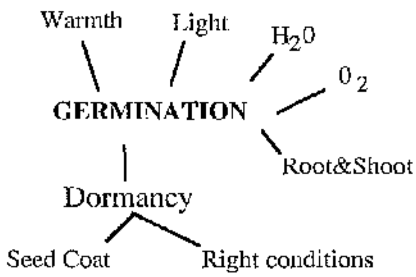
The second aim of using this technique was to gain an insight into students' ideas lodged in cognitive structure. Because mind maps, like concept maps can serve as a vehicle for obtaining a graphic representation of information held in memory, then students can realise that the ideas or concepts in their minds are interrelated (like a network) as well as being hierarchical. This power of mind maps should also enable us to look at the associations between ideas which students formed in their minds and to see the effect of particular thinking styles, such as convergence and divergence, over these associations. In addition to these two purposes, to reveal missing ideas and misconceptions about the topic seed germination, the students' mind maps and their essays were also examined in detail to look for correspondence between them.

7.2.1 Comparisons Between Mind Map Groups (Qualitative approach)

As mentioned in section 5.4.3.1 (in Chapter 5), before using a quantitative approach to mind mapping, a qualitative approach was attempted. Students' mind maps were classified as good, moderate and poor mind maps without consideration of their essay marks. In fact, this was purely by *impression marking* of the overall structure of each map. The three groups (i.e. good, moderate and poor) were then checked using the criteria set out in Table 5.3 (which was given in section 5.4.3.1) and, if necessary, reallocated. Three examples of mind maps were chosen to illustrate general characteristics of students' mind maps. One example of a poor, a moderate, and a good mind map are given in Figure 7.9.

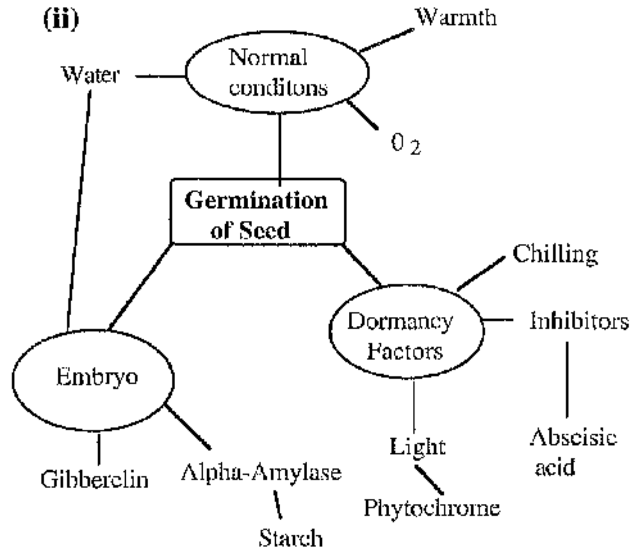
As can be seen from the Figure 7.9 there are substantial differences between the examples of a poor and a good mind map. The poor map for planning the essay indicates a low level of understanding of the topic of seed germination. It has only a few links, a low number of hierarchical levels and branches as well as few main ideas attached to the key word. The moderate concept map is more hierarchically organised with more linkages. However, in the good concept map, there are more levels of hierarchy and more branching of ideas, plenty of linkages, cross links and specific examples which all indicate a much more integrated structure and better understanding of the topic. In addition, the main ideas were put into a sequence for presentation in the essay to follow.

(i)



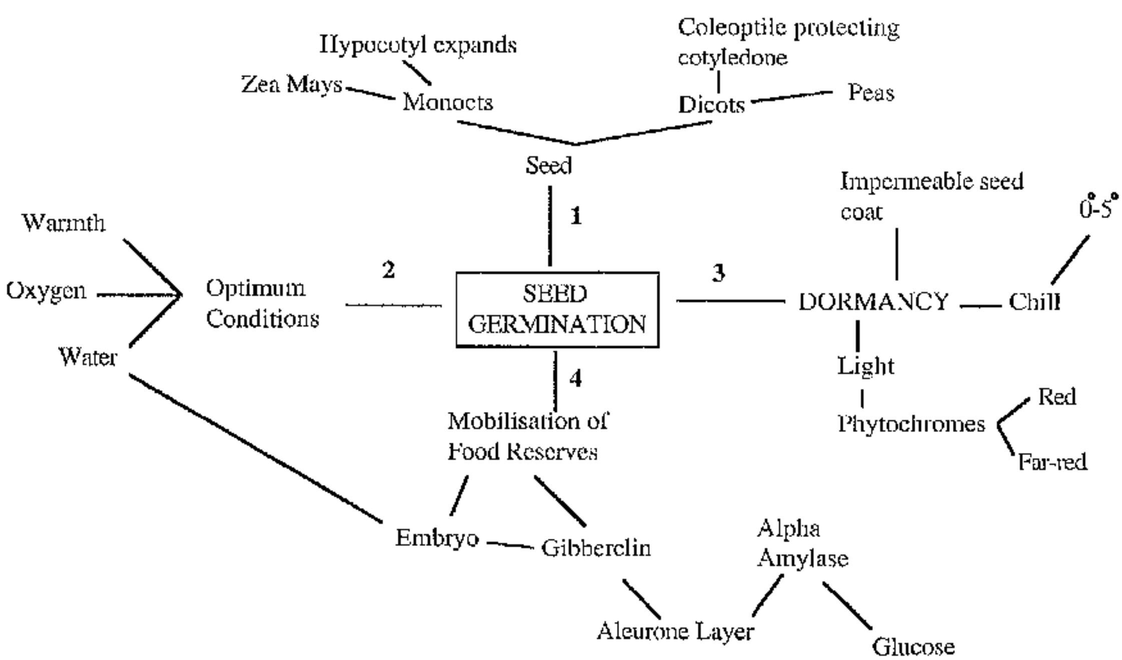
Essay score= 3

(ii)



Essay score= 50

(iii)



Essay score= 85

Figure 7.9 Three examples of a poor (i), moderate (ii), and good (iii) mind map

After classification of the students' mind maps in three groups the mean scores of these three groups in essay "Seed Structure" were calculated. As noted in section 5.4.3.2 the essays were marked independently of the researcher, on a percentage scale. Table 7.7 shows the mean essay scores of good, moderate, and poor mind mappers.

Groups	Mean Essay Score
Good M.Mappers N=91	66.9
Moderate M.Mappers N=98	60.3
Poor M.Mappers N=62	54.1

Table 7.7 The mean scores of three groups of mind mappers in essay

As can be seen from Table 7.7 there were differences between mean essay scores of these three groups of mind mappers. These differences between the groups might be considered as an early sign of a relationship between the complexity of mind maps and the quality of essays. In other words, more complex mind maps may help in the organisation and presentation of the ideas during essay writing.

7.2.2 Comparison Between Mind Map And Non-Mind Map Groups And Testing The Hypothesis

Table 7.8 shows the mean essay scores of the students who used mind maps for their essay writing (Mind Mappers), for the students who did not use mind maps (Non Mind Mappers) and for the whole sample (Mind Mappers + Non-Mind Mappers).

	N	Mean
Mind Mappers	251	61.2
Non-Mind Mappers	510	58.7
Whole Sample	761	59.5

Table 7.8 Mean essay scores of mind mappers, non-mind - mappers and whole sample (and number of students in each group)

It can be seen from Table 7.8 that the mean scores of the Mind Mappers and Non-Mind Mappers did not appear to be very different. The difference was only 2.5 marks. However, when a two sample t-test was used to compare the mean of the Mind Mappers and the Non-Mind Mappers, the difference between the two mean scores was found as statistically significant (at the 2% level).

Another way of looking at the data is to use a boxplot which can allow comparison of the essay marks of the test group who did mind maps for planning their essay and the control group who did not draw mind maps. Examination of the boxplots of the two groups in Figure 7.10, the rectangular box which contains half of the data is slightly more positively skewed for the Mind Mappers. Also the median (which the symbol "+" represents) for the Mind Mappers is higher than the median for Non-Mind Mappers. It also should be noted that there are outliers (which the symbol * represents) in both of the groups.

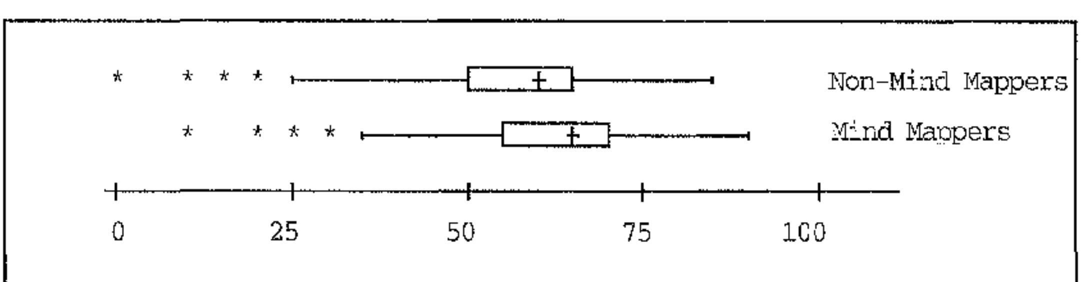


Figure 7.10 Boxplots comparison of mind mappers and non-mind mappers

In the light of the boxplot comparisons and test statistics (two sample t-test) it can be concluded that the **Hypothesis 5.4-** *Overall performance in the essay of the students who used mind maps for planning their essay writing is expected to be better than students who did not use mind maps* is accepted.

7.2.3 Correlation Between Students' M. Map Scores And Their Essay Marks

As pointed out in section 5.4.3.2 (in Chapter 5), in this research study a scoring key was developed to measure the students' performance in mind mapping and the researcher also prepared a model mind map as a guide from the model answer sheet for the question (i.e. Seed Germination) and this model answer sheet was used during marking. Essays were marked, independently of the researcher, on a percentage scale. The highest mark in the mind maps was 183.

In order to look at the relationship between students' essay scores and their mind map scores a scatter plot was drawn (Figure 7.11).

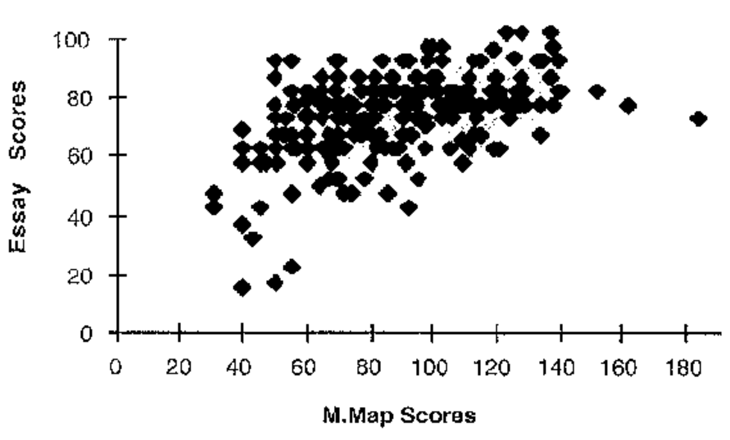


Figure 7.11 A scatter plot between the students' essay scores and their mind map scores (N=251)

As can be seen from the scatter plot, there is a positive relationship between two scores. As the students' essay scores and their mind map scores were plotted against each other, a statistically significant positive correlation emerged. The Pearson P. M. Correlation Coefficient was **0.47** (degrees of freedom = 249/two tailed tests). *The null hypothesis,* that there is no relationship between students' mind map scores and their essay scores, could be rejected at the 0.1% level.

It is necessary to mention that even though all the results clearly indicate that students who had good mind maps obtained higher scores in the essay (or vice versa), there were a small number of students who drew good maps but had low scores in essays. When their map were examined in terms of hierarchy, branching, the total number of number of ideas and cross links, these students were classified as good mind mappers. However, as their map was examined deeply, it was seen that although the number of the ideas, and level of hierarchy and branching were plentiful in these students' maps, the numbers of *valid* linkages and cross links as well as content of the topic were not sufficient. They drew a mind map that was good enough in terms of general shape but not good enough in terms of content as well as valid fundamental linkages. Consequently, they could not give enough detail or missed fundamental ideas in their essays and had low scores. In the same way, in the mind mappers group, although there was a minority of students who drew poor maps but had high marks in the essay. This might be due to reasons that, these students either did not take the mapping into the consideration or as White and Gunstone (1992) indicated, "a poor mind (or concept) map coupled with reasonable performance on a test of detail suggests that these students' learning may be rote, hence that the knowledge will soon be lost."

7.2.4 Comparison Of The Content Of Students' Essays And The Content Of Their Mind Maps

When the essays of those who used mind maps were examined, the missing ideas, which were identified and written down at the end of each essay by the essay marker were noted. When these missing ideas or topics were looked for in the mind maps of the students, it was clearly seen that most of the students missed the same ideas in the mind maps as in the essays. In other words, if they did not mention an idea in the mind maps, they did not give it in their essays. In fact this is not a surprising result, because mind mapping is a technique for externalising concepts, for visualising the ideas in the long term memory. Students wrote their essays in the light of their mind maps which were a true reflection of ideas that students had in mind. The number of students and the main ideas which were missing from the mind maps (and in the essays) are given in Table 7.9. This analysis was applied only to students who had done mind maps (N=251).

As can be seen from Table 7.9, a substantial number of students did not to give any account of dormancy mechanisms (i.e. mechanisms that prevent germination). Briefly, these mechanisms include (Note: these dormancy mechanisms which are given below were taken from model answer sheet for the essay);

(i) impermeable seed coat where an external wax layer prevents water penetration, as in some varieties of wheat,

(ii) a chilling requirement (e.g., in apple)

(iii) chemical inhibitors in seed coat for instance, abscisic acid in charlock,

(iv) a light requirement such as that found in a variety of lettuce and which led to the discovery of the light regulated pigment system "Phytochrome". There are a number of these pigments (e.g., Phytochrome A, B, C, D, E, etc.) all of which can exist in a red and far red light absorbing form and each comprising a specific protein coded for by the phytochrome genes a, b, c, d, etc. and a linear tetrapyrrole chromophore. This pigment system accounts for the red and far-red reversibility of these wavebands of radiation in regulating a wide range of developmental phenomena. As can be seen from Table 7.9, a considerable number of students (N=70 nearly 30% of the mind map sample) did not give an account of these light regulated pigment systems. Some students did not give an account of other dormancy mechanisms like the role of abscisic acid and the chilling requirement. This was also true for the topics "seed structure, and mobilisation of food resources."

Topics		Number of Students
Dormancy mechanisms	Light requirement (Phytochrome)	70
	The role of abscisic acid	44
	Cold requirement	37
	Impermeable seed coat	35
Seed structure	Dicotyledonous non-endospermic seed	44
	Monocotyledonous endospermic seed	32
Mobilisation of food reserves	The release and function of alpha amylase	31
	The release and function of gibberelins	28
Insufficient illustration		13
The role of environmental factors	Temperature	6
	Water	5
	Oxygen	4

Table 7.9 The topics missing from mind maps (and from essays) and the number of students

7.2.5 Misconceptions in Mind Maps and in Essays

In addition to these topics which were missing in the mind maps and in the essays, it was also noticed that some important *misconceptions* (i.e. ideas which are scientifically not true) were identified by the markers in the students' essays and by the researcher in students' mind maps. It is important to mention that, like the missing topics in the mind maps and in the essays, the misconceptions which appeared in the mind maps were clearly stated by the students and noted by the markers in the essays. However, in the mind maps, it was impossible to detect all the misconceptions which students mentioned in their essays. This is because mind maps do not show enough detail in spite of the fact that each linkage between two ideas in mind maps indicates the relationship between these two ideas and consequently the structure of whole topic.

These scientifically incorrect ideas or misconceptions which appeared in the mind maps and in the essays about "mobilisation of the food stores, external factors affecting germination and light requirement" are given in Table 7.10. The rest of the misconceptions which appeared only in the essays and were not detected in the mind maps are given in Appendix 17.

	Incorrect statements in the essay	*The way these incorrect statements (Misconceptions) appeared in M.Maps*
1	Seed coats have acidic chemical inhibitors like Auxin, that prevent the seed from germinating	Seed coat — Auxin
2	The important reason for dormancy is the presence of inhibitory chemicals in the seed coat known as gibberelic acid	Chemical inhibitors in seed coat —e.g— Gibberelic acid
3	The embryo produces chemical signals called auxins which make the seeds produce alpha amylase	Embryo — Auxins — Alpha amylase
4	Alpha amylase helps the endosperm to synthesise sugar	Alpha amylase — Endosperm — Sugar
5	Endosperm sends a chemical message, gibberelic acid, to the aleurone layer which swiches on the alpha amylse synthesis	Endosperm — Gibberelins
6	During the germination the embryo will send a chemical called IAA to the aleurone layer of the cell and the layer produces the enzyme alpha amylase.	Embryo — IAA — Alpha amylase
7	Some seeds will only germinate at low temperatures	Germination — at very low temp.; at very high temp.
8	Some gases such as carbon dioxide affect germination	Environmental factors — O_2; Humidity; CO_2
9	Acetic acid (a germination inhibitor) stimulates enzymes in the aleurone layer to make alpha amylase	Acetic acid — Aleurone layer — Alpha amylase — Starch to glucoses
10	The water intake of seed causes on increase in enzymes, namely gibberelic acid which break down the storage materials within the seed providing nutrients	Food supply — Gibberelic acid — Starch
11	Light has to be present for germination	Germination — Basic requirements — Light; Water; Warmth; O2

Table 7.10 The misconceptions about mobilisation of food stores, environmental factors and light requirement which were identified by the markers in the essays and the appearance of these misconceptions in the mind maps which were identified by the researcher.

As is shown in Table 7.10, students had misconceptions or made incorrect statements about the topic of mobilisation of food stores during germination. The most common mistakes were about;

(i) the place where gibberelin is produced and its function (Statements 2, 5, 9 and 10),

(ii) the function of Auxins (Statements 1, 2, 3)

(iii) the function and the production of the enzyme Alpha Amylase (Statement 4),

(iv) the difference between Indol Acetic Acid (IAA) and Gibberelin (Statement 6) and

(v) the effect of external factors for germination (Statements 7, 8, 11).

From the markers' notes on the essays it was found that another common mistake was about "light and phytochrome". This was also obvious in a substantial number of students' mind maps (Statement 11 in Table 7.10). In their mind maps, they thought of the concept "light" as a basic requirement for seed germination. The same students stated in their essays that light is an essential factor for germination, but generally speaking this is not the case. Most seeds do not need light to germinate. The misconceptions about the pigment system "phytochrome" were also common among the students. These misconceptions and brief information about phytochromes are given in Appendix 17. As mentioned in the previous section 7.2.4, a number of students (N=70 nearly 30% of the mind map sample, as can be seen from Table 7.9), could not give an account of the light regulated pigment system "phytochrome". It was also seen, as is given in Appendix 17, that a considerable number of students who gave information about light requirement and phytochrome, had serious misconceptions like the statement 11 in Table 7.10. In the light of these findings it can surely be said that students had problems about light requirement and phytochrome.

As an additional interesting point, not only did the students have misconceptions but even the lecturer might have them. For example, (i) not all the markers had the same opinion regarding the effect of gravity on seed germination, and (ii) there were also two incorrect statements which were noted by two different markers in students' essays. They were "far red light prevents the germination completely" and "far red light is needed before the seed germinates." In the light of the information about phytochrome which is given in the Appendix 17, it cannot be said that both statements were incorrect. It is true that the statement “far red light is needed before the seed germinates” is incorrect, however, this can not be said for the first statement. But one marker treated this statement as wrong. In this case, it is possible that even the marker was not very clear in terms of light requirement (Phytochromes). The results of some studies (e.g., Sanders, 1993; Soyibo, 1995; Yip, 1998) suggest that, in terms of the source of students' misconceptions in biology, teachers who are not confident in their subject might cause incomplete or erroneous views to their students through inaccurate teaching or uncritical use of textbooks. In this study, the similar confusion or misconceptions between some markers and some students regarding the effect of far-red light on seed germination may suggest that some lecturers may have served as a direct agent for propagating and reinforcing the incorrect views of the students about the effect of light on seed germination.

Module A (Plants and Microbes) of which the seed germination essay was part, was found most difficult by the students during the teaching session. The scientifically wrong ideas or inadequate knowledge about particular concepts (e.g., light requirement, the function of hormones or enzymes) might be among the reasons behind these difficulties. It is also important to note that although students perceived Module A as the most difficult during the teaching session, it appeared to be the easiest in the exams. The kind of assessment method can be the main reason for this discrepancy. In three option multiple choice questions, it is almost impossible to catch the misconceptions which were clearly seen in the essays. In multiple choice it is possible that a student can give a right answer in spite of the fact that he has serious misconceptions about a topic. For example, a student can give the right answer to the following question: *Which part of the seed synthesises the enzyme "alpha amylase":*

a) Embryo

b) Aleurone layer (right choice)

c) Seed coat

although having scientifically wrong ideas about the function of alpha amylase or how its production is initiated: for instance, alpha amylase helps the endosperm to synthesise sugar, the embryo produces chemical signals called auxins which make the seed produce alpha amylase or acetic acid stimulates enzymes in the aleurone layer to make alpha amylase and so on.

7.2.6 The Effect of Cognitive Style in Mind Mapping and Testing the Hypothesis

One of the purposes of using mind maps in this research study was to gain an insight into ideas of the students who had particular thinking styles. It was hoped to find out if thinking styles have any effect on the quality of mind maps in terms of branching, total number of concepts and cross links. In particular, the effects of convergence and divergence were sought. The hypothesis 5.5 which was made in section 5.4.4 (in Chapter 5) is *The mind maps of divergent students are expected to be more complex and branched than convergent students. Consequently, divergent students may benefit more* *than convergent students in terms of getting higher scores in their essay.* Now let us examine the results to test whether this hypothesis can be accepted or rejected.

Table 7.11 shows Pearson P.M. Correlation Coefficients between students' scores which they had in Convergent/Divergent Tests and their Mind Map scores. In addition, the total number of different concepts in each student's mind map was counted and these were correlated with the score in CON/DIV Tests.

	CON/DIV Tests Scores N=184
M.Map Scores N=184	**0.18** * df 182 Sig. at 0.02 level
Total No of Concepts N=184	**0.24** * df 182 Sig. at 0.001 level

* in favour of divergency

Table 7.11 Pearson P. M. Correlation coefficients

It can be seen from Table 7.11 that statistically significant positive correlations emerged between students' CON/DIV tests scores and their Mind Maps' scores. Pearson P.M. Correlation Coefficient was **0.18** (degrees of freedom = 182/two tailed tests). *The null hypothesis*, that there is no relationship between Mind Mapping and Convergent/Divergent thinking style, could be rejected at the 2% level. From this correlation it can be said that the students who had a divergent thinking style were better in mind mapping and consequently gained higher marks in mind maps than the students who had a convergent thinking style.

A statistically very significant positive correlation emerged as the Pearson P.M. Correlation Coefficient was **0.24** (degrees of freedom = 182/two tailed tests) between students' CON/DIV tests scores and the total number of concepts in their map. *The null hypothesis*, that there is no relationship between the total number of concepts in mind maps and Convergent /Divergent thinking style, could be rejected at the 0.1% level. This was also confirmed by the results which are given in Table 7.12.

Group	M.Map Scores Mean (per student)	Total Number of Concepts Total	Mean (per student)
Convergers N= 58	83.8	867	14.9
Divergers N= 63	99.8	1123	17.8

Table 7.12 Mean mind map scores and total number of convergent and divergent thinkers

As is shown in Table 7.12, the total number of concepts which divergent students used in their mind maps was higher than the total number of concepts which convergent students used in their mind maps.

In order to compare the difference between convergent and divergent students in mind mapping another count was made in terms of branching and cross linking in their maps (Table 7.13).

Group	Branches		Cross links	
	Total	Mean (per student)	Total	%
Convergers N= 58	154	2.66	21	29.3
Divergers N= 63	259	4.11	51	46.0

Table 7.13 Branches and cross links in mind maps of convergent and divergent thinkers

Note: % indicates the percentage of the students in the group who had cross links in their map.

As can be seen from Table 7.13, the total number of branches and also the average number of branches of divergers were significantly higher than those of convergers. It is necessary to mention that the essay topic "seed germination" was not potentially rich in cross links or connections, but still divergent students had more cross links between the ideas than did the convergent students. As is shown in Table 7.13, the total number of cross links which were seen in divergent students' mind maps was higher than convergents. While 46% (29 of 63 students) of the divergers had cross links in their mind maps between the ideas, only 29.3% (17 of 58 students) of convergers had cross links in their mind maps.

All these results clearly show that the mind maps of divergent students are more complex and branched than convergent students. To learn if the complexity of the mind maps was responsible for the superior essay marks, the following data were examined;

(i) the students' scores in the essays and in the CON/DIV tests were plotted against each other to look at the relationship between these two factors (Figure 7.12). A significant positive correlation appeared as the Pearson P.M. Correlation Coefficient was **0.12** (degrees of freedom = 296 and two tailed tests). The *null hypothesis,* that there is no relationship between students' degree of divergence and essay scores, can be rejected at the 5% level. On the basis of this result it can be said that divergent students, who had higher scores in CON/DIV tests, showed better performance and had higher scores than convergent students in the essay.

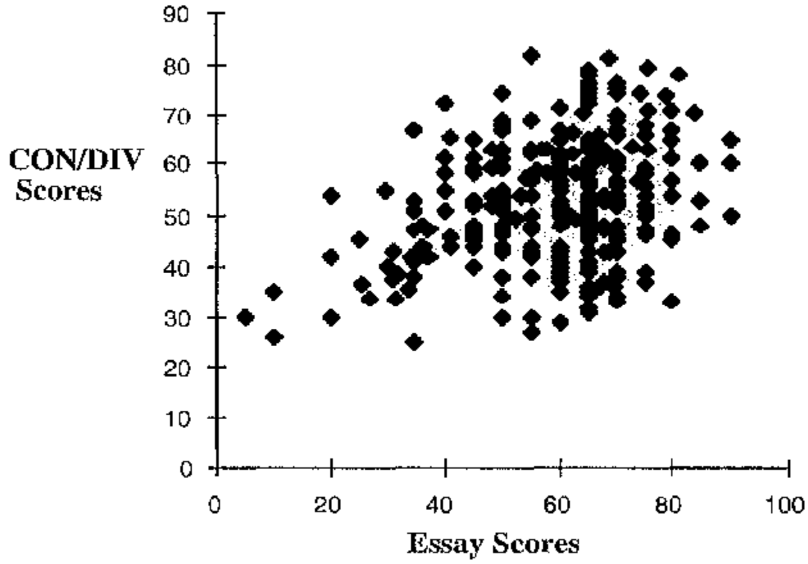


Figure 7.12 A Scatter plot between students' essay scores and their CON/DIV tests scores (N=298)

(ii) To compare the mean essay scores (they are given in Table 7.14) of these two groups of thinkers statistically, two sample t-tests were used and the difference between the mean scores was found to be statistically significant (at the 5% level) in favour of divergers.

	N	MEAN
Convergers	58	58.0
Divergers	63	63.2

Table 7.14 The mean essay scores of convergers and divergers

In the light of all these results the hypothesis 5.5: *The mind maps of divergent students are expected to be more complex and branched than convergent students. Consequently, divergent students may benefit more than convergent students in terms of getting higher scores in their essay* is accepted. According to results, divergent students performed better in mind maps, had more cross links, more branches of ideas and more concepts in their mind than convergers. Consequently, they should have a more complex, integrated network of ideas in their mind. Higher mind map scores of the divergent students also indicate that they used the advantages of the mind maps better than convergent students and this advantage helped them to gain higher scores in the essay.

7.3 Structural Communication Grids

In this research study, as mentioned in section 5.5 (in Chapter 5), the Structural Communication Grids (SCG) were used primarily as a technique to gain insight into students' thinking, and as a tool to reveal the effect of some cognitive styles in the performance of the grid type of questions of a particular concept area in biology. The cognitive styles which were focused on in this part of the study were Convergence/Divergence and Field dependence/Field independence. It is important to mention that the grids were also used as an assessment tool as well as a diagnostic tool for the first year biology students on the topic "Haemophilia".

7.3.1 Results for Secondary Schools

Two grid questions namely "Food Digestion" and "Chemistry of Respiration" were given to pupils in four different Scottish Secondary Schools.

In order to follow the results and arguments better, the grid questions and their answers are given again in Tables 7.16 and 7.18. Table 7.16 shows the grid questions and the answers on Food Digestion.

As mentioned in section 5.5.2.2 (in Chapter 5), the full mark for each grid question on Food Digestion was 10 and possible full mark was 60. In order to calculate the facility value (i.e. the average students' success rate for each question) of each question the marks of pupils for each question was summed and this was divided by the possible highest sum of the pupils' marks. Facility value of each grid question on Food Digestion test is given in Table 7.15.

	Q1	Q2	Q3	Q4	Q5	Q6
Facility Values	0.89	0.30	0.36	0.45	0.53	0.56

Table 7.15 Facility values of the grid questions on food digestion

Questions 1 and 6 in the grids of food digestion appeared as the easiest questions. This may be explained because these two questions required only one answer (as in multiple choice questions). There could have been a guessing factor but this would have been only 1 in 9. However, in the light of the responses to the other questions, it was possible to detect whether pupils had been guessing. For instance, a number of pupils gave the right answer for question 6. As can be seen from Table 7.16 they were asked in this question for the name of the enzyme which is active only in the stomach. However, the same pupils had also given the enzyme "pepsin" as an answer for question 2 which was not true. Therefore, it was clear that these pupils had a problem about where pepsin is active. Also question 3 appeared as one of the difficult questions. Most of the pupils were confused between enzymes and end-products of digestion.

The grid below contains the names of digestive enzymes, fluid and breakdown products.

Use the numbers from the boxes to answer the following questions. Each number can be used once or more than once.

1 glucose	2 pepsin	3 maltase
4 lipase	5 amino acids	6 glycerol and fatty acids
7 amylase	8 bile	9 trypsin

Q1. Which box contains the digestive enzyme which is present in both saliva and pancreatic juice?

Number ....7..............

Q2. Which boxes contain the enzymes which are active in the small intestine?

Numbers .....3 - 4 - 7 - 9

Q3. Which boxes contain the enzymes which are protease?

Numbers ....2 - 9...........

Q4. Which boxes contain the enzyme and fluid that play a role in fat digestion?

Numbers ......4 - 8...........

Q5. Which boxes contain the end-products of digestion?

Numbers ......1 - 5 - 6......

Q6. Which box contains the enzyme which is active only in the stomach?

Number ....2.........

Table 7.16 The grid questions and the answers on food digestion

Moreover some pupils thought the fluid "bile" was a protease. Although it is not an enzyme, it emulsifies large drops of fat into tiny droplets, thus increasing surface area of fat upon which lipase can act.

As a result, from pupils' answer to grid questions on food digestion, it was seen that:

(i) Pupils had a problem about the classification of the enzymes especially about protease.

(ii) They were not competent enough in terms of the difference between enzymes, end-products of the digestion, and fluids. For example some pupils thought the fluid "bile" as an end product of digestion.

(iii) Because a considerable number of pupils used the fluid "bile" which plays a part in fat digestion as a wrong answer to questions 3 and 5, they were not clear about its function. It was also obvious in question 4 that a substantial number of the pupils failed to give the fluid "bile" as an answer.

Table 7.18 shows the grid questions and the answers on Chemistry of Respiration. As stated in section 5.5.2.2 (in Chapter 5), the full mark for each question on the Chemistry of Respiration grid was 25 and possible full mark was 100. To calculate the facility value of each question the same method applied as in the grid test on Food Digestion. Table 7.17 shows the facility value of each grid question on Chemistry of Respiration test .

	Q1	Q2	Q3	Q4
Facility Values	0.38	0.53	0.64	0.36

Table 7.17 Facility values of the grid questions on food digestion

Questions 1 and 4 appeared to be the most difficult questions. In question 1 pupils had to choose 4 boxes from the grids to get the full marks. The relatively high number of boxes which had to be chosen may be one of the reasons for the difficulty of the question. Also a substantial number of pupils had given as answers reactions which occur after glycolysis. Therefore, they did not have a true understanding of what glycolysis is, where it happens, under which conditions it happens or whether it is part of aerobic respiration and so on. From their answer it was obvious that, if they had a true understanding of glycolysis, they would have been able to give a right answer for questions 2 and 3. In these two questions pupils were required to select reactions which happen after glycolysis.

The grid below contains the metabolic reactions that happen during respiration in a living cell.

Use the numbers from the boxes to answer the following questions. Each number can be used once or more than once.

1 The breakdown of a molecule glucose to 2 molecules of pyruvic acid	2 The binding of hydrogen and oxygen to form water	3 Temporary binding of hydrogen to coenzyme molecule
4 The releasing of CO_2	5 $2ATP \rightarrow 2ADP+2Pi+Energy$	6 The production of ethanol
7 The transfer of hydrogen from coenzyme molecules	8 Conversion of pyruvic acid to lactid acid	9 $4ADP+4Pi+Energy \rightarrow 4ATP$

Q1. Which boxes contain the reactions which happen in the cytoplasma of an animal or plant cell during glycolysis?

Numbers 1.-.3.-.5.-.9

Q2. Which boxes contain the reactions which occur in the central matrix of mitochondria?

Numbers ....3.-.4.......

Q3. Which boxes contain the reactions that occur in the cristae of mitochondria?

Numbers ....2.-.7.......

Q4. Which boxes contain the reactions which happen in the absence of oxygen only in a plant cell?

Numbers ....4.-.6........

Table 7.18 The grid questions and the answers on chemistry of respiration

In question 4 they were required to choose the boxes containing the final metabolic products which are produced by plants in the absence of oxygen (anaerobic respiration). The metabolic process of breakdown of glucose to pyruvic acid is common for plants and animals but, in the absence of oxygen (anaerobic respiration), the final metabolic products are ethanol and CO_2 in a plant cell and lactic acid in an animal cell. 32 out of 94 students chose the answer "conversion of pyruvic acid to lactic acid" for Q4. Obviously, they confused the particular reactions which are characteristic for plants or for animals. There were only 4 pupils out of 94 who got full marks for Q4.

As can be seen from the results of both grid questions on "Food Digestion" and "Chemistry of Respiration", structural communication grids can be used as an effective diagnostic tool to find out the relationship between ideas. Food Digestion and the Chemistry of Respiration were only two clusters inside the network of ideas in pupils' cognitive structure. By using the questions, it was possible to detect where the connections were missing between ideas, where the pupils were weak or had problems. In addition some pupils gave partial answers that showed that they were not adequate but they were still partially rewarded for what they had already in their mind. This is precisely what happens when an extended answer question is scored.

7.3.2 Results for University students

As mentioned in section 5.5.2.1 (in Chapter 5) in the second year of the study, a grid question on Haemophilia was administered to first year biology students (N= 396) in the university and these grids were neither prepared nor administered by the researcher but by a co-operative lecturer. The grid question was: *The following statements have been arranged in random order in the grid below. You should select the statements which are relevant to haemophilia, and place them in order that leads logically from genotype to phenotype.*

<u>Statements</u>

1. Mutation
2. Altered primary structure of polypeptide
3. Defective function of factor VIII
4. Prolonged clotting time
5. Reduced wound healing
6. Infection
7. Premature death
8. X chromosome
9. Red cells lyse in blood vessels
10. Red cells sickle
11. Autosome
12. Haemoglobin S

Correct answers for the grid question on haemophilia:
Students should exclude the statements of 9, 10, 11, 12
correct orders of included statements can be: 8,1,2,3,4,5,6,7. or 1,8,2,3,4,5,6,7. or 8,1,2,3,4,6,5,7. or 1,8,2,3,4,6,5,7.

Four issues were considered for marking of the grids. These were:
(i) If they confuse sickle cell and haemophilia they get zero.
(ii) Statements 5 and 6 may be in either order.
(iii) Students must make the link between 2-5/6 to get any marks for correct sequencing.
(iv) A mark is deducted for those who think the gene for factor VIII is autosomal.

The students' scores which they gained in the grids were part of their official exam and the total weight of grids was equal about 8% of their total exam mark. Table 7.19 shows the distribution of the students' marks which they had in the grid question on "Haemophilia".

	0	1	2	3	4	5
No of Students N= 396	14	154	92	51	55	30

Table 7.19 Classification of the students' scores in the grid question on haemophilia

As can be seen from Table 7.19, a large number of the students (65.7% of the sample) in the sample have failed to gain a mark over 2. Also a considerable number of the students (N=14) scored 0 because of serious misconceptions about Haemophilia. As mentioned in the marking scheme for grids on Haemophilia at the beginning of the section, students who thought statement 10 "Red cells sickle" or statement 12 "Haemoglobin S" were related with Haemophilia were clearly confused between Haemophilia and Sickle Cell Anemia. Brief information is given in Appendix 18 about Haemophilia and Sickle Cell Anemia to understand the misconceptions which students had in their long term memory.

As mentioned in section 5.3.1 (in Chapter 5) there were 10 key words in the word association test and these key words were Mutation, Gene, Pedigree, Gamete, Chromosome, Phenotype, Cell Division, Genetic Engineering, Haemophilia and

Backcross. The first year biology students (in 1997-98 session) who were given the word association tests also were given the grid question about Haemophilia. Therefore, there was an opportunity to look for any common pattern (overlap) between these two techniques and to compare the performance of students who were particularly weak in both tests. In the word association tests, there were several different responses to the key word "Haemophilia", however, as stated before, the total number of responses and total number of different responses were low for this key word if it is compared with others in the WAT. The students' responses to the key word "Haemophilia' showed a number of serious misconceptions and most of them related with "Sickle Cell Anemia" rather than with Haemophilia. As noted before, 14 students had a score of 0 in the grid exam and 7 of them were also given the WAT. In the word association tests all 7 students gave misconceptions of some kind (e.g., Sickle Cell, Malaria, Anemia) to the key word "Haemophilia."

As can be seen from Table 7.20, almost all unrelated (or even misconceptions) response words to the key word "Haemophilia" in the word association tests were given by the students who scored either 0 or 1 in grid exam on Haemophilia.

Response words in the WAT	Frequency of these R.words	No of students
Malaria	3	3
Sickle cell	12	10
Haemoglobin	16	13
Red blood cell	15	15
Africa	4	4
Anemia	2	2
Dominant	3	2
Autosome	2	2
Oxygen	7	5
Lymphocytes	2	2
Iron	9	7
White bood cell	2	2

These students scored 0 or 1 in the grid question on Haemophilia

Table 7.20 Frequency of some response words (most of them were misconceptions) to the key word haemophilia in the WAT and the number of students (who scored 0 or 1 in grid question) who gave these responses in the WAT

As an additional interesting point, the word association test responses of the students (who scored 4 or 5 and 0 or 1 in the grid test) to the key word "Haemophilia" were compared. The results revealed that students who scored 0 or 1 in the grid question on "Haemophilia";

(i) gave responses in the word association test to the key word Haemophilia which were mostly not related to Haemophilia or mainly related to Sickle Cell Anemia (i.e. misconceptions like the words "malaria" and "anemia"),

(ii) gave very few responses (in other words their cognitive structure were not rich in terms of concepts which attached to the key word Haemophilia) or,

(iii) they gave most frequent responses, which are not essential to understand the concept, between one and four such as Blood, Red Blood Cells, Disease, Defect, Hospital, Blood Transfusion etc.

All these results indicate that these students did not have deep level understanding of this concept and their cognitive structure was not rich in terms of ideas which attached to the key word "Haemophilia". On the other hand, when the word association test responses of the students (who scored 4 or 5 in the grid exam) to the key word "Haemophilia" it was clearly seen that they gave responses like Mutation, Factor 8, Blood Clotting, X-linked, Male, Royal Family, Infection etc. These are the concepts which students must have in their long term memory in order to understand the concept "Haemophilia". Of course, there were some students who scored low in the grids that gave meaningful and acceptable responses to the key word "Haemophilia" in the WAT, but the number of these students was a minority.

7.3.3 The Effect Of Cognitive Styles On Grid Performance And Testing The Hypothesis

7.3.3.1 Effect Of Field Dependence/Field Independence On The Performance In The Grids (Results Of Secondary Schools) And Testing The Hypothesis

The Hypothesis 5.6 was that *overall performance of the field independent pupils should be better than field dependent pupils, because by definition field independents are better than field dependents in terms of ability to select relevant from irrelevant.* To test this hypothesis the following analyses were made:

(i) In order to look at the effect of the thinking styles on grid performance instead of looking at the pupils' performance on grid questions in Food Digestion and Chemistry of Respiration separately, the pupils' scores in both grid tests were added and the mean scores of the pupils were calculated.

The mean scores of field dependent and field independent pupils in the grids are given in Table 7.21.

Group	C.of Respiration + F.Digestion
	Mean
Field Dependent N=36	45.3
Field Independent N=32	55.2

Table 7.21 The mean scores of F. Dependent and F.Independent pupils in the grid questions

As can be seen from Table 7.21, the mean score of field independent pupils was higher than field dependent pupils in grid questions. But to reveal whether this difference between mean scores of two groups is statistically significant or not, a two sample t-test was used. The results of t-test appeared as statistically significant (at the 1% level). From this result it can be inferred that the mean scores of field dependents and field independent pupils on the grids were significantly different in favour of field independence.

(ii) When the pupils' grid scores and their scores in the FD/FI tests were plotted against each other (Figure 7.13) a statistically significant positive correlation emerged as the Pearson P. M. Correlation Coefficient was **0.28** (degrees of freedom = 92/two tailed tests).

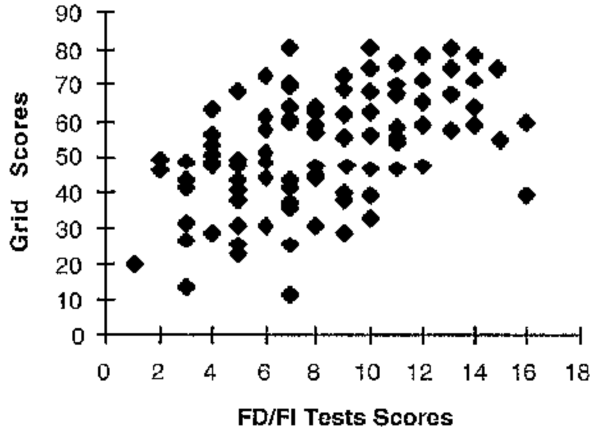


Figure 7.13 A scatter plot between pupils' grid scores and their FD/FI tests scores (N=94)

The null hypothesis, that there is no relationship between students' degree of field dependency and their performance on grid questions, could be rejected at the 1% level. According to this significant correlation it can be concluded that field independent pupils had higher scores than field dependent pupils on grid questions. This may be explained by their better ability to select relevant from irrelevant.

In the light of the t-test statistic and statistically significant correlation, the hypothesis 5.6 *"Overall performance of the field independent pupils should be better than field dependent pupils, because by definition field independents are better than field dependents in terms of their ability to select relevant from irrelevant"* is accepted.

7.3.3.2 Effect Of Convergence/Divergence Over Performance In The Grids And Testing The Hypothesis

The results above showed that field dependence/field independence dimension of cognitive styles had an effect on the pupils' performance of the grid questions. As mentioned in section 4.2 (Chapter 4), in addition to FD/FI tests, pupils also were given Convergent/Divergent (CON/DIV) Tests. The researcher also wanted to look at the effect of this thinking style and the following hypothesis 5.7, as stated in section 5.5.3 (Chapter 5), was proposed: *Overall performance of the convergent pupils is expected to be better than divergent pupils, because convergent pupils have higher ability in solving problems requiring one acceptable solution clearly obtainable from the information available. They can focus the content of each box and can decide which box or boxes are required to answer the question.* To examine this hypothesis following analyses were made:

<u>Results for Secondary Schools</u>

(i) Firstly, the mean scores of convergent and divergent pupils were compared. As was done for Field dependence/Field independence, the pupils marks in both grid questions (i.e. Food Digestion and Chemistry of Respiration) were averaged for each pupil. Table 7.22 shows the mean scores of Convergers and Divergers in grid questions.

Group	C.of Respiration + F.Digestion **Mean**
Convergers N=28	42.4
Divergers N=24	54.8

Table 7.22 The mean scores of convergent and divergent pupils in the grid questions

As is shown in Table 7.22 that mean score of divergent pupils was higher than convergent pupils in grid questions. In order to find out whether this difference between mean scores of two groups is statistically significant or not two sample t-test were used and t-test result appeared as statistically significant (at the 1% level). From this result it can be inferred that the mean scores of divergent and convergent pupils on the grids are significantly different in favour of divergency.

(ii) When Convergent/Divergent tests scores and pupils' grid scores were plotted against each other (Figure 7.14) statistically significant positive correlation emerged between as the Pearson P. M. Correlation Coefficient was **0.25** (degrees of freedom = 79/two tailed tests).

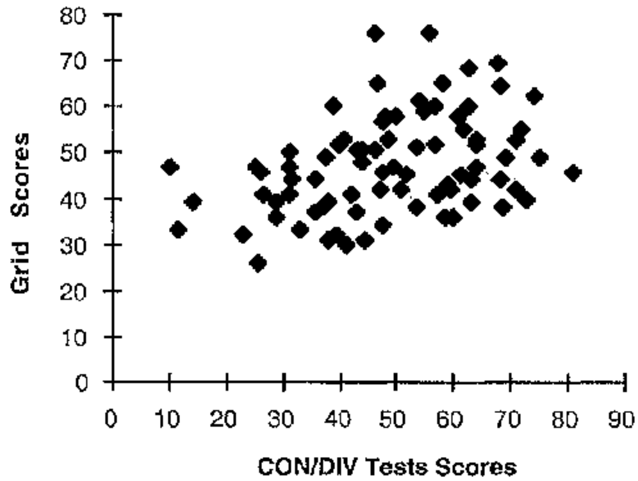


Figure 7.14 A scatter plot between pupils' grid Scores and their CON/DIV tests scores (N=81)

The null hypothesis, that there is no relationship between students' degree of divergency and their performance on grid questions, could be rejected at the 5% level. According to this significant correlation it can be said that pupils who had divergent thinking style had higher scores than the pupils who had convergent thinking style on grid questions.

Results of University students.

As mentioned in section 5.2 (Chapter 5) students in the university were given both grid tests and CON/DIV tests. But because of some difficulties (e.g., time) FD/FI tests could not be given.

Like in the secondary school sample, a statistically significant positive correlation emerged between students' CON/DIV tests scores and their grid scores in Haemophilia. Pearson P.M. Correlation Coefficient was **0.14** (degrees of freedom = 296/two tailed tests). *The null hypothesis*, that there is no relationship between student's thinking style and his performance on the grid questions, could be rejected at the 2% level. From this correlation it can be said that the students who had divergent thinking style were better in grid questions and consequently gained higher marks than the students who had convergent thinking style.

An additional interesting observation was, as stated before that 14 students had a mark of 0 on the grid question "Haemophilia". 10 of these students were also given Convergent/Divergent tests and 7 of these students appeared as strong convergers, 2 of these 10 students were All Rounders and only one student out of these 10 students who had mark 0 was divergent. This result also indicates the superiority of the divergers over convergers in the performance on the grids.

On the basis of all these analyses the hypothesis 5.7, *Overall performance of the convergent pupils is expected to better than divergent pupils, because convergent pupils have higher ability in solving problems requiring one acceptable solution clearly obtainable from the information available. They can focus the content of each box and can decide which box or boxes are required to answer the question* , is rejected. All results clearly indicate that overall performance of the students/pupils who had divergent thinking style was better than the students/pupils who had convergent thinking style.

Both psychological factors (i.e. field dependence/field independence and convergence/divergence) showed an effect on the performance of the grids. As mentioned before the correlation coefficient value between students' scores in FD/FI tests and grid scores was significant at the 1% level. The correlation coefficient value between grid scores and CON/DIV tests scores were significant at the 2% and 5% level. On the basis of these correlations, it may be said that field dependence/field independence had slightly more affect on the performance of the grids than the convergence/divergence factor. The better performance of the field independents over field dependents was expected and, as stated before, this may be explained by their better ability to select relevant from irrelevant. On the other hand, the superiority of the divergers over convergers in the grid questions was not expected. Since convergers can focus on the content of each box and can decide which box or boxes are required to answer the question, they were expected to show a better performance than divergers. But why did divergent students/pupils have higher marks than convergent students/pupils on the grids? This may be explained as follows: the results (in section 6.1.1, in Chapter 6) revealed that there is a relationship between convergence/divergence and field dependence/field independence cognitive styles. Divergent students tend to be field independent and field dependent students tend to be convergers. This might be the reason behind the better performance of the divergers over convergers in the grid questions. Divergers might have used their more field independent characteristics in the selection process of the right boxes in the grids.

7.4 Misconceptions Revealed By The Techniques

All these three techniques revealed that students/pupils had scientifically wrong ideas or misconceptions in their long term memory about the topics which were investigated. As is known from educational psychology, new knowledge is not attached to existing knowledge in the long term memory without changes taking place. In other words, knowledge has to be reconstructed as it passes from the teacher to students/pupils. However, after the topics are taught, students may think that they understand whatever they have been given. It is true that the new knowledge can be attached to existing knowledge and stored however, this may, in fact, be a misattachment or the new knowledge can be attached into an existing situation that already had some misconceptions or alternative frameworks in it. In the light of the Information Processing Model, the misfit of new knowledge into the existing knowledge or the misconceptions which have already been there can disturb the selection process in later perception, because the perception filter uses what is available in long term memory to select what is thought to be important information and also may provide wrong ideas for working memory which may interrupt the working function. So the difficulties of the concept areas which were investigated in this study might arise due to the misfitting of new knowledge to the existing corpus or misconceptions (e.g. about haemophilia, phytochrome (light requirement), the function of hormones in seed germination etc.) that already exist in the network of ideas in the long term memory. The effect of the misconception in the complex, connected network may be far more detrimental than expected.

In addition to the misconceptions, the results of the three techniques also showed that some students were not able to give any account about some topic although they had been taught about it. This knowledge which could not be recalled from long term memory may be stored as discrete, unconnected bits and may not be attached to the main network. This type of learning can be regarded as rote learning in which no interaction takes place between new knowledge and existing knowledge. Therefore it can be easily lost or hard to recall. Any idea which is part of the branched, well integrated and connected network is easier to recall than the idea which stored as a separate island somewhere in the long term memory. An idea can be triggered easily if it has more retrieval paths (connections).

7.5 General Discussions

As stated in section 1.4.1 (in Chapter 1) knowledge can be represented by a web or a network in the network models of memory. In this network there is a hierarchy and links between the concepts. The students' knowledge about biology can be thought of as a network of ideas in which main ideas like botany, zoology, molecular biology are attached to the key concept "biology" and each main idea radiating from the key concept has many branches and interconnections. In this study, some particular nodes in these complex, interconnected networks in the long term memory were visited and the relationship between the ideas was investigated through the techniques namely, word association tests, mind maps and structural communication grids and all these three techniques were used primarily for diagnostic purposes.

Like any other techniques which are used in the field of science education, they have advantages and disadvantages, similarities and differences.

In this study, the word association test was applied after the teaching session of genetics. As in other research studies (e.g., Shavelson, 1973, 1974; Geeslin and Shavelson, 1975; Preece, 1976, 1978; Kempa and Nicholls, 1983; Carrie, 1984; Johnstone and Moynihan, 1985; Cachapuz and Maskill, 1987; Gussarsky and Gorodetsky, 1988) the results of this study showed that it is a powerful technique for revealing the type and number of concepts in students' minds as well as the links between them. The test is easy to write and simple to administer and can be applied to a large number of students in a period of only five minutes. However, calculating relatedness coefficients to look at the overlap between the response words to stimulus words is difficult and can be time consuming for a large number of students. But teachers are still able to look at the type and number of responses and, by inspection, to form a composite judgement about the quality of understanding that each set of responses to stimulus words shows. It is also possible to draw a map using response frequencies (which was done first time in this study) instead of relatedness coefficient values. This is much easier and less tedious to do.

Mind mapping is also a powerful method for revealing the ideas which students have in mind. However, like the word association test and the structural communication grid question, the mind maps cannot be thought of as a mirror which shows all the ideas and linkages about a particular topic in the long term memory, but they can be thought of as the best approximation to the cognitive structure. It may be said that, mind mapping might be more powerful and effective than the word association test because (i) in the mind map, students construct the relationship between the ideas step by step, and (ii) like any other visual aid, a mind map offers the advantage of using visual memory. As the results showed, mind mapping helped students to organise their ideas and aided in planning their essay (on Seed Germination) as an alternative to a linear way of planning. On the other hand, one disadvantage of the mind maps is that they require more time than the word association test and structural communication grids, because a practice session is necessary to teach students how to draw the mind maps and at least 10 minutes are required to draw the mind maps themselves. However, once the students have learned the mind mapping technique, they can use it for lifetime.

Although there was no opportunity to apply the test to measure the size of the working memory capacity, one of the advantages of mind mapping might also be related to this psychological factor. As stated in section 1.2.2.2, because of its limited capacity, working memory can be easily overloaded and this can be an obstacle to acquiring the information. During mind mapping (or during essay writing when students follow their mind maps in order to write their essay), concentrating on each main idea one at a time and extending each main idea step by step may prevent the confusion and might lessen the overload of the information which has to be handled in the working space. It can even be more useful if a student learns to see ideas branching from the main concept as a smaller unit, these ideas plus main concept may form a *chunk*. And from this, even the students who have low working memory capacity might benefit. Furthermore, because the more salient a stimulus, the less working memory is needed to the task of extracting it (Case, 1974) a mind map, as a visual aid, makes the ideas more obvious and this may lessen the burden on the working space.

Criticism about the techniques as assessment or evaluation tools

(i) Structural communication grids

As the information is given to a whole class, there will be similarities in the structure of the knowledge in the students' minds. But because each of those minds has a different perceptive filter (the prior knowledge in their long term memory, their beliefs and cultures and consequently their perceptions are different) what the students make of the instruction will differ and consequently their understanding will be not the same. However, if each student's understanding and construction the knowledge differs, why we are assessing their understanding by using only one kind of testing device? As mentioned in section 6.2 (in Chapter 6), 70% of the exam marks of all main courses at the first year university level consisted of multiple choice questions. In multiple choice testing, like in many types of fixed response questions, there is only one "correct" answer. If a student selects this one, the teacher is not able to decide if the selection was by guessing, by intelligent reasoning, or by false reasoning. Also if a student makes a "wrong" selection, it is impossible to tell if this choice was through ignorance or for a good logical reason that the teacher had not anticipated. Structural communication grids, which were used in this study avoid these pitfalls to a large extent. Guessing is almost eliminated, that the number of boxes is large, the student has to decide how many boxes to choose and the sequencing of the response indicates the reasoning. Any guessing can be caught by analysing the responses to the other questions as was done in the grid on food digestion in this study.

No testing method can be totally objective. The aims of the course are chosen subjectively and the content chosen to meet them the subject of value judgement. The test items themselves are subjectively constructed in their content, language, level of complexity and format. The only genuinely objective part of the exercise can be the scoring, if it is done using fixed response items. This is the main reason behind the popularity of multiple choice questions although they have serious weaknesses (like guessing factor). However, structural communication grids can also be scored objectively and manipulated by the computer.

Another advantages of the grid questions is that the content of the boxes can be words, phrases, pictures, equations, definitions, numbers, formulas and so on. Because the content of the boxes can be varied they can be made suitable for visual thinkers as well as verbal thinkers.

As a result, as indicated in several research studies (e.g., Johnstone, 1981; Johnstone et al., 1981, 1983; MacGuire and Johnstone, 1987) the flexibility of the structural communication grids as an assessment tool is enormous and would lend itself to the production of much shorter and less wordy exams while at the same time testing many objectives at several levels of complexity. Like the word association test, students were able to handle structural communication grids competently and quickly (about 5 minutes per grid test in this study) after a little practice. It is important to mention that the structural communication grids, as an assessment tool, are clearly superior to mind maps and to word association tests. This technique gives an insight into subconcepts and linkages between the ideas as well as showing an overall picture of the network of ideas. Accordingly, they can assess a deep level of understanding.

It is necessary to note that the grid question on "Haemophilia", as stated before in section 5.5.1.2 (in Chapter 5), was neither prepared nor administered by the researcher but by a co-operative lecturer and, as indicated in the previous paragraph, did not reflect all the aims regarding the use of structural communication grids. Because, even though 12 boxes (which include statements) were given, only one question was asked (rather than several questions) and students were required to select 8 appropriate boxes to the question and exclude 4 inappropriate boxes. However, the four inappropriate boxes were given as the last four (9, 10, 11, 12) rather than being scattered randomly and this could cause confusion among students.

(ii) <u>Word Association Tests</u>

As mentioned before, the word association test is very powerful as a diagnostic tool for revealing the relationship between concepts in the cognitive structure. Although the students' responses in the WAT were scored (only to look at the relationship between their performance in the WAT and in their exams), in fact, the word association test was not used as an assessment tool in this research study. However, as an assessment tool, the word association test cannot be as powerful as structural communication grids or mind maps. This might be explained by the fact that:

i) it very clearly favours divergent thinkers and,

ii) inferences about understanding which are made from the response lists in the word association test may be more subjective than the other techniques.

However, the word association test may still be used as an assessment tool because the number of responses that a word receives is an important and direct indication of the student's understanding of it (because meaning can be defined as being proportional to the number of links the person can make to the word (White and Gunstone, 1992). If two concepts are close in semantic memory (distance), the more related they are, and the mental search process which retrieves information about the concepts is faster (i.e. semantic relatedness or semantic distance effect) (Rips et al., 1973; Ashcraft, 1978; Kounios and Holcomb, 1992).

As an interesting additional point, as was seen from the results in section 7.1.2 (in Chapter 7), statistically very significant positive correlations (at the 0.1% level) appeared between students' performance in the word association tests and their scores in the exams of almost any courses at the first year university biology. These results may suggest that this strength of the word association tests might be used to predict the performance of the students in exams. It might also be possible to identify the students who have very bad performance in the WAT and help them before the exam. Because it was clearly seen in the former research studies that, where students did not relate a particular key word to other key words in the word association tests, they tended not able to do the achievement test items requiring this conceptual relation (Cachapuz and Maskill, 1987). Also where existing concepts are firmly linked in the cognitive structure, facility values for questions testing these concepts are high (Johnstone and Moynihan, 1985).

(iii) Mind Maps

As stated in section 5.4.3.2 (in Chapter 5) for the first time in this study, a scoring key which is based on Ausubel's theory of learning was developed and the students' mind maps were marked. Mind maps have not been used before as an assessment tool, but the results in this study such as;

i) Good mind mappers had better essay scores than poor mind mappers,

ii) There was a statistically very significant correlation (at the 0.1% level) between mind map scores and essay scores,

iii) The same major ideas were missing in the mind maps and in the essays, and

iv) Some similar misconceptions were present in the mind maps as well as in the essays

might suggest that mind maps can be thought as a short version of an essay and may be used as an assessment tool.

On the other hand, mind maps, as an assessment tool, cannot be as powerful as structural communication grids. The reasons might be attributable to the facts that:

i) Although the number of the students was very small, there were some students who had bad mind maps, but high essay scores and,

ii) In spite of the fact that mind maps show the overall picture of ideas and connections between them, they may not give detail of the information in which some scientifically wrong ideas and deep level of understanding lie.

The overlap between the three techniques

It is important to mention that there was no opportunity to investigate the same concept areas by the three techniques, therefore different concept areas were investigated by each of three techniques. The topics;

i) "Food Digestion and Chemistry of Respiration" at the secondary school level, "Haemophilia" at the university level were investigated by structural communication grids,

ii) Seed germination at the university level was investigated by mind maps and,

iii) Genetics at the university level was investigated by the word association tests.

There was only one concept area (i.e. Haemophilia) which was investigated by the structural communication grids and partially by the word association tests. As was seen in the results, students who had very low marks in the grids on "Haemophilia" also had misconceptions as well as a low number of responses to the key word "Haemophilia" in their word association tests. This shows an overlap between these two techniques. But because of investigating different topics by the techniques no further overlap was able to be seen.

The important characteristics of the three techniques which were used in this research study are given briefly in Table 7.23.

Techniques	*Ease of Construction by Teacher*	*Ease of Application to the Student*	*Ease of Processing*	*Type of Information Obtained*
WAT	very easy	very easy	difficult	-revealing the type and number of concepts as well as the links between them (i.e. a diagnostic tool) -possible to draw a map from relatedness coefficients as well as from response frequencies
Mind Map	easy	moderate	moderate	-revealing the ideas and linkages between them (i.e. a good diagnostic tool) -offers advantage of using visual memory -a effective alternative method to a linear way of planning for essay
SCG	moderate	very easy	moderate	-giving an insight into ideas and linkages between them (i.e. a good diagnostic tool) -assesses deep level of understanding (i.e. a good assessment tool) -suitable for verbal as well as visual thinkers (because content of the boxes can be varied)

Table 7.23 The important characteristics of three techniques

CHAPTER 8

Conclusions, Recommendations and Teaching Implications

8.1 Conclusions

The primary purpose of this research study was to investigate biology students' cognitive structure. In order to do that three techniques have been prepared and used. The results have been reported and their advantages and disadvantages as diagnostic tools or assessment tools have been discussed. In addition to that, the relationship between some psychological factors and their effect of these psychological factors on the information which is laid down in the long term memory were sought.

The aspects which have emerged in this research study could be summarised in the following conclusions.

8.1.1 Relationship Between Psychological Factors and Between Psychological Factors and Exam Performance

8.1.1.1 Findings In Terms Of The Relationship Between Psychological Factors

* Correlation between FD/FI tests scores and CON/DIV tests scores yielded low values (0.20 and 0.19) in a university (Volunteer sample) - and a secondary school sample, indicating that these two factors are fairly independent but, divergent subjects if anything, tended to be field independent and convergent subjects tended to be field dependent.

* A statistically significant positive correlation (at the 0.1% level) emerged between students' FD/FI tests scores and their Working Memory Capacity test scores, showing that field dependent students generally have low working memory capacity and field independent students have high working memory capacity.

* Two hypotheses were proposed in terms of the relationship between Convergent/Divergent thinking styles and the Working Memory Capacity. The results

showed (i) a statistically significant correlation (at the 2% level) between CON/DIV tests scores and the scores of the test to measure WMC and, (ii) a higher occurrence of convergers at the low working memory capacity end, and a higher occurrence of divergers at the high working memory capacity end. In the light of these findings it can be said that, divergent thinkers tend to have high working memory capacity which may be an advantage in generating ideas and seeing things from different perspectives. Most of the convergent thinkers tend to have low working memory capacity which would tend to make them converge rather than juggle with many ideas.

* The overlaps between all three psychological factors involved in this research study emerged in the following ways; (i) There is likely to be an overlap between the field independent, high working memory capacity and divergent thinking style and, (ii) between field dependent, low working memory capacity and convergent thinking style (Table 8.1)

	Tendency	
Dimensions	Grouping 1	Grouping 2
Working Memory Capacity	LWM	HWM
Convergence/Divergence	CON	DIV
F. Dependence/F. Independence	FD	FI

Table 8.1 Summary of two tendencies for linkage between the dimensions measured in the three psychological tests

8.1.1.2 Findings About The Relationship Between Psychological Factors And Exam Performance

* In the first year of the study (for the Volunteer sample), correlation between psychological factors (i.e. FD/FI, CON/DIV and WMC) and students total exam scores in four different modules (i.e. Plant and Microbes, Molecules-Cells and Genes, How Animals Function, Ecology and Evolution) were very low and the results revealed no significant correlation, suggesting there is no relationship between students' overall exam

scores (including Continuous Assessment, MCQ, Short Notes etc.) and psychological factors.

* One hypothesis has been tested in terms of the effect of the convergent and divergent thinking styles on the performance in the MCQ tests in the first year of the study (for the University Volunteer sample). No significant correlation appeared between the MCQ scores and CON/DIV tests scores suggesting that convergent students are not superior to divergent students, although convergent students might see information leading to a restricted answer or solution, they may converge their mind to find the one correct choice in the multiple choice and therefore they can be more successful than divergent students in the MCQ.

* These insignificant correlations (for the volunteer sample) between students overall exam scores (as well as their MCQ tests scores) may be explained in following ways (in the light of the findings of Johnstone and El-Banna (1986) and Johnstone and Al-Naeme (1991) which were mentioned in sections 1.2.2.2 and 2.2.1.1): because the demand of the questions in the exams were well within the capacity of the working space, and so FD/FI did not come into play, nor did CON/DIV. In other words, as long as the demand of the test questions do not exceed the capacity of anyone, then no discrimination can be expected. It is only beyond a certain point that the effect of these psychological factors will show and will correlate with exam scores.

* In the second year of the study (for the university sample), statistically significant correlation (at the 5% and 0.5% level) appeared between students' total exam scores in four different modules and CON/DIV tests scores, indicating students who were divergent had higher scores in the exams. But no significant correlation appeared between CON/DIV thinking style and Study project. Also low correlation values between CON/DIV tests scores and MCQ scores indicate that divergent students might not have a superiority over convergent students in the MCQ.

* In the second year of the study (for the secondary school sample), a significant correlation (at the 1% level) emerged between pupils' FD/FI test scores and their Higher Grade Biology exam scores. As was expected in this study, this indicates that field independent pupils showed a better performance and consequently had higher marks in Higher Grade Biology exam than field dependent pupils. However, no significant correlation appeared between CON/DIV test scores and Higher Grade Biology exam scores of the pupils.

8.1.2 Findings About The Techniques Which Were Used In This Research Study

8.1.2.1 Word Association Tests

* The results of the word association tests in both 1997 and 1998, clearly revealed that the ideas about genetics clustered as only a few isolated islands in students' cognitive structure and they did not appear to see the overall picture as a network of related ideas. This was seen from the frequency maps as well as from the relatedness coefficient maps.

* Some key words, for instance "Mutation, Genetic Engineering, Chromosome and Gene" received more varied responses than others. The higher number of different responses to the stimulus words "Mutation" and "Genetic Engineering" may be the result of recent problems about a nuclear station or political and ethical debates about cloning (especially of the human embryo and of the sheep), particularly as presented in television and current science fiction films. This was supported by students' responses using words like Alien, Chernobyl, HIV (for Mutation) Dr Moreau Island, Government, Controversy, Super race, Creation, Dolly the Sheep (for Genetic Engineering). The responses to the stimulus words "Chromosome" and "Gene" are also diverse. Chromosome and Gene are seen in almost any topic in biology, therefore students may be more familiar with the words associated with these two stimulus words than to the others.

* Statistically very significant positive correlations (at the 0.1% - 0.2% level) emerged between students' word association test scores and their scores in exams, indicating that students who produced a high number of responses to the key words in the WAT showed better performance in the exam than the students who offered a low number of responses to the key words in the WAT. In spite of the fact that most of the students see the key words in small clusters as isolated islands and do not appear to be as good at seeing the links between all the key words, it is possible that the questions in the exam required answers to specific questions about isolated islands in the frequency map, and did not emphasise the links between the topics being assessed. Consequently, students still can get good scores although they cannot see all the information as the complete network which the teacher may have had in mind.

* All results revealed that **only** convergence and divergence dimension of cognitive styles showed a significant relationship with the word association tests. As stated in the hypothesis, the cognitive structures of the divergent students were rich in terms of total

number words and total number of different words about genetics. It might be that this reflects a more complex and branched network structure of genetics concepts in mind than convergent students have.

8.1.2.2 Mind Maps

* T-test result (significant at the 2% level) and a box plot comparison revealed that, students who drew a mind map used the advantages of mind maps, over a linear way of writing, for better planning and for better essay writing (on Seed Germination) and as a result they gained higher marks than the students who did not use mind maps for their essay writing.

* A statistically significant positive correlation (at the 0.1% level) emerged between students' mind map scores and their essay scores, suggesting that students who drew better mind maps, had higher scores in essays.

* By examining students' mind maps as well as their essay, it was found that most of the students missed the same ideas in the mind maps as in the essays. If they did not mention an idea in the mind maps, they did not give it in their essays. The missing topics in the mind maps (and in the essays) were mostly about dormancy mechanisms, seed structure and mobilisation of food reserves.

* Like the missing topics in the mind maps (and in the essays) some misconceptions appeared in the students' mind maps as well as in their essays. But it is necessary to mention that not all the misconceptions which appeared in the essays were detectable in the mind maps. The most common mistakes which appeared in the mind maps as well as in essays were about mobilisation of food stores during germination and the light requirement.

* Some contradictions between markers' notes during essay marking inferred that not only the students, but also some lecturers may have misconceptions. The markers were not necessarily specialist in the topic of the essay.

* In terms of the effect of cognitive style (i.e. Convergence/Divergence) in Mind Mapping one hypothesis was proposed. All results clearly indicated that, as predicted in the hypothesis, the mind maps of divergent students were more complex and branched than those of convergent students. Consequently, divergent students benefited more from

the use of mind maps than convergent students in terms of getting higher scores in their essays.

8.1.2.3 Structural Communication Grids

* For the secondary school sample, it was found that pupils had scientifically wrong ideas regarding the topic Food Digestion (e.g., about the classification of enzymes and the function of enzymes, digestion fluids like the function of "bile") and the topic Chemistry of Respiration (e.g., the particular reactions which are characteristic for a plant cell like the production of ethanol and carbon dioxide in the absence of oxygen or for animals like the production of lactic acid).

* The effect of some psychological factors namely, Field dependence/Field independence and Convergence/Divergence on the performance of the grids were also sought and two hypotheses were tested. All results (i.e. statistically significant positive correlation and t-test results (both significant at the 1% level between FD/FI tests scores and grid scores) indicated that, as predicted in the hypothesis, overall performance of the field independent pupils in the grids was better than field dependent pupils. Also the results of significant positive correlation (at the 2% level), and t-test (at the 1% level) secondary school - as well as university sample, between CON/DIV tests scores and grid scores suggested that pupils/students who had a divergent thinking style had higher scores than the pupils/students who had a convergent thinking style, on grid questions. The better performance of the convergers was predicted in the hypothesis but results showed the opposite. This may be explained as follows: divergent students tend to be field independent and convergent students tend to be field dependent. Divergers might have used their more field independent characteristics in the selection process of the right boxes in the grids.

* An overlap between the word association test and structural communication grids (not for all techniques because the topics were different) was found. That is, students who had very low scores on the grid question on "Haemophilia" had given wrong responses or a very low number of responses to the key word "Haemophilia" in their WAT. The misconceptions were mostly related to the concept the Sickle Cell Anemia.

As can be seen from above paragraphs, there are several conclusions of this research study. However, as an overall conclusion it can be said that, the results of this research study clearly showed that the word association tests, mind maps and structural communication grids are very effective as diagnostic tools to illuminate the relationship between ideas in the long term memory of the students/pupils. Structural communication grids are also an effective assessment tool.

8.2 Recommendations and Teaching Implications

Let us imagine three hypothetical situations of a teacher:

(1) A teacher wants to check what is available (i.e. prior knowledge) in pupils/students long term memory before starting to teach a new topic because he takes into consideration the fact that "what we already know and understand controls how we interpret, process and even store the new information" (Johnstone, 1988).

(2) A teacher, who is sure that pupils/students have some misconceptions about particular topics, wants to identify and replace these misconceptions with scientifically right ideas.

(3) A teacher wants to stimulate his pupils/students to realise for themselves how their ideas and interconnections between them are growing and changing (i.e. being aware of their own cognitive growth).

For the first purpose, the word association test can be a suitable method for revealing the prior ideas in students' minds and the teacher can take a "snap-shot" of the students before beginning his teaching. However, as can be seen in Table 7.23 (in section 7.5, in Chapter 7), because the processing of responses (i.e. calculating the relatedness coefficients) is difficult, the teacher can ignore this process and focus on the type and the number of total responses which still give an overall picture of prior ideas in students' minds. In addition, as stated before, he can draw a map from the frequencies of the responses so that prior concepts in students' minds can be shown visually. This is much easier and quicker to do.

For the second purpose, all three techniques can be used but, particularly structural communication grids and mind maps can be used in combination. Firstly, the teacher can give some examples of mind maps and then he can ask his students to draw a mind map step by step by using the rules applied in this study, based on the topics in which he thinks that students have some misconceptions. After a quick look at the students' mind maps, he can draw his mind map in the blackboard with active involvement of the students and he can ask his students why they connect particular ideas with each other and this may lead a discussion especially on the ideas with which students have problems. And then students can compare their mind maps with the teacher's mind map. To investigate whether the mind maps have made the students aware of their misconceptions and they have been replaced with the right ideas, he can prepare structural communication grids by using the model mind map which he drew in the classroom. It is necessary to mention that because the purpose of the teacher is to investigate the misconceptions in the students' long term memory he can use both techniques for diagnostic purposes and, to save time, may ignore the scoring of the mind maps and structural communication grids.

For the third situation, mind maps and grid questions can be used, however, the mind map might be the most appropriate technique for this purpose. Perhaps one of the most important factors in learning is to be aware of one's own cognitive growth (Metacognition). By encouraging students to draw a mind map at the beginning and at the end of a course gives them something tangible for comparison. By doing this, a student can follow visually the changes which have occurred in his mind. This might lead to the discovery of new links "Ahha!!!! there is a connection between this and this or this is happening because of this and so on." It is also important for a student to consider how he got from his original to his final map.

In addition to using the mind map as a self-instructional device, the teacher can also use the mind maps and word association tests before and after the teaching session and the two results can be compared to see the changes in students' learning. The teacher can also encourage students to compare their own responses and maps with those of other students in order to show them that there is more than one way to see things and they can recognise that learning is individual and involves individual construction of meaning. This comparison of the responses and maps may lead to a discussion which can broaden their understanding. It is not unreasonable to think that changes in the mind maps are associated with similar changes in the conceptual structure of the students and the differences between two successive maps occur because of the learning. Therefore mind maps can enable the teacher to monitor the effect of teaching on the conceptual structure of the students and have the opportunity to check how the students reorganise their cognitive structure after a teaching activity.

A mixture of assessment methods can be used to give equal opportunity to the different types of thinkers, because a particular assessment type may favour a particular thinking style. It is also important to mention that, although the exam marks were high, the results of a particular kind of testing device may not be a reliable indicator of the related, interconnected network of ideas. The exam questions (e.g. multiple choice questions) mainly concentrate on the islands of the network rather than interconnections between the ideas. So, as the results of the word association test showed in section 7.1.2, in Chapter 7, students may get a high score despite the fact that they fail to see the ideas as a related, interconnected network. Furthermore, the results of the particular type of the exam can fail to show the difficulty or ease of the courses. This was seen in Module A (Plants and Microbes) which appeared as the easiest course in terms of the exam marks (in which three-option multiple choice questions were used), but was reported by students as the most difficult during the year. This may underline the importance of using a variety of testing devices so that the results of the exam feed back reliably to the teacher and changes can be made to courses in the light of the results.

As was done in this study for the topic of genetics, teachers can construct a model map from the students' responses to the word association test in any topic and can let students see this map as a permanent reminder to them of the links they saw. This may encourage students to look for new links in new topics. By doing this, divergent thinking can be encouraged. It may also help teachers to modify their teaching to foster the growth of linked knowledge.

In brief, the fundamental message of this research study's results to the teachers is that when you present any information to the classroom, every student of yours takes something out of it but each of them may differ in this process because each one of them differs in terms of prior knowledge, learning styles etc. As the results show in this study, even though students do not have a complete picture of related concepts of a network in their mind, they still can get good scores in your exam, thanks to the nature of a particular test, for instance multiple choice question. Therefore, most of the time exam results may not really show what comes out of your teaching and your students' learning. However, here are three techniques which give you the actual picture of the connections between ideas in your students' mind. You should not hesitate to use them separately or as a combined method for your own purposes, for better teaching, more effective assessment and diagnosing the misconceptions and for the sake of students, for development of metacognitive skills and meaningful learning rather than unconnected, boxed learning of ideas.

8.3 Suggestions For Further Study

As in any other research study, questions have arisen from this study and each one of them can be a point of departure for further research. Some suggestions are offered below:

(a) It could be very interesting to find out how the type of teaching style affects the ways of storing the knowledge.

(b) A further research study may be relevant on the involvement of another psychological factor such as motivational styles, namely achiever, conscientious, curious and social, on the laying down of interconnected ideas.

(c) Is it possible to apply all these techniques by using a computer? Does the computer have any effect on the responses of the students (if it is compared with paper and pencil tests).

(d) It could be useful to apply the same research in another field, for instance in chemistry or physics.

(e) Can students who have trouble in the biology courses be identified and be helped by using these three techniques?

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