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PROBLEM SOLVING IN BIOLOGY AT UNIVERSITY LEVEL

By

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In memory of my late father

When my father passed away in January 2005, I was torn apart, to say the least.

Now at this time, I figure it is most appropriate to pay tribute to my late father with the fruit of my labour.

My father was a very hard working man, never gave up, and he worked all his life. He built his own way of life to be a unique person and lead his tribe.

My father was an example for me to follow.

He simply taught me to stand up for what I believed in even if it meant standing alone, on my own.

I only wish he was alive to see my beautiful daughters (Deema and Danah). I wish that my daughters would know what a wonderful person he was, the best father in the world.

I wish I can say to him Yes I did it baba, Yes your dream has come true.

I love you baba, you are always in my heart and I am still your favourite girl.

I dedicate this thesis to my late father and to a very patient woman who I proud of, my mum.

Sharifa

Abstract

> *"Your problem may be modest; but if it challenges your curiosity and brings into play your inventive faculties, and if you solve it by your own means, you may experience the tension and enjoy the triumph of discovery. Such experiences at a susceptible age may create a taste for mental work and leave their imprint on mind and character for a lifetime."* (Polya, 1973, p. v)

Every educator is familiar with the term problem solving and most would agree that the ability to solve problems is a worthy goal of education. Problem solving is a process and problems are solved each time a person achieves something without having known beforehand exactly what to do. Problems are encountered every day but problems in school and university education are often different in appearance.

In every problem, there are the data given, the methods to be used and the goal to be reached (Johnstone, 1993). Very often in education, all three are fairly well specified, reducing the problem to be solved to that of an exercise. This study looks at open-ended problems where one or more of these three features is not fully specified. In that sense the problems are much more like the problems of daily life.

Problem solving has received significant attention in science in particular although this has been limited in biology where problem solving has been focussed largely on genetics themes. From previous observations (Yang, 2000), it has been suggested that the presence of *nodes* of knowledge and accessible *links* between the nodes of knowledge, as they exist in long term memory, play a vital role in determining problem-solving success. The purpose of this study was to examine this further, focussing on first year biology students. A total of 524 students were involved in a preliminary study at the University of Glasgow while 1167 students participated in the main experimental work.

The preliminary study sought to identify the main areas of the first year biology curriculum where students tended to encounter difficulties. These areas were seen to encompass potential themes where open-ended problems might be devised: *light and dark reactions in photosynthesis*, *phytochrome and germination*, *cell mediated immunity*, *antibodies*, *the immunological armoury* and *gene function and gene expression in plant growth*. The main experiment had three stages. In each stage, a battery of tests (cognitive and attitudinal) were used and the outcomes related to students' performance on an open-ended problem. Four new open-ended problem-solving units were developed.

The battery of tests in the first stage (with 642 students) were True-False tests, a Word Association Test, a Structural Communication Grid test and assessments of attitudes to learning (using a Perry Position Questionnaire). Several open-ended problems were devised and used but the outcomes from the cognitive tests were related to one individual problem-solving unit on the topic: *Forests that Need Fires*. This stage attempted to gain some kind of insight into the extent to which nodes and links in long term memory contribute to success in problem solving. The results indicated that problem-solving success might be related to *factual knowledge*, *links between nodes of knowledge* and *understanding*. However, *generic ability* in biology might offer an alternative explanation.

To test the latter, stage two involved the same sample of students in a second battery of tests, most of which were on a parallel but unrelated topic: *Evolution*. The outcomes showed that, while some kind of generic biological ability was a factor, this did not seem to explain all the correlations observed in the first stage.

The third stage approached from a fresh perspective. Working with 525 students, this involved the same four problem based units but a new set of tests was applied: tests of Lateral Thinking, a test of Convergency/Divergency, another Ranking test and a Self-Report Questionnaire. The results suggested that the number of accessible nodes and links in long term memory (reflecting '*brain architecture*' and, perhaps, aspects of cognitive styles) do seem to be related to success in a problem-solving task. However, it is recognised that the validity of the test battery is an important issue in drawing such conclusions.

This study raised important questions: is the way of storing the knowledge or the order of storage a factor? Is it something relating to the physical factors such as structure of the brain (*architecture*) in terms of *neurons* and *synapses*, psychological factors such as structure of information in terms of nodes and links or emotional factors such as desire and willingness to store specific ideas other than others (*knowledge filtration*)?

While it is well known that working memory is a key factor in determining problem-solving success (and this was not explored further in this study), the study suggests that the following factors may be important in leading to success with open-ended problems in biology:

- *Factual knowledge held in long term memory;*
- *Understanding of conceptual knowledge;*
- *Generic biological ability (skill);*
- *Number of accessible nodes and links in long term memory;*
- *Effect of 'brain architecture';*
- *Aspects of cognitive styles (divergency, creativity or lateral thinking).*

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Chapter One

Introduction

1.1 The Background

One of the highest goals of science education is to improve pupils' and students' ability to think critically and solve problems effectively. In 1980, the National Science Teachers Association (NSTA) declared that:

> *"... high school laboratory and field activities should emphasise not only the acquisition of knowledge, but also problem solving and decision making."*
> (NSTA, 1980 cited by Blosser, 1988)

Research in educational studies has focused on certain methods of problem solving. In the 1960s, research on problem solving was focused on how people solve puzzles and games. In the early 1970's, science education researchers used tape recorded "think aloud" interviews to gather data (Good and Smith, 1987). Current research on problem solving in science education involves information processing models. These involve two processes: retrieval from memory of the applicable information, and appropriate application of the information to the problem (Yang, 2000). Research studies now being published are conducting their research in all science disciplines such as biology, chemistry, and physics. These studies are frequently comparisons of expert and novice problem solvers. Stewart (1988) discussed different problem types that may contribute differentially to learning outcomes in biology. Stewart's explanation of problem types will be discussed later in chapter 2 (section 2.8). Specifically in the biological field, most of the problem-solving research in high school biology involves genetics (Blosser, 1988).

Each scientific discipline has particular areas which have been seen to cause difficulty for problem solving. For biology, genetics has often been regarded as such an area. One of the aims of this thesis is to test whether this is true for the sample population studied. Previous researchers came up with one common finding: the students had misconceptions in one or more discipline areas in biology and in some basic genetics concepts in particular. These misconceptions acted as an obstacle to their performance in solving problems and understanding the underlying conceptual knowledge (Hurst and Milkent, 1996).

Problem solving is identified as one of the higher thinking skills involved in all science curricula and problem solving is seen as a way to facilitate students' analytical and logical skills (Hurst and Milkent, 1996). These skills include analysing, hypothesising, manipulating variables, designing experiments, predicting, interpreting results. All these are considered to be skills vital for success in science learning.

1.2 Approaches

In science education three principal traditions have influenced research on learning and problem solving. These traditions are distinguished by their concepts of the nature of knowledge, and by their methods. They will only be outlined briefly here, and will be discussed in more detail later in chapter five where their impact on problem solving is considered.

First of all, the Ausubel (1968;1969) tradition has focused on existing knowledge as a factor influencing new learning. Prior knowledge was assessed, typically, by students being asked to solve problems using paper and pencil. It was emphasised that prior knowledge has a major influence on problem solving (Stewart, 1982).

The second is the Piagetian tradition (Stewart, 1982). Piaget's model is based on the idea that the developing child builds cognitive structures. The model asserts that mental 'maps', schemes, or networked concepts for understanding and responding to physical experiences within their environment develop learners thinking (Bahar, 1999). Researchers such as Lawson (1975;1979) argued that:

> *"... the developmental stage of a student can be used to account for his/her success or failure with particular science content."*

In addition, Lawson (1979) argued specifically that, in order to solve genetics problems, a student must be able to "think formally". Formal thinking is logical use of symbols related to abstract concepts.

Finally, there is the cognitive science tradition, a tradition introduced by Newell and Simon (1972) and based on computer modelling in understanding human problem solving. A major approach for investigating problem solving comes from information processing psychology.

This tradition aims to:

> *"Produce knowledge about how individuals think, the mechanisms of their problem solving, the causes of errors, differences between skilled and less skilled performance, and a teaching perspective, the hope of improving instruction."* (Heyworth, 1999)

These goals have been used to obtain models of human problem solving in scientific domains. Based on this approach, Newell and Simon (1972) addressed their studies by categorising problem types and analysing the strategies that students use during solving any type of problems. They tried to bridge the gap between the *conceptual knowledge* (knowing what) and *procedural knowledge* (knowing how).

A few years later, Greeno (1978) argued that all problem solving is based upon two types of knowledge: knowledge of problem solving strategies, and conceptual knowledge. Knowledge of actions in a particular area may be more useful than the acquisition of general strategies. This was called the procedural knowledge that governs what was called the 'problem space' constructed by the problem solver.

Looking at the development of these ideas over time it becomes clear that problem solving involves the person constructing and developing ideas which are used in an attempt to resolve the problem. This view became known as constructivism and its main ideas are outlined in the following section.

1.3 Constructivism

Constructivism had its roots in the work of Ausubel and Piaget (Hurst and Milkent, 1996) and concerns the integration of internal knowledge. The development and integration of structures is a process by which the learner constructs a cognitive network linking declarative and procedural knowledge.

> *"The general tenet of social constructivism is that knowledge is constructed by people through social interaction and collaboration with others - generated, established, and maintained - by a community of knowledgeable peers."* (Cheung and Hew, 2004)

Social constructivism is only part of the constructivist idea. However, it illustrates the general way constructivism has developed. The key tenet is that knowledge is not transferred directly from one person to another. The learner constructs his or her own understanding from the information transmitted in social interactions. The use of argument and discussion may be effective in facilitating such a process (Cheung and Hew, 2004). This model has obvious implications in problem solving. Hurst and Milkent (1996) claimed that there are several models from the fields of developmental psychology and cognitive science which perceive learning as the "serial development and integration of internal knowledge structures". This is a process by which the learner actively constructs a cognitive network in long term memory linking declarative and procedural knowledge. The idea of the network between ideas and skills will be explored in this study.

The constructivist views of learning contended that "knowledge grows in such ways that learners organise and manage experiences so that their actions maximise desirable results and minimise undesirable ones" (Watts and Jofili, 1998). As a model of learning, constructivism claims that learning is founded upon our experiences. We construct our own understanding of the world we live in, and generate our own rules which can then be used to make sense of further experiences. In brief, constructivism is the idea that we construct our own world rather than passively observing an outside reality, and that understanding depends on both the construction and the observation. The significance of experience in learning will also be discussed later as an important element in successful problem solving in biology.

In the field of biology, Hurst and Milkent (1996) looked at the kind of new skills needed by both students and teachers in order to develop an approach to the processing of biological information which would lead to deep understanding and successful problem solving. Active engagement with the problem was seen as an important process. Within a constructivist instructional method, non-routine problems (e.g. writing an assignment) were used to provide motivation for this active engagement. Hurst and Milkent (1996) supported the constructivist viewpoint. In their investigation, they sought to confirm that a predictive success was enhanced by activities that correlate with cognitive behaviours.

Overall, constructivism has had a considerable impact on learning and teaching developments. It emphasises the importance of making connections between facts and developing new understandings in students' minds. Such connections and understandings are important features for problem solving and will be a major theme in this study. Clearly, open-ended problems will offer opportunities for the development of such connections and understandings while the importance of extensive dialogue among students is apparent. The constructivist view suggests that declarative and procedural knowledge develop together, not independently. Problem solving takes place within a context of prior knowledge, and both types are essential to problem-solving success. The approach of this study makes use of relevant knowledge and links between knowledge.

1.4 Study Overview

Related to the previous discussion, there is evidence in the literature that the wider the range of *nodes*, which are linked, the more cognitive success is possible in terms of understanding (see, for example, the work of Otis, 2001, with medical students). Nodes are cognitive units (concepts or ideas), and *links* represent the relation between concepts. Problem solving seems to be reliant on the functional links between *islands* of knowledge in long term memory (Reid and Yang, 2002b). The knowledge seems to be *chunked* in long term memory as islands or nodes (Otis, 2001). In addition, the quality of links between nodes of knowledge is important (Otis, 2001; Reid and Yang, 2002b). Yang also observed the importance of confidence (markedly greater confidence was observed after school pupils completed a problem) and outlined some of the aspects of this (Reid and Yang, 2002b). Confidence was described, tentatively, as a form of *cognitive risk taking.*

Yang (2000) studied problem solving in chemistry at secondary school level for pupils aged from 14-17 years, and was interested in the nature of open-ended problem solving. She devised a set of eighteen problems and these were used with hundreds of school pupils and data were gathered to examine the nature of difficulties experienced in facing such problems. The key issues generated from Yang's work were that:

> "(a) *It is essential to have the appropriate knowledge which must be linked correctly in long term memory and be accessible.*
>
> (b) *Knowledge seems to exist in long term memory as 'islands' and school pupils of this age (14-17) have great difficulty in forming links between the 'islands' unaided.*
>
> (c) *Links in long term memory have to be made in both directions to be applied effectively. Inappropriate links may lead problem solvers in wrong directions.*
>
> (d) *When facing such open-ended problems, there is a strong unwillingness or inability to plan. These may be a feature of the lack of key links between 'islands' of knowledge. The pathways are not there and the pupil cannot see the logical steps towards solution.*" (Reid and Yang, 2002b)

Some of Yang's conclusions and findings, presented tentatively, generated part of the agenda for this thesis. The main aim was to conduct more exploration of the idea of the importance of linked ideas in long term memory. How can this be assessed? Is it a key factor in enabling problem solving to be successful? How does it relate to confidence? Is problem solving a skill that develops naturally as knowledge becomes more interlinked or has problem solving to be taught as a skill? If so, can it be taught and is it a generic skill?

Thus, the aim of this study is to explore the nature of the process of problem solving in students' minds, specifically seeking to elucidate the key rate-determining factors influencing success, with particular emphasis on the importance of links in long term memory, their strength and nature.

Based on Yang's (2000) work two hypotheses were suggested:

- *The number of relevant links in long term memory is proportional to chunking ability (ability to group ideas into meaningful units) which may then be proportional to success in problem solving.*
- *The ability to create links is related to creativity or lateral thinking, perhaps divergency.*

1.5 Plan of Study

In the first stage, working with first year university biology students at the University of Glasgow (October 2003), the aim was to find out which topics in their course were causing problems. This might reveal fruitful areas where open-ended problem-solving exercises could be developed. It was important that the students also should gain something from such exercises and might be assisted in the areas where they found greatest difficulties in understanding.

At this stage, the problem units were developed on topics that were found to be difficult for students. To assist students in gaining confidence, a small set of group problem-solving exercises were developed while one individual problem exercise was developed. This explored the linking of ideas in long term memory and was assessed by a battery of test materials developed specifically for this study. Samples were large but time constraints made it impossible for each student to complete every test. Two successive year-groups were used, the tests used with the second group being developed to explore questions which had been generated by the results from the first year group measurements.

1.6 Outline of This Thesis

Much of the research to date has been heavily focused on problem solving in chemistry and physics and with very little in biology. Indeed, the attention given to biology was itself very narrow, being largely concerned with the subject of genetics. The attention here is to address the approach of problem solving in biology more generally. The aim is to focus on the idea of usable links in long term memory as a rate determining factor in successful problem solving in biology.

In the light of this overview, this study is presented in the following way:

- ♣ **Chapter two**: reviews problem solving in science education and in biology specifically.
- ♣ **Chapter three**: explores how information may be stored and then retrieved from long term memory and considers an emphasis on a semantic network activation. The development of information processing and its relationship with problem solving is discussed.
- ♣ **Chapter four**: explores other types of thinking in addition to problem solving and sets a special emphasis on critical, creative, and lateral thinking.
- ♣ **Chapter five**: highlights some learning models and reveals the cognitive techniques that have been used in this study and the purpose of using them.
- ♣ **Chapter six**: describes the construction of four test problem units and reveals the preliminary and main survey adopted in this study. Shows the most topic areas causing difficulties for students in preliminary study.
- ♣ **Chapter seven**: describes the methodology of the first stage in the experimental work and shows what measurement tools were used. The outcomes from this stage are outlined and discussed.
- ♣ **Chapter eight**: describes the second stage in the experimental work, the measurement tools used, with discussion of the outcomes.
- ♣ **Chapter nine**: describes the final stage in the experimental work, the measurement tools used. Again, the outcomes from this stage are outlined and discussed.
- ♣ Finally, **chapter ten**: looks at the outcomes from the whole study, bringing together the findings and attempting to draw conclusions. The strengths and weaknesses of the study are summarised together with the possibilities for future research work.

The aim of this study is to explore something of what is going on in long term memory when more open problems are faced in the area of biology. This task is acknowledged to be difficult although gaining an understanding of some of the main factors which might control success in problem solving is likely to offer powerful insights for teachers and lecturers and could bring considerable benefit to future learners. However, it has to be recognised that problem solving is a complex process and this study starts by looking at its nature in more detail.

Chapter Two

Problem Solving

2.1 Introduction

This chapter surveys the problem-solving literature within the domain of biology, considering first the relevant literature in the other sciences and in education in general. To produce a definitive overview, one question must first be asked: What is a problem and how do researchers distinguish between the problem itself and problem solving? This will be considered in the next section of this chapter.

> *"During the last two decades the tendency in science education has been towards a kind of teaching which seeks to reproduce the process whereby scientific knowledge develops."* (Perez and Torregrosa, 1983)

Perez and Torregrosa (1983) noted that problem solving could be considered as an "investigative task". The implication was that it had characteristics in some ways similar to scientific investigation. However, this notion is ambiguous and raises questions about what is meant by scientific thinking or the scientific method? Perez and Torregrosa (1983) were suggesting that there are seriously inadequate perceptions of the nature of problem solving. This is caused by a lack of clarity about two significant aspects: knowledge, and the understanding of strategies to solve problems, these strategies being potentially very diverse.

The uncertainties have continued with authors tending to view problem solving from different angles reflecting their own perceptions. Mayer (1992) viewed problem solving as synonymous with thinking, Garrett (1987) saw it as "a complex learning activity that involves thinking". However, a problem can only be solved through the adoption of an appropriate strategy and this may be unique to the problem, or problem type, under consideration.

2.2 What is a Problem?

> *"One of the more troubling issues about which problem solving researchers disagree is the exact meaning of some of the most basic terms that we use."* (Smith, 1991, p. 2)

Definition is an issue that has hindered clear communication about problem solving. There are numerous definitions of what constitutes a problem or a type of problem: algorithmic, open-ended, mathematical, scientific, social and so on. Nonetheless, it is now possible to develop common ideas and conceptualise the nature of a problem in such a way that a common language is beginning to emerge. Here are some definitions from several authors.

> *"Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem."* (Hayes, 1981, p. i)
>
> *"A person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it."* (Newell and Simon, 1972, p. 72)
>
> *"A problem exists when there is a discrepancy between an initial state and a goal state, and there is no ready-made solution for the problem solver."* (Bransford and Stein, 1993, p. 7)

Skinner proposed an earlier definition in 1966 (cited by Frensch and Funke, 1995, p. 6; Davis, 1973, p. 13) which is that a problem is "a question for which there is at the moment no answer". Johnstone (1993, p. iv) proposed a similar definition: "a situation where at present you do not know the answer". Wheatley (1984, p. 1) defined problem solving as "what you do, when you don't know what to do", and earlier Newell and Simon (1972, p. 72) noted that:

> *"A person is confronted with a problem when he wants something and does not know immediately what series of actions he can perform to get it."*

In all of these statements, despite variations of language, some common ideas are evident. There is the strong element of uncertainty. Something is unknown and the way to find an answer is not immediately obvious. There are references to starting positions and final positions with some kind of gap between them. The route between them is not known. While earlier work by Davis (1973, p. 13) did not see common ground in the descriptions then available, Smith (1991) noted the common ground in later definitions. while it could be argued that problems are more difficult when compared to exercises, Bodner and

Domin (2000) argued that these definitions have "a logical consequence: there is a fundamental difference between tasks that are routine exercises and those that are novel problems". They claimed that the fundamental difference lies "in the level of familiarity with similar tasks the individual brings to a given task". Bodner and Domin (2000) argued that such algorithmic problems are not really problems at all.

One important feature in all the descriptions is that they all imply that problems are not simply exercises (McCalla, 2003). In an exercise, the way to obtain the answer is established. Thus, most mathematical textbooks contained sets of what are often called problems. In reality, they are exercises, applying some taught principle in a routine way to new data. Indeed, most problems in traditional physics and chemistry texts are exercises or could be called algorithmic problems. Again, routine procedures are required to find answers (McCalla, 2003).

Charles and Lester (1982) stated that a problem is a "task" for which the learner needs to find a solution, and the solution is not immediately obvious. The learner must make an effort to attempt to find out what that solution is. They argued that a problem has three main components or elements: the goal to be achieved, the goal that cannot be reached directly or immediately, and effort to reach the goal. On the other hand, McCalla (2003) claimed that the pathway to solve a problem requires four components: Objective, Given, Pathway, and Answer. In the first component (Objective) there is need for the learners to ask themselves what is the problem, then try to write it down in appropriate way. The Given component involves the learner with extracting the given data and representing it appropriately. The Pathway involves the need to create patterns of schemata which:

> *"Integrate new knowledge into the already established network of old knowledge. If the new knowledge does not fit well within the current network, the schemata may be restructured. Once integrated, the schemata may be used to create new schemata in which old patterns may be linked to new."* (McCalla, 2003)

In this "the process of schemata generation is fundamental to the development of the Pathway" (McCalla, 2003). After this, the Answer should follow "once all the logical connections have been determined only the calculations remain to be done" (McCalla, 2003).

In a personal communication, Whitehead (2005) had pointed out that many problems in mathematics and physics are not merely algorithmic but require an unknown number of algorithmic steps to arrive at the answer. The art of solving such problems is to visualise the steps, making sure that each provides the proper starting point for the next. The good problem solver is the one who builds this chain in the most economical way. Thus it is not uncommon to "work from both ends" to reduce the given problem to another one which, once solved, whether algorithmically or not, allows the solution of the original problem to be found easily. This chain of algorithmic steps, which have usually been learned by doing many exercises, is an example of the patterns about which McCalla is speaking.

Of course, this applies to problems involving calculation of some sort; most do not. Apparently, in real problem solving, there may be no logical pattern to follow to get a solution (Bodner and Domin, 2000; Yang, 2000).

Fisher (1987) focused on the definition proposed by Bulmersh-Comino, in the very simple 'formula' which is Problem = Objective + Obstacle (Fisher, 1987, p. 21). In his view there is an obstacle that prevents the learner reaching the objective. Later on, Fisher (1990, p.100) asserted that a problem is "a task with a certain number of given conditions and items of information" and he concluded that each problem has to have a goal and, if there is no goal to be achieved, there is no problem. Watts (1991) has given a similar description.

Here are some examples to illustrate these three features of problems. They are drawn from The American Biology Teacher (cited by Jensen and Finley, 1997; from Bishop and Anderson, 1990):

> *"Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could run only 20 miles per hour?"*
>
> *"Cave salamanders are blind (they have eyes that are not functional). How would a biologist explain how blind cave salamanders evolved from sighted ancestors?"*

Zuckerman (1994) presented another example of a similar type but in different area of biology:

> *"The figure below is a diagram of an inverted thistle top funnel which can be used to demonstrate osmosis. At the beginning of an experiment there is a dilute solution of sugar and water inside the funnel. An inelastic membrane permeable only to water has been fitted across the immersed funnel opening. The funnel is surrounded by pure water. Make a graph to show how the solution level in the stem of the funnel changes with time."*

Is it possible to see common components in these problems? Firstly, they all state the goal. Secondly, in each situation the solver is not immediately able to accomplish the goal, because the goal is blocked either through lack of resources or knowledge. These facts can be used as a foundation for a definition of the problem:

> *"Whenever you have a goal which is blocked for any reason - lack of resources, lack of information, and so on - you have a problem."* (Kahney, 1993, p. 15)

In particular, the word "blocked" shows the interaction between the problem environment and solvers themselves.

> *"The knowledge and skills required in science problem solving can vary widely, depending on the specific properties of the problem and the experience of the problem solver."* (Taconis *et al*., 2001)

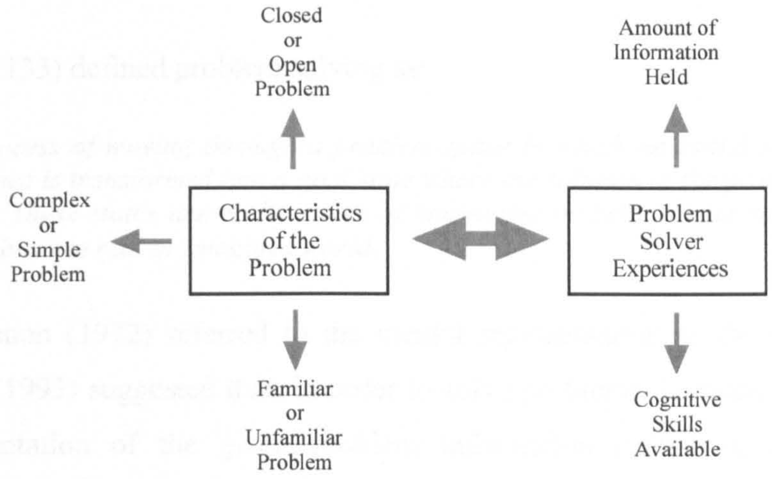
While it is self-evident that problems can vary and the experience of the problem solver can vary, Taconis *et al.* (2001) list five dimensions that contribute to that variability of problems and so influence problem-solving success:

- Complexity of a problem relies on several factors such as the number of sub-problems, formulas, laws, and principles that needs a planned strategy to be solved.
- Familiarity of a problem: "it is decisive for the amount of routine skills he/she can use and the amount of interpretation needed of new elements of the situation presented and the process involved".
- A problem can be closed or open: strictly speaking, closed problem has one unique answer but the open one has variety of possible solutions and no single correct answer.
- Amount of information in science problems.
- Type of cognitive activities which are called problem solving skills.

Adapted from Taconis *et al.* (2001)

These ideas can be summarised as in Figure 2.1.

Figure 2. 1 Problem characteristics and problem solver experiences



In terms of complexity and familiarity, Heyworth (1998) identified two types of problems: basic problems which require a small number of steps and composite problems which, on the other hand, require a multi-step procedure. Students have to distinguish between these two types of problems to devise a procedure to solve the whole problem.

2.3 Problem Space

The notion of constructing a problem space is derived from the constructivist paradigm or from information processing (Appleton, 1995). In his view, the information is organised as "mental schemata". Previously, Newell and Simon (1972) introduced the problem space (internal representation) principle as follows:

> *"The rational activity in which people engage to solve a problem can be described in terms of a set of states of knowledge, operators for changing one state into another, constraints on applying operators and control knowledge for deciding which operator to apply next."*

Simply speaking, problem solving involves the mental representation of a situation in the world and that problem space requires an active manipulation during solving of the problem (Newell and Simon, 1972). Consequently, the problem space is the representation of the problem with possible states and operations that includes initial, intermediate and goal states of the problem and the knowledge of each step carrying forward. Thus, the problem is considered as a set of given information and operations (possible moves or actions) to achieve a certain goal. Appleton (1995) discussed an initial stage of problem solving involving the construction of an internal, mental representation of the problem using existing schemata.

Green (1988, p.133) defined problem solving as:

> *"A process of moving through a problem space in which an initial state of ignorance is transformed into a goal state where the solution of the problem is known. These states are really states of knowledge or belief about states of affairs in some real or imagined world."*

Newell and Simon (1972) referred to the mental representation as the problem space while Kahney (1993) suggested that, in order to solve problems, learners must construct mental representation of the given problem information (initial state, goal states, operators, and operator restrictions).

The difficulty with the idea of problem space is its vagueness and the fact that it has not been used (perhaps it cannot be used) to develop new understandings of problem solving.

2.4 Types of Problems

In research on every-day problem solving, Strough, *et al.* (2002) described "problems that are regularly experienced in day-to-day life" as complex, multidimensional, "multifaceted". Likewise, Berg *et al.* (1999) described problems that are often ill-structured, having a variety of goals and solutions. This view was supported by Fisher (1990) when he contended that real life problems tend to be ill-defined and multifaceted. Kahney (1986) had classified problems into two types:

(1) **Well-defined problems**
In which the "goal, starting point and legal operations are all clearly set out" (Bolton and Ross, 1997) and Schmidt (2004) defined this type as "the given information, the operations, and the goal states are completely specified". Therefore, the given and goal states are clear and easily specified to reach the achievement. For Example:

(a) Solitaire game.
(b) 3x = 2, solve for x.

(2) **Ill-defined problems**
In which "the task is expressed in only the vaguest terms" (Bolton and Ross, 1997) and Schmidt (2004) defined this type as "there is uncertainty in either: the given information, the permissible operations, or the final state". Therefore, the given and goal states are vague. For example:

(a) Designing a mechanised transport system for a city.
(b) Writing an assignment.
(c) Cooking a dinner.

> *"Problem solving is a complex, multilayered skill, and not one that most students can be expected to develop unaided. Even with carefully graded problems, students commonly reach the sort of impasse from which they need to be rescued by the instructor."* (Bolton and Ross, 1997)

Such a statement is an oversimplification and perhaps reflects certain types of problems. Problem solving is often seen as involving higher order thinking skills or, as Bowen and Bodner (1991) asserted, as "figuring out what to do when one does not already know what to do". Such higher order thinking skills (like analysis, synthesis, critical thought) are often required by students as they face the problems associated with daily living.

Mayer (1996) as cited by Wai and Hirakawa (2001) give two critical definitions of problem solving: "a common pervasive type of thinking directed to achieve some goals" and "a skill of finding appropriate ways to achieve a goal that is not immediately attainable". According to Ausubel's learning model, as defended by Bascones and Novak (1985), problem solving is an exclusive situation of "meaningful learning" while Gagné (1970) saw problem solving as a "process by which the learner discovers a combination of previously learned rules that he can apply to achieve a solution for a novel problem situation" (cited by Kempa and Nicholls, 1983, p. 171). West (1992) supports Gagné in this definition:

> *"A set of circumstances in a particular setting which is new to the student, where the use of pattern recognition alone is insufficient but where specific items of knowledge and understanding have to be applied in a logical analytical process in order to identify the factors involved and their interaction."* (West, 1992, cited by Chin, 1993)

However, there is still one real area of difficulty, at least at school level. Reid and Yang (2002b) noted that, "in contrast to real-life problems, most problems presented at school tend to be well defined". Perhaps, the same could be said of university problems. For example, the well-structured problems commonly found at the end of textbooks have single solutions, single solution strategies and specified goals. On the other hand, real-life problems often possess many solutions, many potential strategies for their resolution and unclear goals.

> *"Because of the difference in nature between the two types of problems, the process for solving well-structured problems will probably not work for ill-structured problems."* (Shin *et al.*, 2003, cited by Cheung and Hew, 2004)

Overall, in science education, problem solving is thought to be important but there is often a lack of clarity about what it involves.

2.5 The Nature of Problems

Although many writers had used the idea previously, it was Johnstone, in 1993, who offered the analysis of problems which has given a common language and can be applied to all problems, anything from the mathematics classroom with its algorithmic exercises to the world of real-life problems with all their openness and uncertainty.

He appreciated that every problem has three components:

(1) The data provided;
(2) The method to be used;
(3) The goal to be reached.

These are common to all problems. However, each can either be known fully or not known fully. This gives rise to eight types of problems (see Table 2.1). It was this insight that offered some kind of common language and a simple classification, which can be applied anywhere. Reid and Yang (2002a) used this as the basis of their large scale experimental work in seeking to understand what factors aided or hindered successful problem solving at school level. Bennett (2004) used the same analysis as the basis for his survey of examination papers at university level.

Table 2. 1 Classification of problems
(Source: Johnstone, 1993, p. v)

Type	Data	Methods	Outcomes/Goals	Skills bonus
1	Given	Familiar	Given	Recall of algorithms
2	Given	Unfamiliar	Given	Looking for parallels to known methods
3	Incomplete	Familiar	Given	Analysis of problem to decide what further data are required. Data seeking.
4	Incomplete	Unfamiliar	Given	Weighing up possible methods and then deciding on data required.
5	Given	Familiar	Open	Decision making about appropriate goals. Exploration of knowledge networks.
6	Given	Unfamiliar	Open	Decisions about goals and choices of appropriate methods. Exploration of knowledge and technique networks.
7	Incomplete	Familiar	Open	Once goals have been specified by the student these data are seen to be incomplete.
8	Incomplete	Unfamiliar	Open	Suggestion of goals and methods to get there; consequent need for additional data. All of the above skills.

In his analysis, Johnstone (1993) offered a distinction between exercises (algorithmic problems: type 1 problems) and other problems. He was also careful never to suggest that there was any kind of hierarchy. Thus, type 1 problems are not necessarily the easiest. In fact, in the work of Yang (2000), she developed and used problems of types 3 to 7 and found no relationship between problem types and perceived difficulty, supporting the Johnstone position.

Tsaparlis and Angelopoulos (2000) stated that:

> *"Types 1 and 2 are the normal problems usually encountered in academic situations. Only type 1 is of the algorithmic nature (exercise). Type 2 can become algorithmic with experience or teaching. Types 3 and 4 are more complex, with type 4 requiring very different reasoning from that used in types 1 and 2. Types 5-8 have open outcomes and/or goals, and are very demanding. Type 8 is the nearest to real life, everyday problems."*

Their assertion that types 5 to 8 are more demanding is not supported by the findings of Yang although it is conceivable that type 8 might be more demanding. Problem difficulty is not logically related to problem type and it is possible to conceive very difficult problems of type 1, for example, and very straightforward problems of other types.

2.6 The Developmental Theory of Problem Solving

> *"Information processing models develop elements of cognitive development theory (sequence, activity) and social constructivist theory (experience) but emphasise cognitive strategies rather than structures."* (Danili, 2004, p. 21)

Danili's statement is highly perceptive and captures many ideas. In the constructivist paradigm, the problem solvers are considered as constructing their own understanding of the problem, drawing on experience to find methods of solution and building their own understanding of outcomes. The information processing paradigm lays its emphasis on the way information is handled, constructed and used to find solutions. The advantage of the latter is that it offers a precise model of what is happening, and this model can be used to make predictions and offers hypotheses which can be tested. Thus, for example, if a task requires the solver to handle more items of information at the same time than is available in their working memory space, then failure is almost inevitable. Numerous studies have shown this to be true (Johnstone and El-Banna, 1986 and 1989; Christou, 2001), see section 3.12. Johnstone brought much of the evidence together in 1997 (Johnstone, 1997). Reid and Yang (2002b) used information processing to underpin their work and they were able to focus on specific features of problem solving which the model predicts might be critical for success. This offers a clear practical framework.

Newell and Simon (1972, p. 88) argued for a slightly more complicated system with five phases:

> (1) ***Input translation***, *this is considered as an initial process in order to choose the problem space. Information from the external environment is represented internally.*
> (2) ***Method***, *this phase follows the former one in response to the internal representation to select the attainable method.*
> (3) ***Application of method***, *the problem now in control of internal and external behaviour of problem solver.*
> (4) ***New attempt*** *might proceed by selecting another method and different internal representation.*
> (5) *As a terminal phase, some* ***sub-goals*** *may appear for the problem solver.*

Later, Simon and Hayes (1985) postulated that problem solving is a product of elementary information processing activities, which form a framework of three interlinked components:

(1) *Task environment;*
(2) *Problem space;*
(3) *Problem solving strategy.*

They characterised problem solving as an "interaction between a task environment (problem) and the problem solver". Yang considered the problem solver has an information processing system and this system has such some properties like rehearsal in long term memory which has great impact on problem solving outcomes (Reid and Yang, 2002b).

Information processing may be used to interpret what is happening when learning takes place and when problems are faced. Miller (1956) found a way to measure the size of what is now known as working memory and this showed clearly that working memory grows with age (to the age of 16), was finite and limited in capacity (7±2 units could be held at one time), and was not capable of expansion (see section 3.12). Various researchers had followed Piaget's observations of thinking development and had tried to interpret these in terms of information handling. (e.g. Pascual-Leone, 1970). Numerous others have developed models of memory based on information flow (e.g. Bourne *et al*, 1986; and later, Ashcraft, 1994).

Drawing from the work of Ausubel, Johnstone started to interpret his vast range of findings on difficulties in learning in the science in the early 1980s (see, for example, Johnstone and Kellett, 1980; Johnstone and El-Banna, 1986). His major contribution lay in being able to see how the working memory limitation was the key factor explaining learner difficulties in specific topics in the sciences (Johnstone and El-Banna, 1989; Johnstone, 1991). Much of his work was based on the way university students and school pupils handled assessment tasks including various types of problem (e.g. Johnstone *et al.*, 1993).

He also saw how what a person already knew could influence the way he selected what was to be considered in new learning. All this came together in his paper of 1991 (Johnstone, 1991). Here he argued that:

> *"Our senses are constantly assailed with information so complex we cannot attend to it all. We operate a selection system (perception), driven by our Long Term Memory (LTM) and in this way we recognise the familiar and are surprised by the unfamiliar. Interest, previous training and culture play a part in this process. Often the information is incomplete and we can flesh it out from ideas stored in LTM."*

In the Johnstone model (as with other models in information processing), there are three basic components in the human memory:

(1) The sensory memory (perceptive filter);
(2) The short term memory (working memory);
(3) The long term memory.

"The difference between the three types of memory lies in the nature and extent of the processing that the information undergoes, and their capacity" (Chen, 2004). Inward stimuli enter the working memory deliver through a perception filter which is controlled by long term memory (Otis, 2001). The application of this to problem solving offers very useful insights and testable hypotheses in seeking to understand the key critical processes involved in successful problem solving. In this way, information processing offers insights not obvious in other approaches. This will be discussed later in chapter 3.

2.7 Some Factors Influencing Problem Solving Success

Many researchers in the field of science education have investigated the relationship between learner achievement and their problem-solving skills. However,

> *"... research in several domains demonstrated that the performance of the problem solver is narrowly delimited by the nature of the problem being solved."* (Smith, 1991)

Moreover, representation of the problem and its complexity (Cassells and Johnstone, 1984) plays a major role to determine how to solve a problem. Problem solving involves:

> *"... the process of coordinating previous experience, knowledge, and intuition in an attempt to determine a method for resolving a situation whose outcome is not known."* (Charles and Lester, 1982, p. 10)

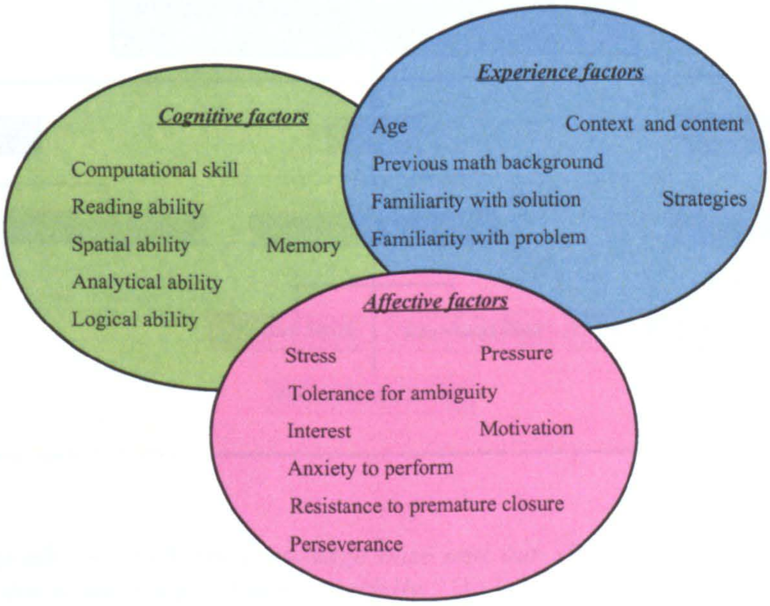
In order to carry on the problem, the learner has to be motivated and able to cope with any stress. Charles and Lester (1982, p. 10) suggested three more groups of factors that may influence problem-solving ability:

(1)	*Experience factors (personal and environmental);*
(2)	*Affective factors (interest, motivation, pressure, and anxiety, etc.);*
(3)	*Cognitive factors (reading ability, reasoning ability, computational skills, etc.).*

Figure 2.2 illustrates a number of these factors.

Figure 2. 2 **Sets of factors that influence success in problem-solving process**

(Source: Adapted from Charles and Lester, 1982, p. 11)



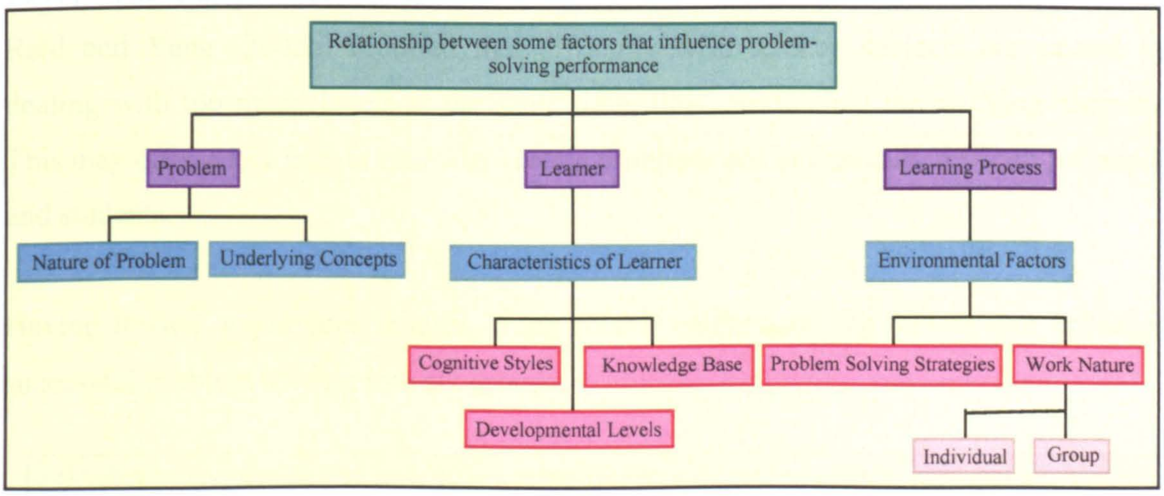
Taking a different approach, Heyworth (1998;1999) noted that there are important factors involved in problem solving such as problem recognition, linkage, cognitive load, and prior knowledge. One is the construction of representations of the problem based on a conceptual understanding of information given in the problem statement. Another is the use of a strategy to guide the search for a solution procedure from the initial state of the problem (the information and data given) to the goal state (the required answer). Other factors influencing problem-solving processes include memory, cognitive goal, and task perception.

This leads us to the findings of Reid and Yang (2002b) in their review of the literature on problem solving. They noted three significant factors that relate to success in problem solving:

> *"... the nature of the problem and the underlying concepts on which the problem is based; the learner characteristics, including cognitive styles, developmental levels and their knowledge base; and learning environment factors, including problem solving strategies or methods, individual or group activity."*

Figure 2.3 is based on Reid and Yang's conclusions and illustrates their findings.

Figure 2. 3 Three significant factors and successful problem solving



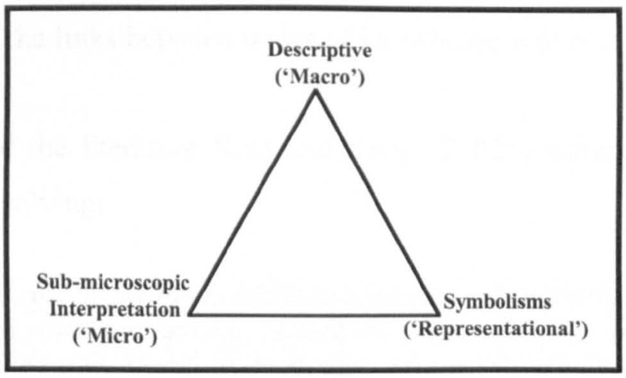
> *"The combination of our knowledge base and our skills base contributes to our ability to solve a problem successfully."* (Lyle and Robinson, 2001)

However, such a statement is a 'catch-all' and is more or less self-evident! Ashmore *et al.* (1979) adopted a network approach in looking at the knowledge base. Reid and Yang

(2002b) viewed information as a network deriving from the problem itself, memory retrieval, or reasoning. Thus, this network helps teachers to "perceive student difficulties in solving problems". Background knowledge and confidence play important role as prerequisite for problem solving. Lack or inadequacy in one or both of these make students uncertain of what they are doing.

In looking at difficulties in learning chemistry, Johnstone (1991) proposed a triangle of three modes of understanding in chemistry (see Figure 2.4).

Figure 2.4 **The Chemistry Triangle**
(Source: Reid and Yang, 2002b)



"No one form is superior to another, but each one complements the other" (Johnstone, 1991). The triangle could be applied to any science subject. Science is hard to learn and Reid and Yang (2002b) reported that difficulty with science subjects are caused by dealing with too many levels at the same time, thus overloading the working memory. This may offer a key insight into why certain problems are intrinsically difficult for pupils and students.

Having looked at previous studies, Yang (2000) categorised the factors that influence successful problem solving into six groups:

(1) *Prior experiences that include prior knowledge base and emotional experience;*
(2) *Individual or cooperative group work;*
(3) *Problem-solving strategies including algorithms, conceptual understanding and problem-solving skills;*
(4) *Factors that arise from information processing ideas;*
(5) *Individual's cognitive styles, developmental levels;*
(6) *The way of teaching problem solving.*

A series of studies of chemistry problem solving by Niaz (1987-1989) showed that working memory space is an important factor in determining problem-solving success. The cognitive variable known as field-dependency - Danili (2004) described it as the ability to see specific information separated form the surrounding information - was found to be a determinant of the problem-solving process (Ronning *et al.*, 1984). Yang (Reid and Yang, 2002b) in her study, found that willingness to take cognitive risks (an aspect of confidence) is an important factor. She also suggested that the presence of accessible links between nodes of knowledge in long term memory is an important factor and the work by Otis (2001) is consistent with this. Yang did not explore the ability to think critically, creatively or laterally and whether it might influence problem-solving success. Many of these factors will be explored in this study, with particular emphasis on long term memory. The links between nodes of knowledge will be a particular focus.

From their review of the literature Reid and Yang (2002b) summarise the key factors influencing problem solving:

"(1) *Procedures and Algorithms: While procedures and algorithms have some place, their value is limited. Using an algorithm does not equate to understanding and, therefore, to a move into a new situation. Too many problems simply cannot be fitted into any neat set of procedures.*

(2) *Long Term Memory: It has clearly been established that what is already known and how that knowledge was gained and stored will strongly influence new learning. Information already held may have been learned in one context which does not readily translate into another.*

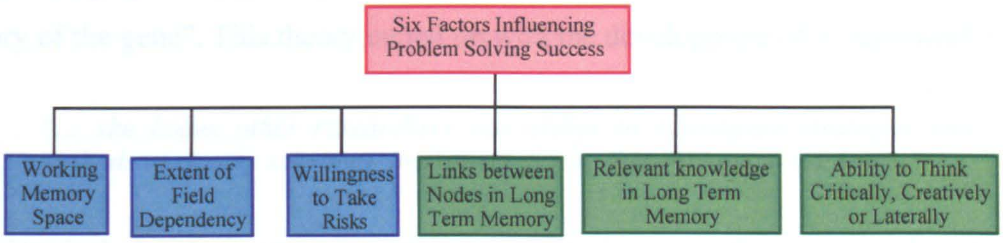
(3) *The Working Memory: This space is needed to hold new information as well as accept information already held in long term memory. On top of that, the working memory space also has to have room to process information. With such a limited space, it is easy for overload to occur.*

(4) *Confidence/Experience/Expectations: Experience, especially successful experience, builds up confidence. Experienced confidence enables the problem solver to use skills and to look at a new problem and to be able to draw from past experience to say, 'it's something like this'.*

(5) *Psychological factors: Factors like the extent of field dependency, extent of convergency-divergency, and the ability to develop representational skills (both mental and physical) may all be very important. It has been shown that field dependency is important while the ability to develop appropriate models is a key skill leading to success. It might be hypothesised that divergency would also be advantageous."*

This scheme of Reid and Yang (2002b) can be summarised in Figure 2.5. Of the six factors in this figure, Yang (2000) studied the factors in blue boxes. This thesis investigates the green ones.

Figure 2.5 The six factors that influence problem-solving success



2.8 Problem Solving in Biology

> *"Biology students in domains such as genetics and ecology are often asked to predict outcomes resulting from the interactions of multiple variables within a dynamic system."* (Hurst and Milkent, 1996)

Aznar and Orcajo (2005) noted that, "problem solving has become one of the most important lines of investigation in the field of science education, particularly in physics and chemistry. In biology classrooms, problem solving is less common". Problem solving in the biology literature is often equated with genetics problems. Work with open problems is very limited (Aznar and Orcajo, 2005). However, biology has received increasing attention in recent years with the rise of nationally significant biological issues of an environmental, ecological, and medical nature (Lavoie, 1993). There is, however, little available literature relating to problem solving in the biological sciences (Gayford, 1989). Very little has been published since then.

Since 1980, research was conducted on what high school biology students learn from standard genetics instruction and how they use that knowledge to solve basic genetics problems. The striking result found that a number of students were unable to obtain correct answers to a straightforward dihybrid cross[1] problem. Stewart (1980) and Thomson and Stewart (1985) also found that a great number of students had little understanding of underlying conceptual knowledge of genetics and meiosis. This makes problem solving in genetics very difficult. They looked at traditional textbooks and found that there was a lack of explicit treatment of how the conceptual knowledge of genetics and meiosis are related to the solution of genetics problems and a lack of development of the algorithms that can be used to solve problems. Both algorithms and conceptual knowledge underlying problem solutions seem to need to be explicit in this area.

[1] Dihybrid cross: A cross between two individuals identically heterozygous at two loci for example, AaBb/AaBb.

Thomson and Stewart (2003) noted that Darden (1991) reported an account of strategies and knowledge geneticists used from 1900 to 1926 to solve complex problems "that led to a theory of the gene". This theory ended up with the development of a framework that:

> *"... she hopes other researchers can utilize to investigate strategies and methods of inquiry scientists' implement during theory change in science."*

The historical development of scientific inquiry is a significant method that can be utilised by teachers to develop and construct thoughtful lessons that offers insight that is:

> *".... how the nature of inquiry has addressed past complex problems in science, rather than providing insight into what they currently do."* (Thomson and Stewart, 2003)

The idea that historical examples of scientific thinking can offer potential ways forward to today's novice problem solvers may be somewhat naive. However, it would be useful exercise for today's learners to appreciate the approaches used in the past.

Aznar and Orcajo (2005) explained how problem solving is taking a place in genetics. As a result of the extensive studies done in classical genetics a consistent finding emerged: "students do not frequently bring knowledge of meiosis (cell division) to bear while solving genetics problems" (Wynne *et al.*, 2001). In addition, researchers noted that students had misconceptions about the process of meiosis and these misconceptions interfered with the students' ability to solve genetics problems (Wynne *et al.*, 2001).

In relation to genetics problems, Stewart and Hafner (1994) stated that "understanding and problem solving are cognitively similar activities". Aznar and Orcajo (2005) were interested more in using a classification system based on the process that students should employ to solve problems. Based on that, they adopted Stewart's classification (1988). They contended that Stewart differentiated two large groups of problems. He stated that there are two main types of thinking involved in solving genetics problems: firstly, reasoning from cause to effect, and secondly, reasoning from effect to cause. These are known as closed thinking and open thinking, respectively. These types of thinking contributed differentially to learning outcomes.

In cause-effect problems, the data are known (such as genotypes). These refer to a group of organisms sharing a specific genetic constitution, biological group or particular alleles at specified loci present in an organism genetic constitution. A target goal or answer is reached (like a phenotype frequency) which refers to expression of a specific trait and observable properties of an organism such as blood type or red hair, and their genotypes. Hence, these are closed problems or exercises.

In effect-cause problems, a solution must be deduced from the effects (phenotypes that are observed) of the causes (possible genotypes) and by identifying the pattern of inheritance involved. These problems are more open and might be considered as real problems as they require the students to use all their knowledge and hypothesise and apply specific strategies.

Aznar and Orcajo (2005) presented a table (see Table 2.2) to show different procedures a student can use to solve genetics problems, closed (cause-effect) or open (effect-cause).

Table 2.2 **Example of difference about procedures in closed-open problem-solving in genetics** (Source: Adapted from Aznar and Orcajo, 2005)

Problem	*Procedures*	*Answers*
	Closed	
The brown eye colour is dominant over the blue. If both parents have brown eyes, could they have a blue-eyed son?	Analysis of data (identification of the inheritance model).	The answer is a simple numerical ratio.
	Open	
Is the appearance of a new characteristic in a family feasible?	Identification of the problem (situation of departure, variables, parts of the problem, etc.). Predictions and hypothesis (from a theoretical framework about inheritance). Experimental design (adequate selection of tests and of a resolution strategy). Transformation and interpretation of data (organization and representation of data in *Punnett square*[2] diagrams or schemas with chromosomes, obtain and interpretation of data). Analysis of data (to confirm the inheritance model). Elaboration of conclusions (immediate inferences from data or from the process, establishing generalizations, critical evaluation of results and of acquisition process).	The answers are multi-steps solutions and explanations.

Problems in most high school or introductory college textbook genetics problems are cause-effect, depending on an algorithmic approach. This type of problem does not require students to be critical thinkers. Over time, Aznar and Orcajo (2005) stated that "the importance of revising the problem-solving model in genetics has been documented in the literature". However, only open problems (effect-cause) allow the students to identify their conceptual knowledge and solve the problems according to the model provided.

[2] Punnett square: A mathematical tool used by geneticists to show allelic combinations of gametes and to predict offspring ratios.

Lavoie (1993) and Hurst and Milkent (1996) outlined some thinking and learning skills that assisted with the problem-solving process. These goals are to encourage the ability of students to think critically, reason logically, and ultimately, to solve problems. However, this is rather like encouraging learners to be good problem solvers in order to be good problem solvers! There is no indication about how this might be achieved.

Although in biology there has been a particular concentration on problem solving in genetics, research has also occurred in other areas in biology. A set of biological problems, mainly for first year university students, were developed in Scotland. They were designed to take from about 1.5 to 2.5 hours each and tended to use group work and often role-play.

- **Air, Land or Water:** Faced with an apparently intractable pollution problem from a chemical production unit, groups of students, working from a biological perspective, have to consider three options for change from the point of view of the environment in order to satisfy the demands of the Pollution Inspectorate.
- **River Blindness:** Students work in collaborative roles (epidemiologists, entomologists and management) to work out a strategy for dealing with a major world health problem in Africa over a twenty year period, seeking to meet the demands of the World Health Organization
- **Super Salmon:** After taking some fundamental biological decisions relating to the development of a stock of transgenic salmon, groups of students role play three perspectives in setting up a new factory farm in order to satisfy biological, environmental and economic demands.
- **The Alien Squirrel:** Groups of students adopt the roles of three interest groups in seeking to find a biological solution to the problem of the growth of the grey squirrel population as it threatens forestry and the extremely valuable hazelnut groves that form the basis of a thriving economy. This unit also exists translated into French.
- **The Pertussis Enigma:** Groups of students re-enact the role of a government established working party that was charged with the task of providing the best advice on the use of the whooping cough vaccine. In this, they have to handle a large amount of information, sometimes incomplete and inconsistent, in reaching the best solution that could affect human lives.
- **The Vaccine Debate:** Working at a global level, groups of students have to present oral persuasive arguments to support the case for the use of resources in developing new vaccines or to leave the resources for other aspects of better health care. This reflects the actual situation today where new vaccine development is a high risk business with few participants left.

Four of these are known to have been used widely and one of them has been subjected to evaluation with very large numbers of students (Clarkeburn *et al.*, 2000). The evaluation showed that the material, used with over 1200 students, achieved the aims set. However, although set in a problem-solving style, the units were not developed specifically to achieve problem-solving skills.

2.9 General Problem-Solving Skills

Problem solving ability is widely regarded as a core skill in the sciences. Kahney (1986) distinguished between well-defined and ill-defined problems (see section 2.4) while Bolton and Ross (1997) asserted that problem solving is a complex, multi-layered skill, and no one student can be expected to proceed without help even with carefully graded problems. Polya (1957), looking at mathematics problems, introduced a series of steps in problem solving:

- ***Understanding the problem***: *The solver gathers information about the problem and tasks, what is unknown? Or what are the data and conditions?*
-
- ***Devising a plan***: *The solver attempts to use prior knowledge to find a method of solution (Do I know a related problem? Can I restate the goal in a new way based on my past experience, working backward from the unknown to the givens? Or can I restate the givens in a new way that relates to my past experience, working forward from the givens to the goal).*
-
- ***Carrying out the plan***: *The solver attempts the plan of solution, checking each step.*
-
- ***Looking back***: *The solver attempts to check the result by using another method, or by seeing how it all fits together, and asks, Can I use this result or method for other problems?*

Although these steps might seem to be an encouraging approach to follow, the evidence suggests that students cannot follow such procedures (e.g. Reid and Yang, 2002b; Bodner and Domin, 2000). Indeed, such procedures might work for mathematics and for routine exercises but not for other subjects. Mayer (1977) contended that Polya's four steps are still vague and had not been experimentally well studied.

However, it has been shown that possession of knowledge and skills is not necessarily sufficient to enable student to solve problems (Frazer and Sleet, 1984). Hence, O'Neil *et al.* (2003) asserted that a good problem solver:

- *Understands the content of a problem well (content knowledge);*
- *Possesses specific intellectual skills (problem-solving strategies);*
- *Is able to plan the use of resources and skills, and during the process, monitors the progress toward the end goal of solving the problem.*

Lyle and Robinson (2001) believed that "the combination of our knowledge base and our skills base contributes to our ability to solve a problem successfully". The student needs to know the relevant information and needs to know, or be able to develop, a successful strategy. No guidance is given as to how such goals can be achieved, especially, the latter one. Lyle and Robinson (2001) went on to suggest that skills are either "domain specific" and relate to one specific schema in the knowledge base (e.g. balancing an equation) or they may be more general (e.g. using significant figures appropriately). Dillon and Schmeck (1983) assert that there are general or specific problem-solving strategies. General strategies can be applied to problems in several domains regardless of content while specific strategies are used only in a particular domain.

Johnstone (2001) contended that it is easy to teach some strategies to solve problems in case of type 1 problems (algorithmic problems – see Table 2.2) by repeating a procedure many times. In the case of types 2-8 (the non-algorithmic problems), the situation is different and it is difficult to sustain such a specific strategy. He stated that, "when we move into the realm of insight and creativity, we are unable to reduce the problem-solving process to any kind of routine". He presented the example of the advice given by an examination board to its high school chemistry pupils:

- *Make sure you understand what is wanted;*
- *Plan the route;*
- *Carry out the plan;*
- *Check that the result is reasonable.*

Johnstone is quite clear that there are some skills which cannot be taught easily:

> *"Problem solving can be thought of as filling gaps between 'certainties'. We can teach ways of narrowing the gap, but I am sure that we cannot teach the last step: the bridging of the gap."* (Johnstone, 2001)

The last step requires knowledge (knowing what and how), experience, confidence and the mental flexibility to "see new things". However, there may be many 'gap-reducing' techniques that are teachable and these might be presented as instructions. He offers an example:

> (1) *"Knowledge has to be in because problem solving is very context dependent.*
> (2) *Let the mind 'hang loose'. If you are getting nowhere in one channel, take a break and look for another approach. Brainstorming in a group is just this.*
> (3) *Break down the field that may lead you into a fixed way of thinking by pulling the problem apart. This removes distracting things and reduces the load on mental Working Space.*
> (4) *If possible make your problem visible by converting words into pictures, diagrams or graphs (for visual thinkers).*
> (5) *Work backwards from the goal, if need be. At the end, go back over how you did.*
> (6) *Establish and reinforce any new technique you may have invented. This will also confirm new linkages you have made in your mind."*

Finally, Johnstone (2001) considered the vexed question: can problem solving be taught? He suggested that:

> *"We can teach techniques that will help to organise the problem and problem solving process.*
> *We can help students to store and organise their knowledge in such a way as to facilitate problem solving.*
> *We cannot teach insight which is the ultimate key to real problem solving."*

According to learning theories, knowledge is used to process external information by relating it to what the learner already knows. This involves interpreting the information provided and identifying the goal of the problem. The search process takes place in long term memory, which seeks for the knowledge that contains specific strategies that are relevant to the problem. If the problem is familiar, a plan for solving it is created, carried out, and evaluated. Therefore, challenging problems may require several cycles of problem-solving skills such as interpretation, representation, planning, implementation, and evaluation.

In the light of these conclusions, Johnstone and El-Banna (1986) proposed a model which is called *working memory overload hypothesis* and this will be explained in chapter three (section 3.12). This model assumes that:

> *"... each learner has a working memory capacity (X) and that each problem has a working-memory demand (Z), which is defined as the maximum number of steps activated by the least able individual."*

In this model, Johnstone and El-Banna (1986) assumed that, if the demand on working memory exceeds the capacity of working memory, then success in problem solving is unlikely. To overcome this problem and to reduce the demand on working memory, the problem solver has to adopt strategies to reduce the working memory overload possibility. These will be discussed later.

2.10 Conclusions

One of the most important types of cognitive processing that occurs often during learning is problem solving. Problem solving is a key process in learning, especially in the scientific domains. Reid and Yang (2002b) raised the questions whether problem solving can be taught and whether it is generic skill.

Yang (Reid and Yang, 2000b) found that, where there was clear absence of key information, pupils' problem solving was unsuccessful. Also, she observed that correct information, inappropriately applied, caused significant difficulties. She found that pupils found a major difficulty in bringing various pieces of information and knowledge together. This implies that the creation of mental pathways between what she called 'islands of knowledge' is extremely difficult. It seems that the learners cannot make linkages between key concepts easily.

Yang provided evidence that learning a procedure in one direction is no guarantee that it can be applied in the opposite direction. This suggests that links in long term memory need to be made in both directions in order to create useful pathway. If there are misconceptions in a domain such as biology, then problem solving shows up the confusion.

Indeed, it has been dogma in physics teaching for many years that the student can easily convince himself or herself that he or she knows and understands some topic. This self-delusion can only be shaken by the inevitable failure when the supposed understanding is applied to the solving of problems. Similarly, success in problem solving has been regarded as one sure way to build confidence (Whitehead, 2005, Personal Communication).

Much of this work raises questions about knowledge and skills stored in long term memory and relates to ideas developed through studies in information processing. The next chapter addresses some of the issues. It will deal with discussions of semantic networks and how process representation, encoding, and organisation in long term memory might be a benefit for a problem solver. This will be followed by discussion about information processing and its relationship with problem solving.

Chapter Three

Semantic Networks, Information Processing and Problem Solving

3.1 Introduction

Based on Yang's findings, the creation of links between nodes of knowledge seems to be a vital factor to solve problems successfully (Reid and Yang, 2002b). This chapter attempts to look briefly at what is known about the way semantic networks operate in the brain and to relate this work to understandings from learning models. The focus at the end will be on information processing in that this model offers the most useful insights when looking at problem solving.

Over 25 years ago, Johnstone and Mahmoud (1980) surveyed pupils in Scottish schools to find out what were the most difficult topics in biology. This survey revealed that there were two main topic areas difficult to understand: *water transport in plants* and *genetics*. A later study found that *water transport* problems had largely disappeared, but the *genetics* difficulties still remained (Bahar *et al*., 1999). Indeed, the *genetics* topics have caused concern in biology education research because persistent confusions and misconceptions are common, usually arising because genetics by its very nature is a high information topic and working memory overload with learners is common.

3.2 Representation of Biology Problems

Zuckerman (1998) in his paper about representations of an **osmosis** problem said:

> *"A problem misrepresentation refers to an incorrect representation. A misrepresentation is based on inappropriate or inaccurate knowledge (i.e. on concepts or relations irrelevant to our incompatible with the scientific principles underlying a problem)."* (Zuckerman, 1998)

He observed that problem solvers use their knowledge and the information in problem statements to categorise the problem at first sight. Then, they make their judgments based on their understanding of the problem. Then, they can represent the problem. This representation can vary from one solver to another. Consequently, this affects the quality of answer, and the solvers ability to generalise that answer. He contended that misrepresentation is very common in science problems because students' scientific knowledge is incomplete and often inaccurate and students tend to associate objects in a problem statement with familiar events rather than with scientific phenomena and principles they have learned.

3.3 A Brief Overview of the Brain

Before turning to semantic network models, a brief summary will be given of the nervous system and its main components in order to make sense of ideas like *nodes* and *links* and how they relate to each other.

> *"The nervous system refers to more than just the brain. It refers to the various sensory systems that gather information from parts of the body and to the motor system that controls movement."* (Anderson, 2000, p. 16)

Neurons are the most important components of the nervous system from the point of view of information processing system (Anderson, 2000). A neuron is the functional unit in the nervous system and a basic building block of the brain and entire nervous system. It is a "cell that is specialized for receiving and transmitting a neural impulse" (Ashcraft, 2002, p. 55). Neurons vary in their shapes and sizes according to their locations and functions. Figure 3.1 and 3.2 illustrate the structure of the brain and a typical neuron.

Figure 3. 1 **The brain**
(Source: anon, undated)

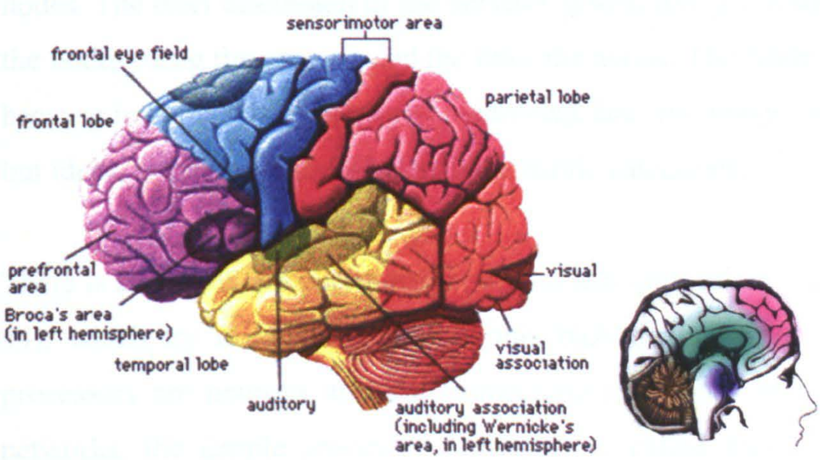
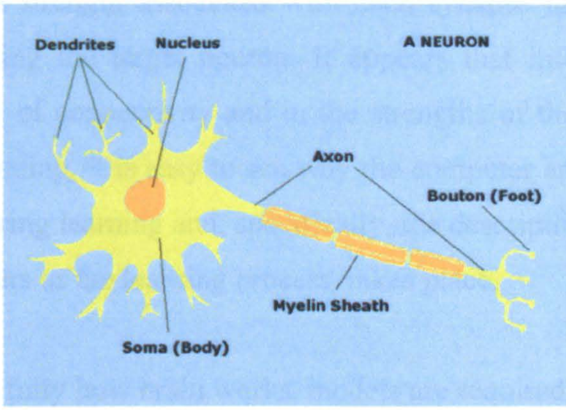


Figure 3. 2 **The neuron**

(Source: anon, undated)



"The brain is a massively parallel information processor" (Shastri, 1988, p. 117), consisting of about 10^{10} to 10^{12} neurons. They form a highly interconnected network. A typical neuron makes around 1000-10,000 connections (synapses) with other neurons, resulting in a total of around 10^{14} connections. A neuron receives incoming signals from other neurons, mainly through its dendrites, integrates them, and propagates its output to other neurons via its axon. The output of neurons usually is in the form of electrical impulses, the frequency of which encodes the strength of the neuronal output. Furthermore, the nature of information transmitted from one neuron to another is highly constrained (Shastri, 1988). Each neuron communicates only a few bits of information.

Many of the ideas reviewed in this chapter refer to networks of nodes and links between nodes. The brief discussion of the nervous system just given shows this network structure, the nodes being the neurons and the links the axons. The reader must be careful, however, because in some of the networks mentioned later the nodes are not physical things at all but ideas, or pieces of knowledge, or semantic categories.

There is a class of computational models of learning, called *connectionist model* (see page 44), which try to capture some of this biological structure. In the brain, the simple processors are neurons and the connections are *axons* and *synapses*. In connectionist networks, the simple processor elements are called pseudo-neurons or *units* and the connections consist of links between these units. The units are usually influenced by nearby units. Each element takes inputs from a small group of units and passes outputs to another group of neighbours (Clark, 2001).

An important aspect of neural computation is that inputs differ in their ability to affect the response of a neuron. Some inputs are excitatory while some others are inhibitory. Additionally, there is a strength associated with each synapse that encodes the inputs along a synapse affecting the target neuron. It appears that information in the brain depends on the pattern of connectivity and in the strengths of these connections. From this biological understanding, it is easy to see why the computer analogy is so often used to describe activities during learning and, specifically, the description of the processing of information, which occurs as the learning process, takes place.

Because nobody knows fully how brain works, models are required to help thinking about problem-solving processes applied in education.

3.4 Semantic Network Models

There is a large amount of information in our minds, but how is all of that information stored? Memory seems to be organised on the basis of meaning. There are different models of long term memory and how the representation occurs through encoding processes. Semantic network models are one general class of memory models.

The nodes represent concepts, and the links represent the relations between the concepts. The relations of specific types (e.g. '*has a*' or '*is a*'). The directions of the relations are also specified (*a bird is an animal*, but not vice versa). Getting information out of the network involves searching through the various relations. There are two varieties of nodes. *Superset nodes* define a particular concept (e.g. *bird*). *Sub nodes* are particular instances of that concept (e.g. *the robin you saw on the way to school*).

Network models are based on two different types of assumptions: structural and processing. Structural assumptions refer to geometric characteristics of memory networks. They specify how information is stored or represented in memory, whereas processing assumptions describe how information is retrieved and recalled (Klimesch, 1994).

3.5 Network Models of Semantic Memory

There has been a proliferation of semantic memory models in recent years and today this is one of the major topics in cognitive psychology. These models can be broken down into a few general classes. The largest class is the *network model* (e.g. Anderson, 1976; Anderson and Bower, 1973; Rumelhart *et al.*, 1972; Quillian, 1969). In network models of memory, knowledge is represented by a web or network, and memory processes are defined within that network (Bruning *et al.*, 1995). In most such models, the network consists of nodes, which are cognitive units (usually either concepts or schemata), and links, which represent relations between these cognitive units.

A second class of models considers material in long term memory to consist of *sets* of information (Reynolds and Flagg, 1983). These sets are assumed to summarise the information about various categories that exist in memory (e.g. *birds*, *foods*, *plants*). This information includes a category membership and the attributes or properties of a category (e.g. *fish have scales*, *fins, can swim*). A third class of models views long term memory as consisting of *semantic features* (*visual* or *auditory*) (e.g. Rips, Shoben and Smith, 1973). These semantic features consist of a given object or event that can be characterised by a specific group of features. A final class of model is reflected in the work of Kintsch (1974). Kintsch is concerned with *logical operators* in memory that serve to connect and transform the relationships between memory representations. His approach has common points with the classes mentioned above (Reynolds and Flagg, 1983). In the following sections, the most well-known and accepted models will be outlined briefly and their significance for problem solving identified.

The Collins and Quillian model (1969;1972) and Collins and Loftus model (1975) involve an extensive theory of semantic memory. Two assumptions emerged from these models: firstly, the structure of semantic memory; secondly, the process of retrieving information from that structure (Ashcraft, 2002).

Collins and Loftus (1975) modified the network model by focusing on strength of association between nodes. Also, the model is much concerned about the length of the link. This indicates the semantic distance between the nodes and how close they are in their meanings. Collins and Loftus introduced '*is not*' relations for negative judgments. Three ideas are important:

(1) The strength of initial activation;
(2) The amount of time since the initial activation;
(3) The semantic distance between nodes.

If problem solving involves making links between nodes, clearly the strength of the link will be important. This may depend on how strongly the link is activated originally and how far apart in semantic space the nodes to be linked actually are.

However, Mayer (1983) summarised one of the first popular network models which is called *Teachable Language Comprehender* (TLC) first proposed by Quillian (1968) and Collins and Quillian (1969;972). This work had been carried out in order to develop a computer program that simulates how human beings answer factual knowledge. Teachable Language Comprehender was based on the assumption that memory can be represented by a semantic network arranged into a hierarchical structure. Hierarchical structure is a network in which there are many links forming from a single node into the concept node. In this model, there are sets of relations for category membership. In this hierarchy, the nodes are concepts arranged in superordinate-subordinate relationships. Properties of each concept are labeled *relational links* or *pointers* going from node to concept nodes. The structure of semantic memory is based on words that represent one thing or object (e.g. *bird*), properties associated with the word or object (e.g. *has wings*), and pointers linking objects to properties.

In this model, semantic knowledge is hierarchically organised. Furthermore, the subordinate relations are not redundantly represented. Thus, if a property is common to several concepts, then it is stored at the highest level of the hierarchy. Searching memory occurs from one concept and spreads out through all possible links of the network at once (hence, the search is parallel). As the distance between the relevant concepts increases, the time to make judgment involving those concepts also increases (Klimesch, 1994).

Collins and Quillian (1969) viewed the entries of concepts in semantic memory as being nodes in a network. In other words, the structure of semantic memory is known as a *network*. Network means "an interrelated set of concepts or interrelated body of knowledge" (Ashcraft, 2002, p. 252). Each concept in the network is represented as a node and it means "a point or location in the semantic space" (Ashcraft, 2002, p. 252). Furthermore, concept nodes are linked together by *pathways* which means "labeled, directional associations between concepts" (Ashcraft, 2002, p. 252). The entire collection of nodes is connected to other nodes by pathways to form a network. In this organised structure the pathways can be traced between two concepts and nodes. The semantic network is consisted of a network of interrelated sets of concepts or items of knowledge, pathways between these nodes.

According to Bruning *et al.* (1995), when memory is searched, activation moves along the links from the node that has been stimulated. Collins and Quillian (1969) argued that semantic memory is organised as a *hierarchical network.* In problem solving, if an hierarchical arrangement is present, then semantic distance may well depend on how much up one set of links the person has to move to find another hierarchy which contains the relevant information to be connected. This will clearly affect the speed by which connections are made and, indeed, whether a connection can be made at all if the two nodes to be linked are too far apart semantically.

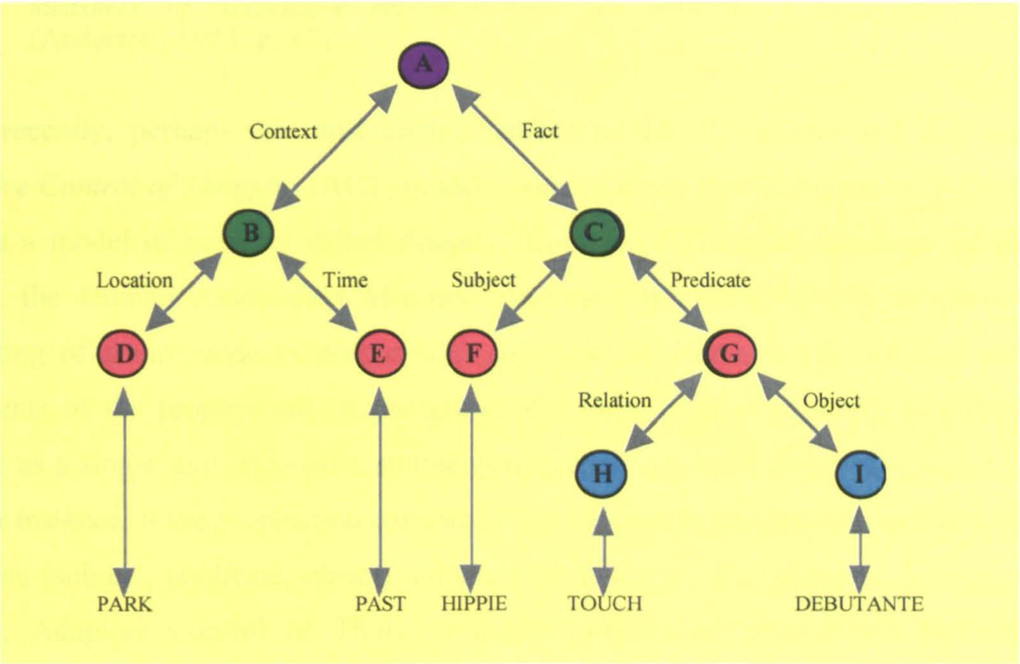
Taking a different approach, Anderson and Bower (1973) proposed a model called *Human Association Memory* (HAM). They suggested that long term memory is taking a large collection of memory locations and labeled associations. The basic unit in Human Association Memory's framework is a *proposition.* This unit consists of four types of associations:

(1)	Context-fact: It is about what happened to the information and in what context it happened.
(2)	Location-time: It specifies "when" and "where" of the context.
(3)	Subject-predicate: The subject tells who or what the fact is about and the predicate tells what happened to the subject.
(4)	Relation-object: It specifies the nature of the predicate.

The junctions formed from associations between inputs are abstract entities called nodes. *Terminal nodes* are served to anchor a proposition in long term memory. In other words, they are actual memory locations between which associations are established; these locations can enter into any number of propositions. These propositions provide a powerful way of representing knowledge.

Human Association Memory is an attempt to find a corresponding stored proposition. When new information is presented, Human Association Memory encodes the input as a proposition. A new set of associations corresponding to the proposition is established in memory. If the inputs request information, the various associations found at the memory locations of the terminal nodes are examined to determine whether the desired information could be found (Figure 3.3). For example (it is introduced in a question form): *'Did the hippie in the park touch the debutante?'* The question will be presented as a proposition and then, search through the appropriate terminal nodes (Reynolds and Flagg, 1983).

Figure 3. 3 Tree diagram of HAM's propositional representation of the sentence
(Source: Reynolds and Flagg, 1983, p.187)



Collins and Loftus (1975) had been able to modify the original model. The new revised network model is called a *Spreading Activation* model (see page 42). Although the new model is still made up of nodes and *relations*, as network models, the hierarchical structure has been eliminated. In addition, the links may vary in type and in importance (Mayer, 1983).

- *Nodes: Conceptual representations (represent individual ideas).*
- *Links: Relationship representations (establish connections through learning- not all connections of equal strength).*
- e.g. Robin may have stronger association with "red breast" than early in spring.

Once a node is activated, activation spreads (in parallel fashion) along links to other closely related nodes. In problem solving, this suggests that once a node is activated, then the search goes on in numerous directions simultaneously, in an effort to find the required idea. Clearly, the person who can activate more pathways at the same time has an advantage in being able to find the required information. It is possible that such a person is one that would be described as a lateral thinker or divergent, or creative. Do such people have an advantage when faced with an open-ended problem?

The idea of activating nodes and pathways had been explored by Anderson 1983.

> *"Activation measures the likelihood that a particular piece of knowledge will be useful at a particular moment. It is a reasonable heuristic that knowledge associated with what we are processing is likely to be relevant to that processing. Spreading activation is a parallel mechanism for spreading measures of associative relevance over the network of knowledge."* (Anderson, 1983, p. 87)

More recently, perhaps the most comprehensive model of memory and cognition is *Adaptive Control of Thoughts* (ACT) model (Bruning *et al.*, 1995). Anderson (1976;1983) created a model of memory called Adaptive Control of Thoughts based on the earlier model, the Human Association Memory. Anderson proposed a basic cognitive unit consisting of a unit node (a proposition) and a set of elements (the relation and the arguments of the proposition). A paragraph of a large number of words is difficult to encode as a single unit. However, simple sentences or a pair of associative words could be. For instance, if the proposition consists of three elements and they are encoded, all the elements (subject, predicate, object) are encoded as a unit. According to Bruning *et al.* (1995), Adaptive Control of Thoughts model consists of propositions that can be cognitive units, such as words and images. Also, they argued that:

> *"The size of the cognitive unit may vary, but generally the upper limit of the number of elements that can be encoded with any cognitive unit is five or fewer."* (Bruning *et al.*, 1995)

According to network models of memory, nodes represent concepts and links represent relations between concepts to form propositions. The propositions represent general thoughts that people have experienced (rather than specific pieces of information). For example, the meaning of sentences presented in classrooms may be recalled well, but the exact wording may be forgotten. Adaptive Control of Thoughts assumes that the strength of the links varies based on the use of links, which is why it is *adaptive*. Central concepts are superset nodes as are general ideas/categories, while peripheral concepts such as sub nodes are specific instances of those ideas/categories (e.g. *sparrow* is a peripheral of the central *bird*) (Anderson, 2000).

In Bruning *et al.* (1995), the concept of *spreading activation* is taken to be a key feature in Adaptive Control of Thoughts. The activation point begins with focus units. Once focus units are activated; either externally from perception (e.g. by reading a sentence) or from working memory (e.g. by thinking about what has been read), activation spreads to associated elements. They asserted that the "attention determines the continued activation of the network; when the source of activation for the focus unit drops from attention, activation decays" (Bruning *et al.,* 1995, p. 71). Anderson pointed out that working memory and long term memory overlap extensively. Activation can spread from working memory to associated elements in long term memory. Also, they argued that activation is a "cumulative" process. The Adaptive Control of Thoughts model implies that more activation occurs on paths leading to stronger nodes. The more units are activated, the more likely an item will be retrieved. This model predicts that "students who are helped to relate new information to existing, well-learned knowledge will have superior recall" (Bruning *et al.,* 1995, p. 71). In very recent work (Hindal, 2005), it has been found that those with greatest number of potential pathways do in fact recall better.

This has considerable implications for problem solving. It can be suggested that the successful problem solver may possess and be able to use more links and thus has a greater chance of making the right connections in order to solve the problem. However, the key to having these useful and accessible links may well lie in the previous learning which has taken place. If knowledge has been stored in a meaningful way in that new knowledge is linked in multiple ways with previously held understandings, then the number of links will be large. Successful problem solving will thus be enhanced.

One of the key issues is how activation takes place and how it is transmitted in memory. The activation flows from a source and sets up levels of activation throughout the associative network. Various nodes can become sources and there are three ways in which an element can become a source of activation in working memory. A node may be activated directly by the question posed. A specified goal may activate a node which represents the task to be accomplished. Of course, one node may activate an adjacent node if the link between them is a possible useful pathway.

According to the Spreading Activation model the activation of a node spreads through the adjacent nodes for several hundred milliseconds. Then it is actively inhibited if it fails to meet its target (Spitzer, 1999). The spreading activation may be triggered by a single word. This causes words of related meanings to become active as well. Because of this activation, subjects are increasingly likely to use associated words and detect them more easily. For example, when a subject is asked about word *white*, activation spreads to some extent to the word *black*. Hence, the word *black* is recognised comparatively faster. Similarly, we store similar words (*table-chair*) and opposite words (*black-white*) close to each other. So that, whenever one of these words is activated, the other becomes active too (Spitzer, 1999).

According to Anderson (2000), activating a concept is the result of bringing that concept to mind. Once the concept is activated. The activation spreads to other concepts that are linked to it. Links that are used more frequently are stronger, so activation spreads down them easily. However, if there are more links from a concept to related concepts, then there will be less activation passed from that concept to any one of other concepts. The increase or decrease of activation results from the number of links. Adaptive Control of Thoughts suggests that more links would result in less activation to any of the linked concepts than if there are fewer links. Thus, the time to recognise a concept should be longer with more links than fewer.

For problem solving, if the nodes which have to be linked are far apart then as activation declines with distance, then the goal node may not be reached. There may well be an attitudinal or motivational factor at work as well. If the first attempt fails to make the necessary connection, the more committed person may (consciously or subconsciously) keep on trying while the less motivated may give up. Confidence may also play a part in this process.

Looking back at section 3.3, the *Connectionist Model* is one in which the nodes and links are represented as neurons and synapses, as in the human nervous system. This model was proposed (Hinton and Anderson, 1989; McClelland *et al.*, 1986) to represent processes ranging from perception to motor control. Anderson was interested in how the human brain manages to store large amounts of information (Shanks, 1997). McClelland *et al.* (1986) contended that the brain has an architecture that better fits a natural information system. The model is concerned with "ways of connecting neural elements together to account for higher-level cognition" (Anderson, 2000, p. 31).

Connectionist Models are often called *Parallel Distributed Processing* (PDP) models. They are computer-based techniques for modeling complex systems. A fundamental principle of Connectionist Models is that "the simple nodes or units that make up the system are interconnected" (Ashcraft, 2002, p. 69). All types of knowledge (simple-complex) are represented as simple interconnected units. The connection between units can be excitatory or inhibitory. Positive or negative activation is transmitted as a pattern from one unit to another. According to McClelland (1988), the major difference between a model such as Parallel Distributed Processing and other cognitive models is that in most models the knowledge is "stored as a static copy of a pattern" (Bruning *et al.*, 1995, p. 75). When access is needed, the pattern is found in long term memory and copied into working memory. In Parallel Distributed Processing, however, the units themselves are not stored. There is no one place where the idea "dog" may be found. Instead the pattern of connection strengths encodes both the semantic categories and the connections between them. "These connection strengths allow the patterns to be re-created when the system is activated" (Bruning *et al.*, 1995, p. 75). If the processing is parallel it can proceed simultaneously in many directions.

It seems likely that network models of semantic memory give a good picture of the brain's processing of information in terms of nodes and links. The focus in Parallel Distributed Processing models is not on nodes of knowledge and connecting links between these nodes. The model emphasises the actual neurons and synapses and tries to incorporate semi-realistic assumptions about how they operate. In a sense, the architecture is there and the knowledge is activated on to the structure. This would suggest that the person who can make links quickly and efficiently does so because the brain architecture is more effective: better links, more links, perhaps. This might imply that the divergent person is divergent because of brain architecture, that the lateral thinker is so because of brain architecture and so on. In the same way, if the number of links and their accessibility (based on brain architecture) is what makes a person a good problem solver, then the skill is more or less fixed genetically. Problem solving cannot really be taught if the accessibility of links is the key factor.

In an interesting piece of work, Otis (2001) did find some evidence in the drawing of Concept Maps that the number of nodes and links was close to a constant for the same person even when working in very different topics. Clearly, 'brain architecture' (to be developed further in chapter 5) is important although it is unlikely that this is the determining factor to the extent that problem-solving skills cannot be developed. Here is an adapted figure from Otis (2001, p. 110) work. This Figure (3.4) summarises the network representation of semantic categories as a map that exhibits branching pattern that is consistent in any individual mind. The top part of the figure shows the pattern of knowledge in the brain according to the accumulating of knowledge exhibited by an individual which is shown as different levels while the lower part shows an example of that pattern.

Figure 3.4 **Semantic network / branching pattern of nodes and links**

(Source: Adapted from Otis, 2001, p. 110)

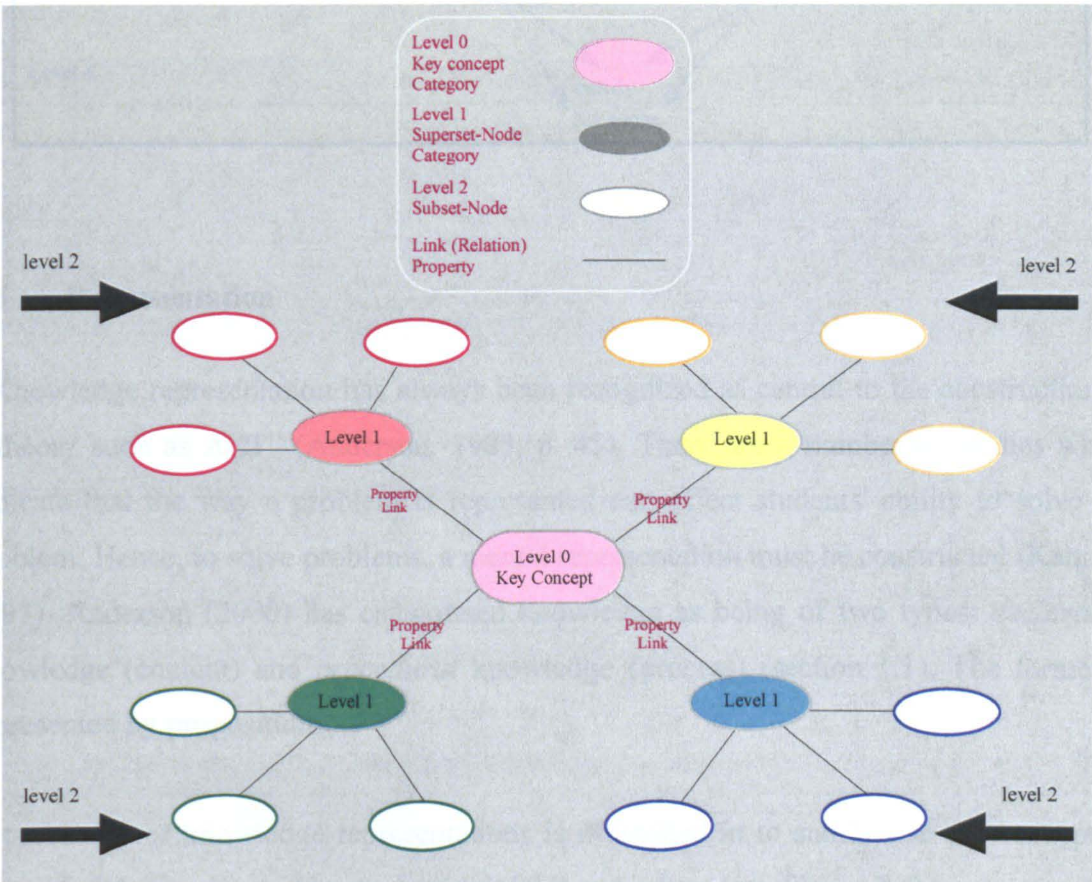
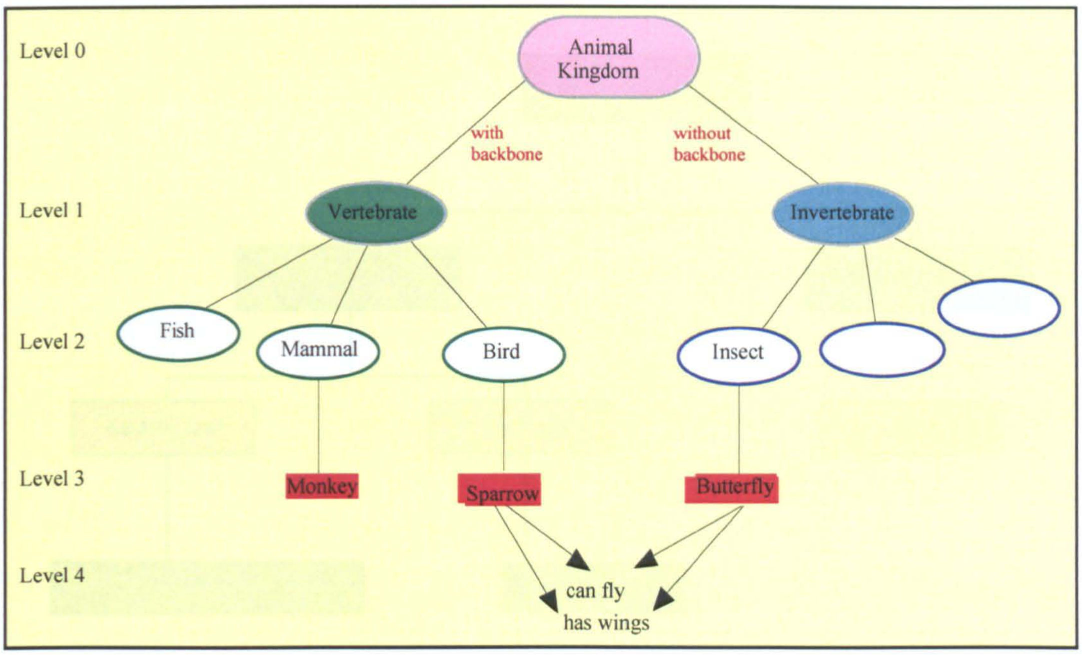


Figure 3.5 illustrates an example of the network representation of semantic categories of animal kingdom.

Figure 3.5 Semantic network for animal kingdom



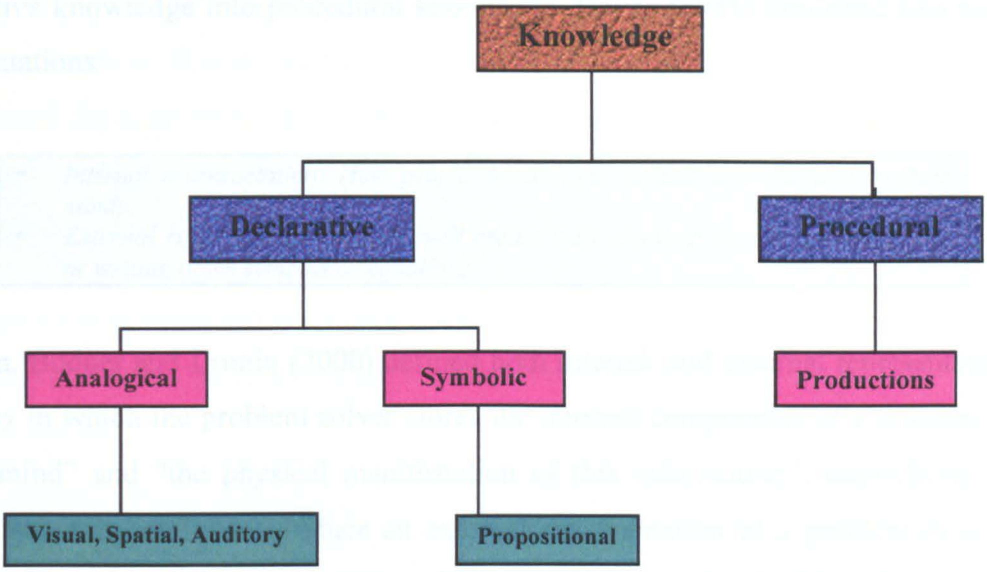
3.6 Representation

"Knowledge representation has always been recognized as central to the construction of a theory such as ACT" (Anderson, 1983, p. 45). There are a number of studies which indicate that the way a problem is represented can affect students' ability to solve the problem. Hence, to solve problems, a mental representation must be constructed (Kahney, 1993). Anderson (2000) has categorised knowledge as being of two types: *declarative* knowledge (content) and *procedural* knowledge (process) (section 1.1). The former is represented by propositions.

A taxonomy of knowledge representations is illustrated in to summarise the conceptual framework being adopted by Anderson (1983) and others (see Figure 3.6).

Figure 3. 6 **A taxonomy of knowledge representations**

(Source: McNamara, 1994, p. 87)



In this taxonomy, declarative knowledge can be represented in two ways:

Analogical representation: This is used to "preserve properties of objects and events in an intrinsic manner" (McNamara, 1994). For example, shapes of birds represented by schematic "silhouettes" as shown in Figure 3.7. This is to preserve visually distinctive properties of birds in a concrete way.

Figure 3. 7 **Picture of a bird**

(Source: Adapted from McNamara, 1994, p. 88)

Symbolic representation: This is used to "preserve structure extrinsically". That means all the necessary structure is built in an explicit way (McNamara, 1994).

Conceptual understanding helps problem solvers to develop a meaningful representation of the problem. Also, it helps to limit the search for solutions by balancing between what they know and how to solve problems. According to Anderson (1995), learners start with some declarative information in a certain domain, and then essentially they convert their declarative knowledge into procedural knowledge. Hayes (1981) described two types of representations:

- *Internal representation: How people develop the objects and relations in their minds.*
- *External representation: People will create it by drawing sketches or diagrams, or writing down symbols or equations.*

Later on, Bodner and Domin (2000) defined both internal and external representations as "the way in which the problem solver stores the internal components of a problem in his or her mind" and "the physical manifestation of this information", respectively. They argued that it is helpful to produce an external representation of a problem in order to solve it. They found that a significant difference between successful and unsuccessful problem solvers is the number and ways of representations used during attempts to solve a problem. This can be enhanced by encouraging problem solvers to use symbolic representations as well as verbal ones.

The representations of knowledge by a web or a network in network models of memory are hypothesised to consist of nodes. These nodes comprise cognitive units (known as concepts or schemata). Having the links is another advantage which are used to represent the relationships between these cognitive units (Bruning *et al.,* 1995). McNamara (1994) stressed that "the concept of mental representation is as fundamental to cognitive psychology as force is to physics".

Rumelhart *et al.* (1972) pointed out some kinds of representative symbols in human long term memory. Under his assumption, there are three classes of information and they are all represented in the same memory format, they are:

(1) *Concept: Refers to ideas.*
(2) *Event: Is action-based, denoting scenario with its associated actors and objects.*
(3) *Episode: Is a series of events or actions.*

They are encoded in identical formats and completely "intermixed" in memory structure. "Together they form the total body of knowledge that the system has at any given time" (Rumelhart *et al*, 1972, p. 211). Rumelhart *et al* (1972) summarised some significant points relating to long term memory and its relationship with representation. The basic element of information in the memory network is the event, consisting of a set of nodes interconnected by a relation. A node is a functional cluster of information that represents a concept, event, or episode with any number of relations attached to it. Secondary nodes are derived from primary nodes. Relations between nodes are directed and labeled. Relational labels are the basic means of encoding logical or semantic functions which interconnect nodes.

Anderson (1983) proposed a tri-code theory of knowledge representation. This theory assumes that knowledge representation in long term memory is based on three different types of codes:

> *(1) A temporal string: Encodes the order of a set of items / records the run of events.*
> *(2) A spatial image: Encodes spatial configuration / represents visual knowledge.*
> *(3) Abstract proposition: Encodes meaning / represents semantic knowledge.*

Relating to tri-code theory, Anderson (1983, p. 47) proposed that there are five processes by which contents of working memory interact. Similar process also is taking place in long term memory:

> *(1) Encoding process: Deposits representations of the environment into working memory.*
> *(2) Storage process: Deposits permanent records of temporary working memory information into declarative memory.*
> *(3) Retrieval process: Brings these records back into working memory.*
> *(4) Match process: Selects productions to apply according to the contents of working memory.*
> *(5) Execution process: Creates new working memory structures through production actions.*

He believed that the encoding process deposits representations of the environment into working memory. Then,

> *"...the storage process deposits permanent records of temporary Working Memory information into declarative memory. The retrieval process brings these records back into Working Memory. The match process selects productions to apply according to the contents of Working Memory. Finally, the execution process creates new Working Memory Structures through production action."* (Anderson, 1983, p. 47)

In order to solve a problem, there has to be a realisation of the existence of the problem and knowing where you are now and where you would like to be. Then, to reach the *goals* there are procedures or *operators* should be mastered. These operators often have *restrictions* on them (Reynolds and Flagg, 1983). A problem representation includes four kinds of information:

(1) Initial state;
(2) Goal;
(3) Operators;
(4) Restrictions on the operators.

The encoding processes have enormous implications for successful problem solving. If the information and the skills are encoded in such a way and the key features of the presented problem activate the codes, then the access to the information and skills will be easy. Thus, if the language and presentation of a problem is set in terms which are familiar to the student in that previous learning has been conducted in a similar way, then access to the information may be rapid. The problem information is coded in a similar way to previously held information and experience. This may explain what Yang observed (Reid and Yang, 2002b). She found that school pupils faced their first problem with trepidation and uncertainty, even although it was straightforward. When they faced their next problem, they moved forward with confidence in that the presentation, format, and style were now familiar. Was it possible that the first problem offered an experience of related to previously held knowledge and, once coding system was established, further problem solving went forward more rapidly? Yang offered other explanations which were quite reasonable, mostly set in terms of pupil confidence and trust.

In conclusion, it is necessary for learners to construct a meaningful representation in order to bridge gaps between the knowledge and the way of representing that knowledge.

3.7 Chunking, Clustering and Organisation

> *"Another vitally important piece of the storage puzzle involves the role organization, the structuring or restructuring of information as it is being stored in memory."* (Ashcraft, 2002, p. 222)

The above quotation shows the importance of organisation of knowledge in memory. Well organised information in memory can be stored and recalled easily. Also, "one of the best ways to learn new material or to help someone else learn it is to organize it" (Bourne *et al.* 1979, p. 55). Organisation means trying to fit the new knowledge with preexisting knowledge in a logical framework. Organisation is defined by Ashcraft (2002, p. 545) as:

> *"The tendency to impose some form of grouping or clustering on information being stored in or retrieved from memory, related to chunking or grouping in short term memory."*

Bourne *et al.* (1979) simplified this in a following example: if someone is trying to improve a recall of pairs of objects by imagining a mental picture. Then, the two objects are interacting with each other to form a certain image or picture.

In the Ashcraft (2002) argument, researchers realised that category groupings are another form of chunks of information (similar to Miller's findings). The *clustering* of information is relating to the capacity of short term memory and these information transfer as chunks into long term memory. As a result, the clustering is powerful recoding strategy "making mass of information memorable" (Ashcraft, 2002, p. 224). For instance, items like *dog*, *cat*, and *cow* can be grouped together into chunk category named *animal* serving as a *code* for that chunk.

Ashcraft (2002) defined the chunk and clustering consequently as a "unit or grouping of information held in short term memory" (p. 540), and "the grouping together of related items during recall (e.g. recalling the words *apple, pear, banana, orange* together in cluster, regardless of their order of presentation" (p. 545).

> *"A related and probably better measure of mental capacity, however, is the ability to remember symbols in sequence."* (Bruning *et al.*, 1995, p. 50)

In conclusion, the importance for efficient and effective learning of knowledge organisation in long term memory is very great. The long term memory has infinite capacity but the key is to organise the knowledge held in such a way that it can be recalled and used when needed. In problem solving, the student is faced with a situation and some information. The student has to search through long term memory for points of recognition, for relevant information and/or skills. The way the long term memory is organised in terms of information storage is critical in making that search effective.

3.8 Encoding

> *"Memory depends on the nature of the subject's perceptual and cognitive analyses of the stimulus, and the deeper and the more elaborate these analyses are, the better retention."* (Kintsch, 1974, p. 229)

The terms encoding and retrieval have their origins in information processing framework in the 1960s. They characterise the human mind as information processing devices (Brown and Craik, 2000). Brown and Craik (2000) defined these terms as a "process of acquiring information or placing it into memory" and "process of recovering previously encoded information", respectively (p. 93). Encoding or representing a problem are terms which refer to the "transformation of sensory information into a certain format of a memory representation, resulting in the formation of a memory code" (Klimesch, 1994, p. 3). The form, composition, and structure of internal representation is known as coding format. Coding is considered as a process of transformation that reflects different stages of information processes, such as perception, recognition, and selective attention. "It becomes clear that memory can be described only if empirically validated assumptions regarding the entire information processing system are made" (Klimesch, 1994, p. 3).

Thinking of the flow process of information, Brown and Craik (2000) asserted that the "key to successful encoding in this model is attention" (p. 94). Of course, this involves the simple process of paying attention. However, rehearsal of information assists as well.

> *"It seems likely that our memory for personally experience events, along with accrued knowledge and skilled procedures, must ultimately be represented in the brain by complex networks of neurons"* (Brown and Craik, 2000, p. 94).

Brown and Craik (2000) assumed that when a particular network is active, we *re-experience* the event or *re-collect* the fact. Klimesch (1994) assumed that structures stored in long term memory are used to identify sensory information. As a result of this, there is a close interaction between long term memory and sensory memory. Hence, the sensory codes and long term memory structures used in stimulus identification must have a compatible encoding format. However, cognitive psychology was concerned with the study of different stages of information processing. These studies led to the important discovery: before a stimulus can be recognised, it must undergo a complex sequence of perceptual encoding processes. Thus, at different levels of processing different coding formats must take place (Klimesch, 1994).

Semantic information is synonymous with the deepest level of encoding in memory and it is a store for meaningful information. According to Rumelhart *et al.* (1972), semantic memory comprises our permanent knowledge on language and all different aspects of general knowledge.

Of course, knowledge can be stored in such a way that the nodes are highly interlinked. It is also possible to store items of knowledge in an isolated way and recall and subsequent use may be very difficult.

Inter-connectedness is a general principle for the encoding of semantic information in long term memory. Each node is represented not in isolation from, but instead in direct relation to, other codes in long term memory. The more links there are between codes, the better the information contained in these codes can be integrated into long term memory. Integrated facts can be best represented by interconnected structures, whereas non-integrated (isolated) facts are best represented by hierarchical structures (Klimesch, 1994).

According to Klimesch (1994), when the following four criteria have been met there is efficient storage:

- *Each piece of information may only be stored at one location in memory.*
- *The information relevant to the goal of the search process must be quickly retrievable.*
- *It should be possible either to form connections between relevant pieces of information easily, or these should already exist.*
- *The speed of the search process may not be systematically decreased with an increasing amount of permanently stored information.*

The semantic code of a word must reveal a specific access point in semantic memory. This specific access is termed concept node. The meaning of a word is not represented by the concept node itself, but by the structure of semantic features to which the concept node gives access. The type, number, and structure of semantic features are, therefore, the crucial variables in the encoding of word meaning. It is clear that concept nodes serve to access the meaning of a word in semantic memory and vice versa.

The implications for problem solving are immense. If the problem statement activates the correct nodes in long term memory, the search for relevant links to lead to a problem solution can follow. If, however, the way the problem is stated does not permit the activation of the appropriate nodes in the right way, problem solution is unlikely. This might offer an explanation as to why problem solving in educational setting is so often unsuccessful.

3.9 The Human Information Processing System

The ideas of information processing have frequently been quoted in relating to problem solving. It is now appropriate to look at information processing and problem solving can be seen in the context of an information processing system.

> *"...although Piaget's work and that which has sprung from it leaves a number of unresolved theoretical and methodological problems, it provides an important background from which to make substantial progress toward a more significant educational objective."* (Lawson, 1985, cited by Niaz, 1993)

For the last 25 years, Piaget's theory of cognitive development has been applied broadly in science education (Niaz, 1993). This is to encourage students to obtain thinking skills and to develop their problem-solving skills. In order to improve students' ability to solve problems, the role of memory should be appreciated by the students. There are two components of memory: working memory and long term memory. The aim here is to focus on long term memory and how it is involved in the problem-solving process. Simon (1978) stated that problem solving is greatly influenced by properties of learners view as information processing systems. These properties are: capacity of working memory, and the amount of time involved in storage and retrieval processes in long term memory.

> *"The idea that memory might not be a single monolithic system but might have two or more components have been current for many years. Willaim James for example used the term primary memory to refer to the specious present, those percepts and ideas that are simultaneously present in the mind, even though they may have happened a few seconds before, and are hence no longer physically present."* (Baddeley, 1986, p. 3)

Higbee (1977) viewed the process of remembering as going through three stages and referred them to as the "Three R's Remembering" (Higbee, 1977, p. 12):

- *Recording or acquisition: Learning the material in the first place.*
- *Retaining or storage: Keeping the material until it is needed.*
- *Retrieving: Getting the material back out when it is needed.*

His view foreshadowed later ideas. As long ago as 1974, Kintsch highlighted the major differences between short term memory and long term memory in terms of some categories as in Table 3.1:

Table 3. 1 Major differences between short term memory and long term memory

	Short term memory **Primary**	*Long term memory* **Secondary**
Information	*Has never left consciousness*	*Has been absent from consciousness for some time*
Recall	*Is easy and effortless*	*Active search process*
Capacity	*Short limited*	*Unlimited*
Trace	*Active*	*Structural*
Decay	*Autonomous*	*Last forever*

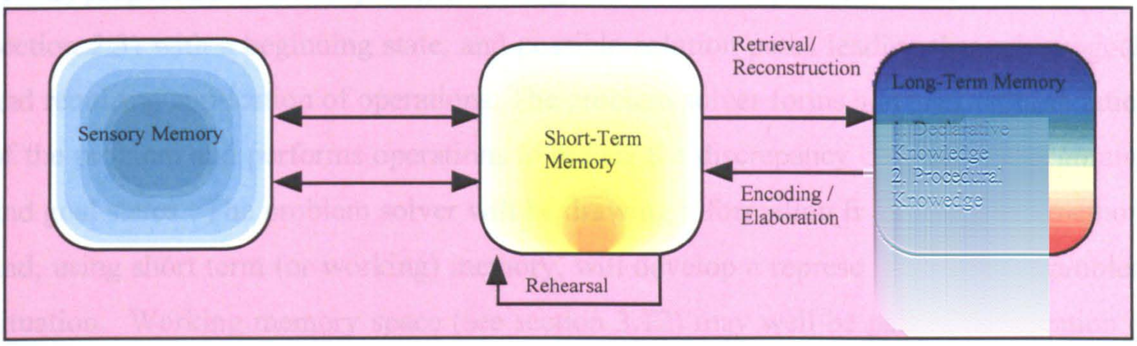
Higbee (1977) attempted to illustrate the memory as a *"filing cabinet*". Short term memory is like the "*in-basket"* on an office desk (p. 17). On the other hand, long term memory is like the "*large file cabinets"* in the office. The in-basket has a limited capacity; it can only hold so much, and then has to be emptied to make room for more. Some of what is taken out is thrown away and some is put into the "file cabinets" without first going through the in-basket.

> *"Similarly, information goes through short-term memory to reach long-term memory. This makes short-term memory the bottleneck in storing information. Not only does short-term memory have a limited capacity, but information In short-term memory must be coded in some way to be transferred to long-term memory. This coding takes time, which limits the amount of information that can be sent into long-term memory in a given period."* (Higbee, 1977, p.17)

Despite the appearance of the notion of short term memory in the early 1970s, this idea had been suggested by Atkinson and Shiffrin (1968) and this, in turn, originated from Broadbent's work in 1958 and the Modal Model (Baddeley;1986). Baddeley (1986) assumed that short term memory plays a part in selecting learning strategies and in maintaining and operating strategies for retrieval from long term memory. The short term memory is more capable of controlling processes and strategies, while long term memory relies more on semantic coding. These differences in processing such information triggered the notion of the Modal Model (see Figure 3.8).

Figure 3. 8 The Modal Model

(Source: Bruning *et al.*, 1995, p. 49)

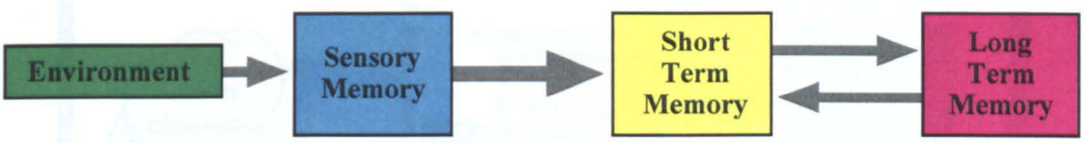


A number of different psychologists have advanced the theory of how human memory system operates in one form or another. The theory has been described in its most complete form by Atkinson and Shiffrin (1968;1971). The common feature of that Model (e.g. Atkinson and Shiffrin, 1968) is known as Information Processing Model (IPM). According to this model, memory is divided into three major categories of information storage (Bruning *et al.*, 1995):

(1) Sensory memory;
(2) Short term memory (working memory);
(3) Long term memory.

Figure 3.9 Human Information Processing (schematically)

(Source: Bourne *et al.*, 1979, p. 30)



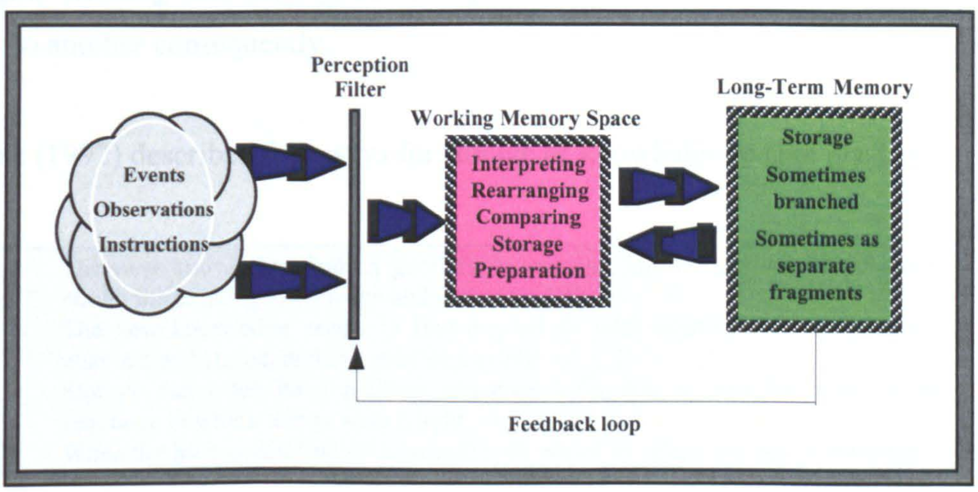
In looking at Figure 3.9, stimuli from the world around enter through sense receptors (e.g. eyes, ears). Visual or auditory stimuli are analysed in a sensory memory for a very short time. They may be passed to what is often called the short term memory. This has a very limited capacity but can hold information for a little longer. In order to hold the information for longer it is possible for a person to repeat it or rehearse it. This requires a willingness to give careful attention to the information. Interruption may cause loss of information. Finally, the information may be passed to long term memory as the 'permanent respository' (Bruning *et al.*, 1995, p. 53).

In the early days of information processing theory and research, Newell and Simon (1972) proposed a model of problem solving that involves a problem space (see chapter 2, section 2.3) with a beginning state, and possible solution paths leading through subgoals and requiring application of operations. The problem solver forms a mental representation of the problem and performs operations to reduce the discrepancy between the beginning and goal states. The problem solver will be drawing information from long term memory and, using short term (or working) memory, will develop a representation of the problem situation. Working memory space (see section 3.12) may well be part of the creation of the problem space.

3.10 The Information Processing Model

Information processing models have been developed primarily as ways to rationalise the observations which have been made about the way humans learn. Success in problem solving will also depend on how learning has taken place, and, if problem solving is seen as a particular aspect of learning, then information processing will offer useful insights on the process. The model of Johnstone (1992) has proved particularly useful in science education (see Figure 3.10).

Figure 3.10 **An Information Processing Model**
(Source: Johnstone, 1992)



> *"The information passing this perceptual filter passes on into a conscious working space where it is interpreted, rearranged, amplified from LTM and then prepared for storage in LTM or for elimination. This working space is of limited capacity and so can process only a few ideas at any one time. The processed information is stored in LTM and this storage is most efficient if the new material is linked to that existing in LTM to form a branched network which can be accessed in several ways."* (Johnstone, 1992)

One of the most recent and effective models proposed by Johnstone (1992) draws in ideas from Piaget's stage theory and Ausubel's importance of prior knowledge in meaningful learning, Gagné's learning hierarchy, and Pascual-Leone's idea of limited space related to age (Danili, 2004). This model emphases the process of learning and the learner and the understanding the limitations of learning.

Interpreting all reactions in the environment through our senses is not an easy task. An individual will select from all the information reaching them. The basis of selection may depend on previous knowledge, biases, prejudices, preferences, likes, dislikes, and of course beliefs – all held in long term memory. Information is handled in two ways: either rejected or stored. Working memory (working memory space) holds this information and manipulates them. The working memory space has two functions as stated by Johnstone (1992):

> *(1) "It is the conscious part of the mind that is holding ideas and facts while it thinks about them.*
>
> *(2) It is a shared holding and thinking space where new information coming through the filter consciously interacts with itself and with information drawn from long term memory store in order to make sense."*

Figure 3.10 shows the key characteristics emphasised by Ashcraft (1994). This model makes such predictions about how input information is dealt within the human's mind so meaningful learning can take place. It represents the flow of information from one memory to another consequently.

Johnstone (1992) described four ways for storage of knowledge to take place as:

- The new knowledge finds a good fit to existing knowledge and is merged to enrich the existing knowledge and understanding.
- The new knowledge seems to find a good fit with existing knowledge and is attached and stored, and this may be a misfit.
- Storage can often have a linear sequence built into it, and that may be the sequence in which things were taught.
- When the learner can find no connection on which to attach the new knowledge.

Each part of the information processing system is now described briefly in the following sections.

3.11 Sensory Memory

The sensory memory is also known as the perception filter. "The process by which we select information is referred to as perception" (Danili, 2004). Sensory memory consists of *sensory registers*. Two important features characterise these: high storage capacity, and extremely short storage duration roughly 200-300 millisecond (Klimesch, 1994). These are linked to the five senses: sight, hearing, taste, touch, and smell. Through them we interact with our environment to receive information from it (Chen, 2004). Ashcraft (1994) illustrated two types of sensory memory: visual sensory memory and the auditory sensory memory.

Neisser (1967) called the former one *iconic* memory, and the second one *echoic* memory. Information can be held for one quarter to one half of a second in iconic memory while, in echoic memory, it is held no more than two or three seconds (Ashcraft, 1994).

3.12 Working Memory (Short Term Memory)

The working memory acts as a "scratch-pad" for temporary recall of information under process (anon, undated). For instance, in order to understand this sentence a person needs to hold in mind the beginning of the sentence as the rest is read. Short term memory decays rapidly (200 millisecond) and also has a limited capacity: 7±2 units (or *chunks*) of information at any time. Chunking of information can lead to an increase in the short term memory capacity. This is the process by which several pieces of information are grouped together so that they are handled as one piece. Both descriptions (working memory and short term memory) are used in the literature. When the holding and recall of information is being considered, the phrase, short term memory is adequate. However, the phrase, working memory emphasises its dual role in both holding and processing information.

> *"... shared holding/thinking space which is known as working memory. Each subject is assumed to have a certain working-memory capacity, X. On the other hand, each problem is attributed a Z-demand. The importance of a limited stored space, the so-called short-term memory."* (Tsaparli, 1998)

Johntone had argued for a working memory overload hypothesis which subsequent evidence supported (Johnstone 1984; Johnstone and El-Banna, 1986;1989). This argued that, for any learner to solve a problem, the Z-demand has to be less or equal to the learner's X-capacity. Later on, Pascual-Leone's neo-Piagetian theory (1970) called working memory capacity/space X (mental capacity) as M-capacity or M-space. It is the 'space' where a person handles information, thinks, and solves problems. It is importance in problem solving must not be underestimated in that its limited capacity is well known as a rate determining aspect of learning and assessment (see Johnstone, 1997)

Research showed that capacity limitation of working memory has a great impact on problem-solving process (Stamovlasis and Tsaparlis, 2003). The working memory overload hypothesis of Johnstone and El-Banna (1986;1989) is regarded as a predictive model for problem solving. It is based on Pascual-Leone's M-Space (mental capacity) theory (1970) as a fundamental of working memory theory. Zoller (1993) considered problem solving one of the most important outcomes of good teaching as a high-order-cognitive skill (HOCS). Baddeley (1986), Johnstone and El-Banna (1986) named the shared holding/thinking space as a working memory on the basis that each person has a specific working memory capacity (Tsaparlis, 1998).

Bruning *et al.* (1995, p. 49) stated that "perhaps the most striking feature of short term memory is its limitations, especially its fragility and capacity". Short term memory is often dependent on rehearsal and repetition of information. This simply means that the capacity of short term memory is limited to a few chunks of information processing (Bruning *et al.*, 1995). Miller (1956) defined a chunk as "any stimulus (e.g. letter, number, word, phrase) that has become unitised through previous experience". Ashcraft (2002) pointed out that short term memory cannot encode huge amounts of new information accurately. Instead, there is severe limitation on encoding, holding, and reporting information immediately. Although Miller (1956) found that 7±2 is the capacity of this memory space, it has been estimated by Simon (1974) that working memory is really limited to about five chunks, where a chunk corresponds to anything that has become a meaningful unit of experience, leaving some space for processing.

Most adults have a working memory capacity lying between 5 and 9. Appears to be fixed genetically and is not open to development. It grows with age, reaching its maximum at around 16 years of age (Miller, 1956).

When stimuli and information pass through the perception filter (sensory memory), they pass into a working memory (see Figure 3.10). Information can also be drawn into working memory form long term memory. Here it is all manipulated before being either rejected or passed into long term memory to be stored (Bahar, 1999).

Kahney (1993) assumed that working memory capacity limits performance of problem solving in everyday life. He justified that in this statement "a solver may extend the capacity of short term memory by writing and referring to notes or intermediate results" (Kahney, 1993, p. 43) during problem solving. He added another way to reduce the load on working memory by having crucial amount of information stored in long term memory.

3.13 Long Term Memory

Long term memory is intended for storage of information over a long time. Information from the working memory is transferred to it after a few seconds. Unlike working memory, there is a little decay (anon, undated). Long term memory is a large store for facts are kept, concepts are developed and attitudes are formed (Johnstone *et al.*, 1994). It is ultimate distination for information a person wants to learn and remember. The memory system is responsible for storing information on a relatively permanent basis (Ashcraft, 1994). Dillon and Schmeck (1983, p. 204) defined long term memory as "where we store all the information we possess about the world – all that we know, but which is not in our immediate consciousness" while Ashcraft (2002) asserted that the long term memory is a "permanent memory store of general world knowledge".

Learning is a flow of information from perception to working memory. There, it is encoded and another further movement takes place in the form of chunks to be stored in long term memory and become available for further use. According to the Information Processing Model (Johnstone, 1992), 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 it provides information for working memory in order to process new information. Short term and long term memory are compared in Table 3.2.

Table 3. 2 **Additional differences between short term and long term memory**

Short term memory	*Long term memory*
Information --- enters quickly, is immediately accessible, is retained briefly (20 sec.), is easily disrupted, capacity is limited (5-9 items).	Information --- enters slowly, is not easily accessible, is retained indefinitely, is not easily disrupted, capacity is unlimited.

3.14 Types of Information in Long Term Memory

Having looked at how information is stored, the types of information to be stored are now considered.

> *"Psychological theories of human memory have been closely tied to one particular type of function: how people learn list of words. Yet the retention of a specific sequence of words is but one of the many demands that are placed on human memory. In fact, during the life of the average adult, rote memorization seems seldom to be required."* (Rumelhart *et al.*, 1972, p. 198)

Rumelhart *et al.* (1972) argued that long past events are not so much remembered as they are recreated. People can answer complicated questions about the information stored in long term memory. They use memory to solve problems, to make logical deductions, to understand ideas, and to memorise facts. Even when people learn lists of words, they attempt to recognise the input they encounter in terms of their past experience. This reflects the natural human tendency to look for meaning. Indeed, in taking information from the world around us, there is a continual attempt, either to see meaning or to create meaning. This may be sophisticated conceptual understanding.

Bourne *et al.* (1979) assumed that there are types of information retained in long term memory: semantic information and visual information. It had been argued that the dominant form of representation in long term memory is semantic and "picture-like codes" can be stored in long term memory. This example illustrates this:

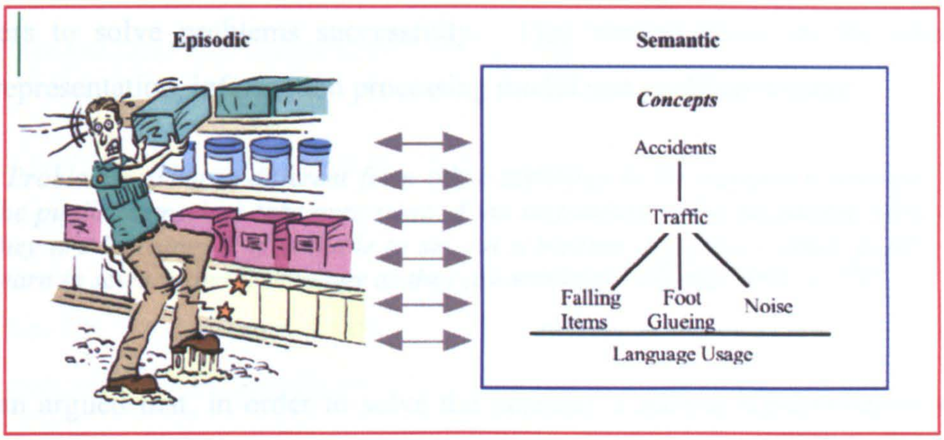
> *"Imagine going to your refrigerator for a drink; imagine opining the door; imagine reaching for a bottle of lemonade; now go to the freezer for an ice cube. Is the freezer compartment at the top or at the bottom? Are the ice trays on the left or on the right? You can practically "see" this in your mind's eye."* (Bourne *et al.*, 1979, p. 60)

Much earlier, in 1972, Tulving made distinctions between episodic and semantic memory (see Figure 3.9). In his words:

> *"Episodic memory receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events."* (Tulving, 1972, p. 385)

> *"Semantic memory is the memory necessary for the use of language. It is a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of these symbols, concepts, and relations."* (Tulving, 1972, p. 386)

Figure 3.11 Episodic and semantic memory are interdependent
(Source: Adapted from Bourne *et al.* 1979, p. 97)



Ashcraft (2002) presented two major types of long term memory: episodic memory and semantic memory. Episodic memory is "storage and retrieval of personally dated, autobiographical experiences" (Tulving, 1983, cited by Ashcraft, 2002, p. 54) and Ashcraft (2002) referred to it as "a personal, autobiographical store" whereas semantic memory is "where your knowledge of language and other conceptual information is stored" and it is "the permanent repository of information you use to comprehend and produce language, to reason, to solve problems, and to make decisions" (Ashcraft, 2002, p. 54).

It seems likely that problem solving is greatly influenced by the way of information being stored and retrieved. Therefore, it is likely that solving problems will be successful if nodes are linked in a right way.

3.15 Problem Solving, Representation and Information Processing Model

Sleet and Shannon (1988) indicated that representation of problems affects the ability of the learners to solve problems successfully. This section focus on the relationship between representation, information processing model and problem solving.

> *"Problem solving is different from other activities in the classroom because the pupils themselves take over some of the responsibility for organizing what they are learning. It is possible to set out a number of ways in which pupils learn in science and technology as they are working."* (Watts, 1991, p. 73)

It had been argued that, in order to solve the problem a *mental representation* must be constructed of the given problem information (Kahney, 1993). The information about the problem is taken in through the perception filter. This information is selected according to what the person already holds in long term memory. Indeed, the problem may be altered and re-interpreted by the person in the light of prior knowledge, attitudes or biases. Hunt (1994) found that problem solving is impossible if the problem solver does not have the right pattern to move from the original state to the goal state. He asserted that human problem solving will be effective when the problem is represented.

It is essential that the problem information taken in along with information drawn from long term memory does not overload the working memory space. The problem information in working memory will create cures so that the working memory can start searching long term memory for nodes which may be useful to solve the problem. If unhelpful information is taken in, then the working memory may overload or these unhelpful pieces of information may lead to nodes in long term memory which lead the person in the wrong direction.

Frequently, problem solving is described in terms of searching a problem space (see section 2.3) that contains various states of the problem. "A state is a representation of the problem in some degree of solution" (Anderson, 2000, p. 242). The initial situation of the problem solver is known as initial state. The situation is on the way to the goal state.

While the idea of working memory overload is easy to grasp and well documented (see Johnstone, 1997), the processes of search in the long term memory are much more intractable. According to tri-code theory view (see page 49), semantic encoding is the deepest form of encoding in human information processing. This means that knowledge stored in long term memory is structured alongside with semantic dimensions (Klimesch, 1994). If this is true, then it explains why understanding ideas taught leads to better recall of these ideas and their application in new circumstances.

To solve a problem, the problem solver must link the information given to the relevant nodes and links in long term memory. This can be helped by *external representations* which may be sketches, diagrams, or writing symbols or equations. Hayes (1981) assumed that the "external representations can't help us at all unless we also have an internal representation of the problem". However, Bodner and Domin (2000) pointed out that "encouraging students to use representations then solving the problem might therefore simply a way of helping them to recognise what information is important in generating the answer" to any question presenting to them.

When a person faces a problem, the situation is like any other aspect of learning. Information is offered and the person tries to make sense of the information by relating the information given to anything held in long term memory. The problem information and information drawn from nodes and links in long term memory are brought together (all at once, or in a series of stages) in working memory in an attempt to find a solution.

In very simple terms, the key steps influencing success might be listed as:

(1) Does the person take in all the relevant information, without taking in unnecessary detail?
(2) Has the person the appropriate nodes and links in long term memory that are relevant to the problem?
(3) Can the working memory cope with all the relevant information?

With complex problems, this series of questions might have to be applied several times.

The influence of working memory is well documented and the aim in this study is to focus on the long term memory and probe the factors which might influence the problem solver in being or becoming more successful. This will involve developing and using several ways to gain some information about the way nodes and links operate in long term memory, both in terms of the number of links and also the usability of these links. This will be related to certain features of cognitive styles.

Chapter Four

Thinking and Problem Solving

4.1 Introduction

> *"THINKING, LIKE ITS RELATED CONCEPTS 'intelligence' and 'consciousness', is something we are all itimately familiar with; and just like intelligence and consciousness, it can be hard to define."* (Roberston, 1999, p. 2)

Doing logic puzzles, solving geometry problems, trying to save a cat trapped under a car, all involve a degree of effortful thinking. Different problems require different types of thinking. Generally, dealing with unfamiliar problems is different from dealing with familiar ones. Furthermore, people vary in their ways of thinking. Some like doing crossword puzzles while others like making the crossword puzzles up. Some like problems with a definite answer while others like things to be open-ended. People face a variety of problems daily and deal with them in different ways. The aim of this chapter is to categorise the types of thinking used to cope with familiar and unfamiliar situations. Throughout this chapter a number of concepts are developed which focus on understanding what thinking is and its implications also. A distinction will be made between thinking and problem solving.

Everyday thinking tends to be effortless since it involves familiar problems. Unfamiliar problems require more effort. Thinking also, involves processing information. Some forms of thinking are effortful because they make great demands on the limited capacity of our processing systems (Roberston, 1999). Problem solving can be considered as *applied* thinking. However, there are another two forms of cognitive processing that are very interrelated to problem solving. These are creative thinking and critical thinking. Creative and critical thinking are essentially forms of *investigative* thinking which are very often involved in problem solving (Fisher, 1990). Depending on the nature of the problem, it may involve creative thinking (which seeks connections between previously unconnected ideas) or critical thinking (which looks at ideas in a fresh way).

The ability of students to apply their thinking to solve problems will be the key to some aspects of success in life. Indeed, problem-solving activities may be able to stimulate and develop skills of thinking and reasoning as learners use relevant knowledge of facts and make relationships between them. In general, being successful helps to develop confidence and capability. Problem solving activities not only promote knowledge, skills, and attitudes, they also provide teachers with opportunities to observe the learners' approach to problems and how they communicate and learn (Fisher, 1990).

Defining skills of thinking has been a difficult task for educators. In fact, terms that describe thinking skills often add to the confusion. Doherty and Evans (1990) observed that the reader can find many terms such as critical thinking, concept development, lateral thinking, cognitive thinking, creative thinking, divergent/convergent, problem solving, inductive and deductive thinking, and decision making. Educational psychologists have tackled the confusion of these terms by dividing thinking into two major categories: the cognitive and creative skills. The cognitive skills deal with the "manipulation of factual knowledge by the mind" while creative skills "transform an emotional expression into a variety of products" (Doherty and Evans, 1990, p. 22). However, this is a rather limited picture of creativity in that creative skills may be entirely cognitive and do not necessarily involve emotional expression.

Cropley (2001) argued that thinking involves:

> - *"**Structures** (internal representations of the external world such as patterns, categories, or networks) that are built up on the basis of information coming in from the outside;*
> - ***Processes** such as exploring, recognizing, organizing, interpreting, associating, and applying, through which this information is processed;*
> - ***Control mechanisms** such as perceptual styles, combinatorial tactics, decision making rules, or evaluation strategies that guide the processes and affect the kinds of structures they lead to."*
>
> (Cropley, 2001, p. 29)

Cognitive structures are internal representations of the external world. They reflect the accumulated experiences of the individual and are stored in memory. When people are being creative, they will be re-considering things they know and the relationships between them. In this, knowledge and links between knowledge are explored, until perhaps new links are developed to generate more ideas or understanding. In all of this, new links, structures, and processes may emerge.

4.2 Bloom's Taxonomy of Learning Objectives

Critical thinking theory found its roots primarily in the works of Bloom in the 1950s when he classified learning behaviours in the cognitive domain (Bloom 1956). Bloom developed a taxonomy of learning objectives for teachers, classifying learning behaviours according to six levels (see Table 4.1).

Table 4. 1 Bloom's Taxonomy of Learning Objectives
(Source: Bloom, 1956)

Level of Objectives	Learning Objectives	Definitions
Level I	***Knowledge***	Remembering and reciting of information.
Level II	***Comprehension***	Relating and organising previously learned information.
Level III	***Application***	Applying information according to a rule or principle in a specific situation.
Level IV	***Analysis***	Critical thinking, which focuses upon parts and their functionality in the whole.
Level V	***Synthesis***	Critical thinking that focuses upon putting parts together to form a new and original whole.
Level VI	***Evaluation***	Critical thinking that focuses upon valuing and making judgements based upon information.

In the 1990s, Anderson modified this taxonomy, largely by inverting the positions of synthesis and evaluation, renaming synthesising as 'creating' (Green, 2003). It was argued that creating comes after the evaluating stage because, according to Anderson, you can be critical without being creative but creating means you have to think critically in advance. Johnstone altered the model considerably by suggesting that knowledge is the underpinning of all the other five, these five not being in any hierarchical order (see Yang, 2000)

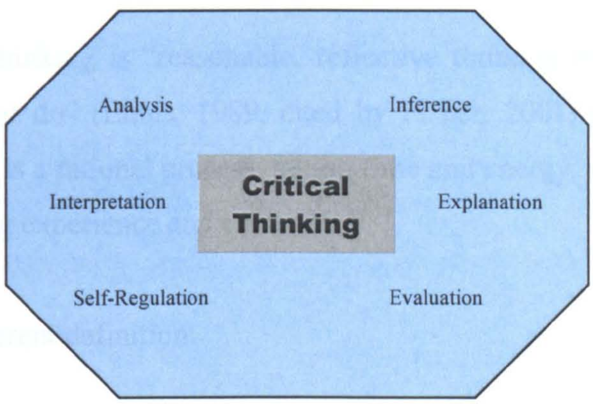
Doherty and Evans (1990) noted that, "the taxonomy was developed to aid communication among educators in developing goals, objectives, curriculum and evaluation of outcomes" (Doherty and Evans, 1990, p. 23). They then suggested that the six levels of Bloom's taxonomy comprise ten basic thinking skills descending from synthesis level (in Table 4.2 sections 7, 8, 9 & 10), and combinations of them define the thinking process (e.g. critical thinking skills, decision making skills, and problem solving).

Table 4. 2 **The basic thinking skills**
(Source: Doherty and Evans, 1990)

I.	Knowledge
II.	Comprehension
III.	Application
IV.	Analysis
V.	Synthesis
	7. Fluency
	8. Flexibility
	9. Originality
	10. Elaboration
VI.	Evaluation

In this, critical thinking might involve several thinking skills: perhaps analysis, flexibility, originality, elaboration, and evaluation. Finally, Facione (1998) described a core of skills that contribute to critical thinking (Figure 4.1), many of which derive from the work of Bloom.

Figure 4. 1 **Core critical thinking skills**
(Source : Facione, 1998)



4.3 Critical Thinking

> *"In recent years 'critical thinking' has become something of a 'buzz word' in educational circles. For many reasons, educators have become very interested in teaching 'thinking skills' of various kinds in contrast with teaching information and content."* (Fisher, 2001, p. 1)

It, of course, a laudable aim is to seek development of such skills. However, most students do not pick up the 'thinking skills' in question easily, or at all. The result is that many teachers are encouraged to teach these skills in a direct way or *explicitly*. There is an implication that such skills are transferable skills: skills like how to structure an argument, make a decision, and judge credibility of a source (Fisher, 2001).

For many years, teachers of critical thinking have been faced with a problem: there are numerous definitions of critical thinking: some emphasise context and world views', some focus on arguments and evidence (Hatcher, 2000). Fisher (2001) gathered some classic definitions from the critical thinking tradition and these are outlined briefly. Socrates began this approach to learning over 2,000 years ago, but Dewey is often regarded as the 'father' of the modern critical thinking tradition. He called it 'reflective thinking' and defined it as:

> *"Active, persistent, and careful consideration of a belief or supposed form of knowledge in the light of the grounds which support it and the further conclusions to which it tends."* (Dewey, 1909, cited by Fisher, 2001, p. 2)

The word 'active' is important. Being active that means the person has to be aware of what the question is implicitly offering. The opposite is 'passive' where the person accepts, without question, what others are offering. A feature of being active is that it takes time, effort, and the commitment to become involved personally, to be willing to weigh arguments, to question ideas, and generate alternative ways of looking at things.

Ennis stated that critical thinking is "reasonable, reflective thinking that is focused on deciding what to believe or do" (Ennis, 1989, cited by Fisher, 2001, p. 4). The whole process of critical thinking is a rational process, taking time and energy. It means bringing together ideas and weighing experience and evidence.

Paul gave a somewhat different definition:

> *"Mode of thinking – about any subject, content or problem – in which the thinker improves the quality of his or her thinking by skilfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them."* (Paul, 1993, cited by Fisher, 2001, p. 4)

In a sense, this is a way of developing one's critical thinking ability through 'thinking about one's thinking' (metacognition) (Fisher, 2001). However, the critical aspect is similar to the definitions of others in that the information being weighed is assessed against some kind of intellectual standard.

Scriven defined critical thinking as "skilled and active interpretation and evaluation of observations and communications, information and argumentation" (Scriven, 1997, cited by Fisher, 2001, p. 10). He pointed out that to be critical, thinking has to meet certain standards of clarity, relevance, reasonability, adequacy, coherence and so on. In other words, critical thinking is much concerned with evaluating the truth and reliability of arguments. Fisher considered 'observations' as an unusual feature. However, critical thinking requires such a feature to interpret and evaluate.

Briefly, critical thinking is to be contrasted with *unreflective* thinking. The unreflective thinking is a kind of thinking which occurs when someone jumps to a conclusion, or accepts some evidence, claim or decision without real or deep thinking about it. Critical thinking requires the interpretation and evaluation of observations, communications and other sources of information, set against some standards. It also requires skills in thinking about assumptions, questioning, and drawing out some implications.

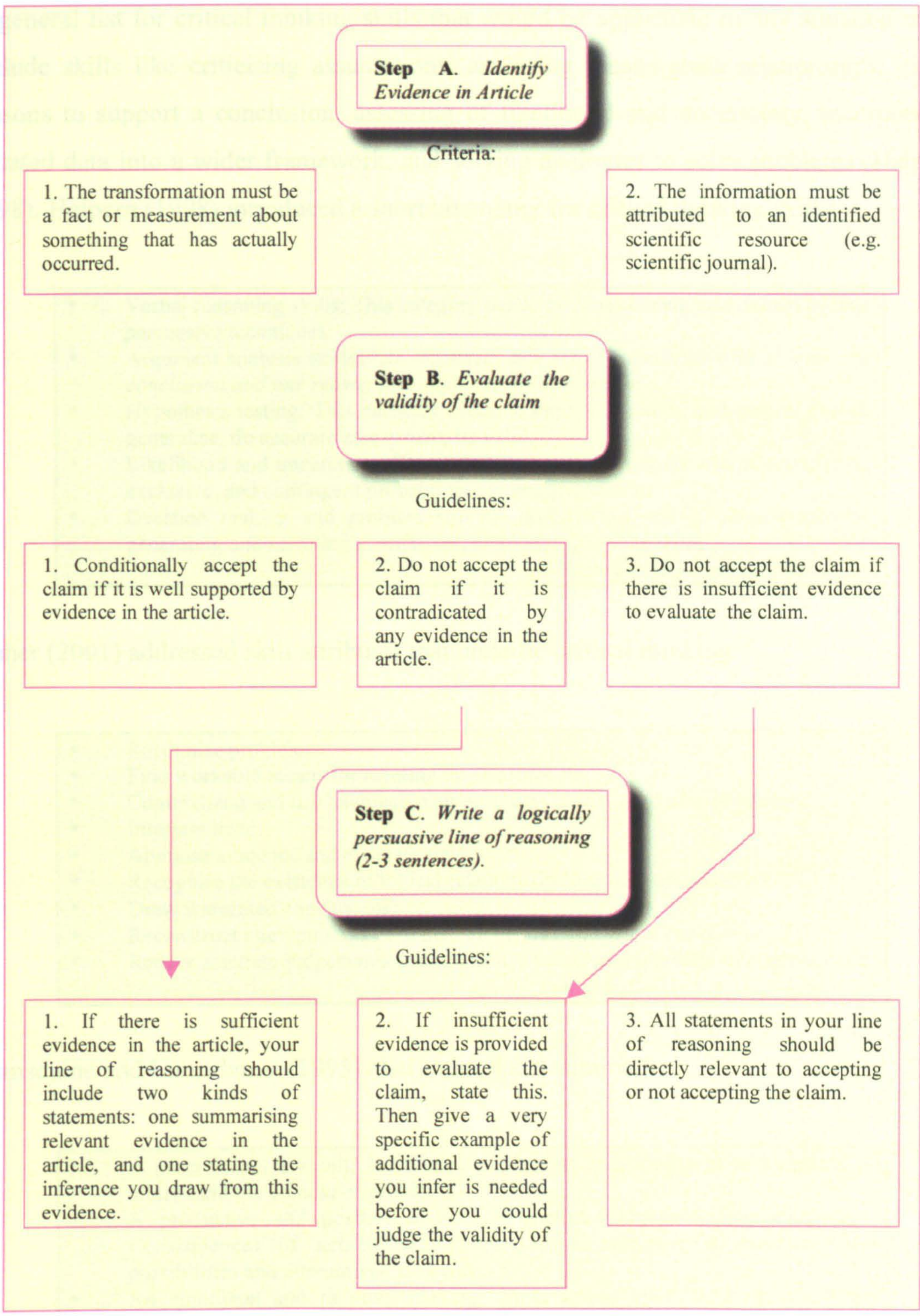
Bloom associated the term critical thinking with 'evaluation'. Bloom (1956) asserted that the critical thinking is the highest thinking skill, while Halpern (1998) viewed critical thinking skills as higher-order-cognitive-skills (HOCS). Slavin (2000, p. 283) argued that one key objective of teaching is enhancing students' abilities "to think critically, to make rational decisions about what to do or what to believe".

Critical thinking is purposeful, reasoned, and goal-directed. It may be very involved in problem solving and decision making. When people think critically, they are evaluating the outcomes of their thought processes. It is the way of making good evaluation and judgement.

Thinking about critical thinking exercises in introductory biology courses, Tyser and Cerbin (1991) focused on how encouraging students to develop science related thinking skills. To do this, they developed what they called 'science news exercises'. Those exercises teach students a model for evaluating information in popular media science articles (see Figure 4.2).

Figure 4. 2 **The line-of-reasoning model used in the science news exercises**

(Source : Tyser and Cerbin, 1991)



As a challenge to teachers to go beyond presentation of content in their introducing biology courses, this attempt is laudable. However, the exercise is time demanding and the evaluation presented is limited and could be expanded in several ways.

4.4 Skills Approach to Critical Thinking

A general list for critical thinking skills that would be applicable in any situation might include skills like criticising assumptions, analysing means-goals relationships, giving reasons to support a conclusion, assessing of likelihood and uncertainty, incorporating isolated data into a wider framework, and solving analogies to solve problems (Halpern, 1998). Halpern (1998) introduced a short taxonomy for critical thinking skills:

- Verbal reasoning skills: This category needs to comprehend, and defend against persuasive techniques.
- Argument analysis skills: "*An argument is a set of statements with at least one conclusion and one reason that supports the conclusion*".
- Hypothesis testing: This category needs to explain, predict, and control events, generalise, do accurate assessment, be valid.
- Likelihood and uncertainty: This category needs the correct use of cumulative, exclusive, and contingent probabilities in every decision.
- Decision making and problem solving skills: They are involved creativity, generating and selecting alternatives, and judging among them.

(Adapted from Halpern, 1998)

Fisher (2001) addressed skill attributes that underlie critical thinking:

- Recognise problems;
- Find workable means for meeting those problems;
- Comprehend and use language with accuracy, clarity, and discrimination;
- Interpret data;
- Appraise evidence and evaluate statements;
- Recognise the existence of logical relationships between propositions;
- Draw warranted conclusions;
- Reconstruct one's patterns of beliefs on the basis of wider experience;
- Render accurate judgements about specific things and qualities in everyday life.

(Fisher, 2001)

Lumsdaine and Lumsdaine (1995) also attempted a summary:

- A process, not a result; it includes continuous questioning of assumptions to understand the context of problems.
- A productive and positive activity; it includes creativity and innovation. Consequences of actions are anticipated. Imagination is practiced and possibilities and alternatives are explored.
- An emotional and rational thinking; "it is whole brain thinking where we recognise our assumptions within the framework of our personal beliefs and commitments as well as within the context of the world around us"
- An objective but not subjective, role playing, and decision stimulation.
- A curious, flexible, honest, and sceptical features.

(Adapted from Lumsdaine and Lumsdaine , 1995, p. 253).

4.5 Critical Thinking, Problem Solving and Biology

From the discussion so far presented in this chapter, it appears that critical thinking is important in the solution of open-ended or unstructured problems. Lumsdaine and Lumsdaine (1995) asserted that, if the problem passes such stages like analysing, identifying the constraints, collecting the data, postulating one or more hypothesis and then testing them, then the goal will be achieved. Whether this is completely true or not, it is clear that some of the skills implicit in critical thinking will also be the same skills that encourage good problem solving. Information has to be weighed and interpreted. It has to be matched against what is already known. Conclusions have to be drawn or methods have to be applied or developed. The outcome has to be measured against the task set in the problem.

Chiras (1992) asserted that education must provide more than facts and a few insights. It must enrich students with skills that help them become better thinkers. "Part of becoming a better thinker is learning to become a critical thinker". He describes critical thinking thus:

> *"A process by which one subjects research findings and theories to examination, looking for consistencies and inconsistencies in logic, alternative interpretations, and subtle but pervasive biases that may have led to erroneous conclusions".*

and

> *"The most ordered kind of thinking of which humans are capable".*

Of these, the first has applications in biological research (or indeed, any research), while the second is too vague to be useful. Chiras (1992) went on to outline some 'rules' for critical thinking and asserted that "the more your students are involved in the process, the more they will get out of it". Gaining skills in critical thinking means being placed regularly in situations where such skills can be developed and practised. The situations must be unthreatening (in the sense of being graded or criticised destructively by authority figures) and the learner must be allowed to experiment cognitively, to play with ideas and to explore options. Constructive feed-back will be important.

Problem-solving exercises may offer considerable potential in seeking to develop such skills but the view of Chiras assumed that critical thinking skills can be taught in a structured or overt way. However, it is likely that there are no systems for critical thinking that can be passed from the teacher to the learner as a neat package. Critical thinking skills are gained when the learner is placed repeatedly in situations where such skills can be practised, where they are valued and seen to offer useful ways forward.

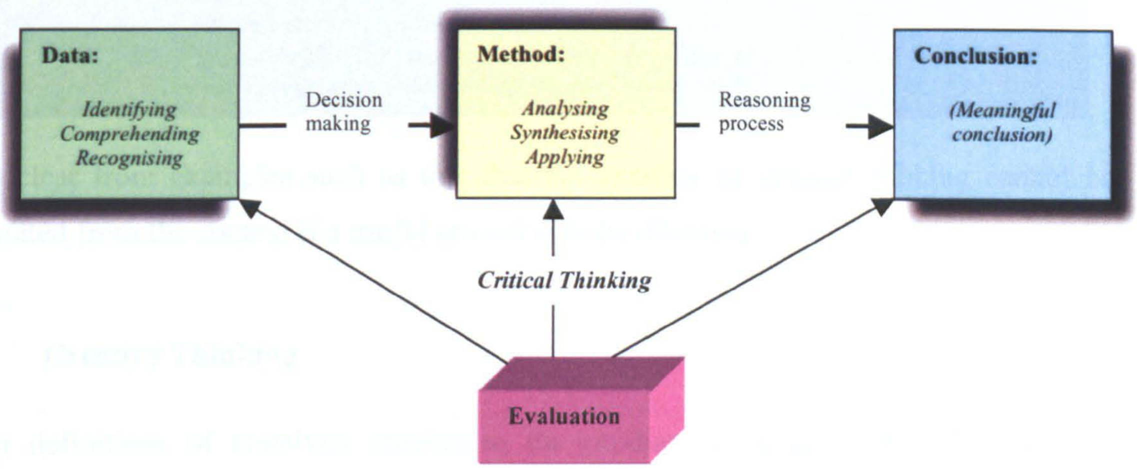
Chiras (1992) identified eleven principles, or skills, that can/should be used in critical thinking:

(1) Don't mistake ignorance for perspective and gather complete information.
(2) Understand and define all terms.
(3) Question the methods by which facts are derived.
(4) Question the conclusions drawn from facts.
(5) Look for hidden assumptions and bias.
(6) Question the source of the facts, who is telling them.
(7) Don't expect all of the answers.
(8) Examine the big picture.
(9) Examine multiple cause and effect. Be wary of simple answers and dualistic thinking.
(10) Watch for *thought stoppers* (words or phrases that, while appealing, switch off the critical thinking faculties).
(11) Understand your own biases and value.

(Adapted from Chiras, 1992)

In order to see how critical thinking relates to problem solving, the three features which Johnstone (1993) used are applied to critical thinking in the map presented in Figure 4.3. In this figure, it seems likely that each component needs to be evaluated in order to be in right way of solving any problem.

Figure 4. 3 Critical thinking map



The teaching of critical thinking skills has become a popular topic within the science disciplines. Such teaching does not necessarily convey the right ideas, though. Often what is taught as critical thinking in schools is rather general and has little relationship to science where specific subject knowledge is usually needed before any useful judgement can be applied. This means that misconceptions and wrong judgements can result. Teaching students to be aware of the unique facts of a situation is important. Here are some examples of critical thought in biological contexts:

> ***First example***: **Most people would say that carrots are good food.** ***Are carrots really good for everyone? Would it be a good idea to follow a carrot-only diet?***
>
> **To give a proper answer it is necessary to ask questions like:**
>
> ***Are carrots being heavily contaminated with pesticide or other chemicals?***
> ***Are there people who have serious allergies to carrots?***
> ***Can the heavy consumption of certain foods be fatal?***
> ***Are beta-carotenes (often cited as important substances obtained from carrots) ever harmful, rather than useful, to the body?***
> ***Is there any evidence that overdoses of vitamins can be fatal? If so, could eating a high-carrot diet be bad for normal people?***
>
> ***Second example***: **There is a part of the human eye called the *iris*. The iris gives the eye its colour. By changing size the iris regulates the amount of light entering the pupil (the hole in the centre of the iris). Transferring from a dark room to one which is brightly lit can cause sudden pain in the eye. The pain is annoying and can be irritating, but it is normally slight and only lasts a moment.** ***Why does this happen?***
>
> **Before suggesting an answer the student should be asking questions like:**
>
> ***Could the sudden change of iris size cause the pain by itself?***
> ***Could the sudden increase in the light reaching the retina cause the pain?***
> ***Is there a change in the local blood flow involved? If so could this be the cause?***
> ***Are there muscles involved?***
> ***Is it possible that the pain is not really in the eye at all? Could it be that the sudden increase in brain activity plays some part?***

It is clear from examples such as this that the exercise of critical thinking cannot be separated from the context if a useful answer is to be obtained.

4.6 Creative Thinking

Most definitions of creativity emphasise the products of creative thought. Creative products have two important features: they should be novel and they should be valuable or useful either to the person who created the product or to the culture into which it was created. This is named as *psychological creativity* or P-creativity (Roberston, 1999).

Suppose you are making a cake and you want to separate the yolk from the white of an egg. You might think to make a hole in the egg and do the separation by spoon without making a mess by pouring back and forth from each half. If you had never seen this done it would be an example of P-creativity. Your imagination has produced a new product. To be *historically creative* (H-creative), the novel product would have to be one nobody had ever seen before (e.g. Van Gogh's *Sunflowers*). The source of creative products (creative thinking) has to be viewed as involving some form of inspiration (Roberston, 1999).

Roberston (1999) suggested that there are two general types of thinking: *divergent thinking* and *convergent thinking.* In convergent thinking, the thinker is expected to 'converge' on the appropriate answer to a problem. Convergent thinkers "prefer problems that have a single correct answer". In turn, the other type, "involves producing a variety of possible answers to a problem" (Roberston, 1999, p. 43). Thus, divergent thinkers prefer open-ended problems that allow them to be novel in their answers. As such, they are considered as creative individuals. There are tests designed to measure the creativity of divergent thinkers, for example:

(1) Suppose that all humans were born with six fingers on each hand instead of five. List all the consequences or implications you can think of.
(2) List as many edible, white things as you can in 3 minutes.
(3) List all the words you can think of in 3 minutes.

Responses to the first and third questions are considered to be *fluent* thinking, defined by Doherty and Evans (1990) as a first basic creative thinking skill. The key is to produce as many ideas, attitudes, or behaviours as possible. "The number of times someone switches categories in response to an item" known as *flexible* thinking (Roberston, 1999, p. 44), considered as the second basic creative thinking skill: looking at things from many points of view to produce different categories of ideas, attitudes, or behaviours (Doherty and Evans, 1990). Counting the responses, gives an indication of *originality* in thinking (Roberston, 1999). This third skill - *originality* - deals with producing as many new unique ideas, attitudes, or behaviours as possible (Doherty and Evans, 1990). Doherty and Evans (1990) added that *elaboration* is the final basic skill of creative thinking. It concerns the ability to expand a given group of ideas, attitudes, and behaviours or add detail to one of them.

Dewulf and Baillie (1999) have analysed the whole area of creativity in the context of higher education in some detail. They ask some searching questions, which expose the complexity of the concept:

> *"Is creativity a process or a property of products?*
> *Is creativity a personal or social phenomenon?*
> *Is creativity common to all people or a unique characteristic of a select few?*
> *Is creativity a domain-general activity that is essentially the same in all contexts or a domain-specific activity that depends on the context under consideration?"*

The fundamental question is where creativity best conceived as a set of characteristics which everyone holds to varying degrees, or as something uniquely manifested in creative individuals?

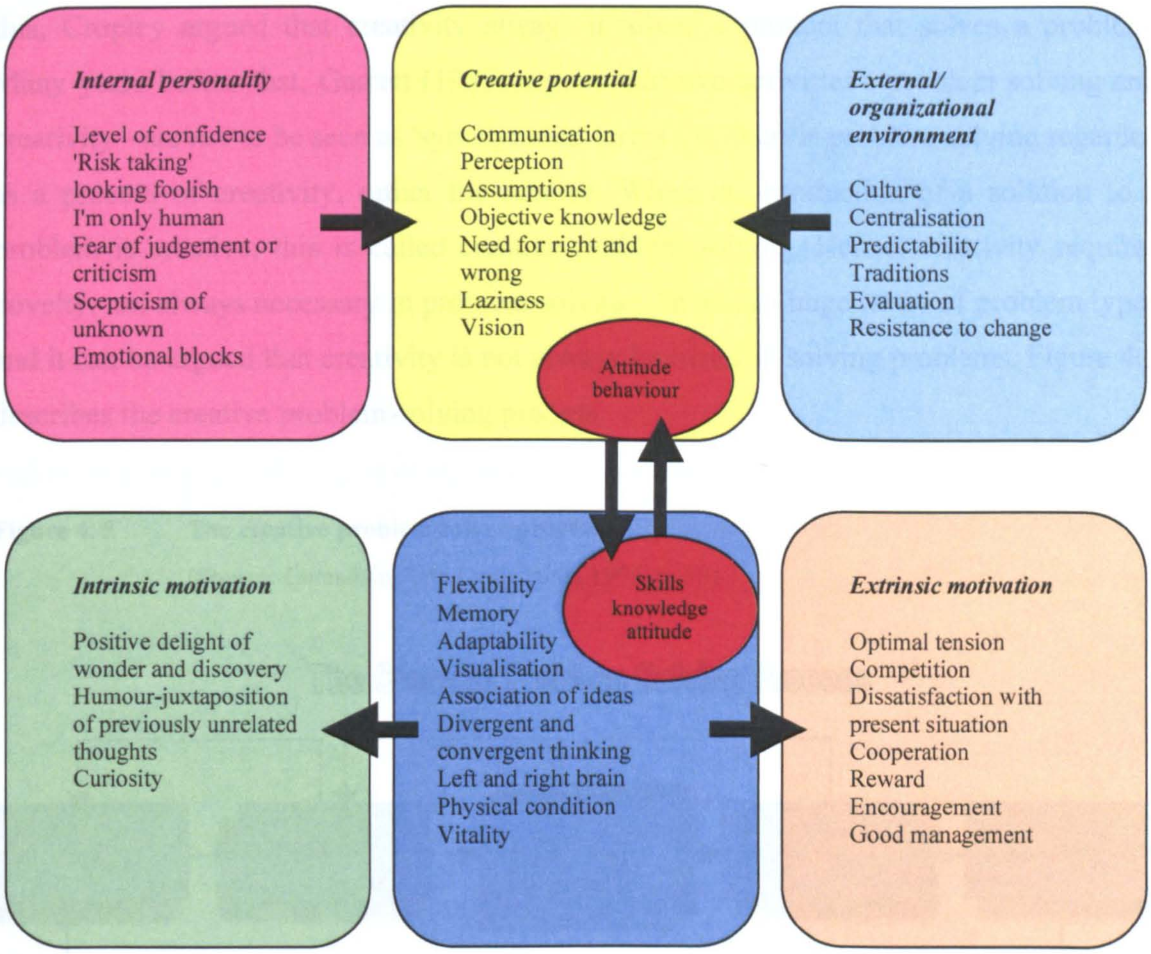
Dewulf and Baillie (1999) appreciate the complexity of the notion of creativity. Even definition is difficult and they consider numerous attempts by others, including:

- *"The development of creative alternatives in decision problems."* (Clemen, 1996, cited by Dewulf and Baillie, 1999)
- *"The ability to perceive reality accurately and compare cultures objectively, having a genuine degree of spontaneity and being able to look at things in a fresh, simple, naive way."* (Davis,1996, cited by Dewulf and Baillie, 1999)
- *"Conceptual combination-merging of two or more concepts resulting in a novel entity."* (Ward *et al.*, 1997, cited by Dewulf and Baillie, 1999).

Interestingly, Cropley (1999) defined creativity in a broad and practical way, as the "production of novelty", thus requiring originality and newness: there must be something fresh to the idea. This tends to present creativity in terms of products which none of the definitions quoted by Dewulf and Baillie actually do explicitly.

However, there are conditions which might hinder the demonstration of creativity, Figure 4.4 will show these hindrances. These conditions and obstacles "leading towards a creative output are linked" (Dewulf and Baillie, 1999, p. 8).

Figure 4. 4 **The hindrance of creativity**
(Source: Dewulf and Baillie, 1999, p. 8)



A final and very important question about the nature of creativity is to what extent it is innate or are there conditions which tend to foster this development? Even personality may be a key factor to be creative: internal motivation, confidence, non-conformity, good-self image, being emotional, perceptual and openness to new ideas (Dewulf and Baillie, 1999).

In general, there is no acceptable definition by all for creativity.

4.7 Problem Solving and Creativity

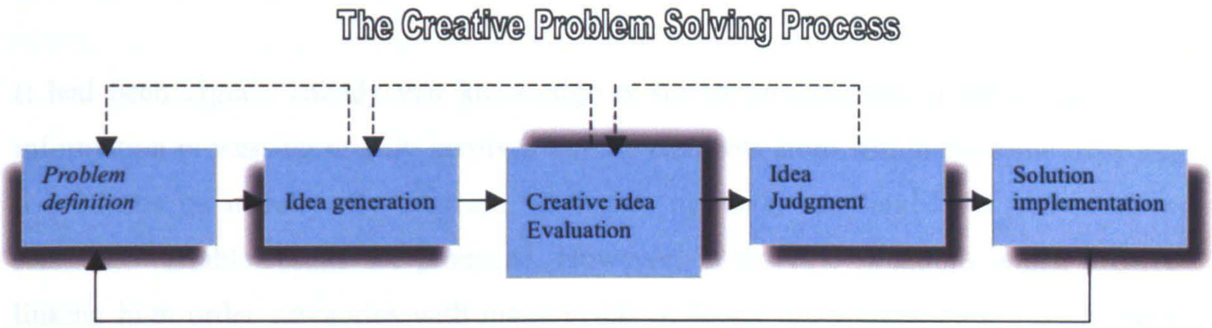
Guilford (1959) linked creativity directly with problem solving and suggested that the creative process has four stages:

(1)	Recognition that a problem exists;
(2)	Production of a variety of relevant ideas (e.g. divergent thinking);
(3)	Evaluation of the various possibilities produced;
(4)	Drawing of appropriate conclusions that lead to the solution of the problem.

Many have considered that 'problem awareness', 'problem recognition', and the process of 'problem finding' are major elements of creativity (e.g. Cropley, 2001). In the light of this, Cropley argued that creativity always involves a product that solves a problem. Many years before that, Garrett (1987) argued that two activities - problem solving and creativity - are *not* to be seen as 'synonymous' terms. Neither is problem solving regarded as a process of creativity, rather the reverse. When the production of a solution to a problem is creative, this is called creative problem solving. Hence, creativity requires novelty, not always necessary in problem solving. There is a huge range of problem types and it can be argued that creativity is not always involved in solving problems. Figure 4.5 describes the creative problem-solving process.

Figure 4. 5 The creative problem solver process

(Source: Lumsdaine and Lumsdaine, 1995, p. 53)



The flowchart (Figure 4.5) above shows creative problem solving as a *'sequential'* activity. It is a flexible and cumulative process. In other words, to move from one step to another the learner has to perform satisfactory and obtain good results (Lumsdaine and Lumsdaine, 1995). That means it is a circular process and each component is dependent on the other to reach the proposed goal. It seems that evaluation is a key component which helps to judge the results successfully. Problem solving needs to be evaluated in each step to keep the learner moving in the right way. That means critical thinking is the core of problem solving (see Figure 4.3).

4.8 Creative Cognitive Structures and Building Networks

Creativity means producing something new or having the potential to do so (Cropley, 2001). This must demand that ideas are linked in some new way to generate something new. Cropley (2001) supported the idea that the essence of creative thinking is 'network thinking'. He argued that broad networks require joining concepts. In terms of concepts, the building of networks is an extension of the coding process. There are different categories that may share properties. He simplified this in the following example: weight, balance, length, rigidity and portability are all properties of weapons. At the same time, they are properties of bats and rackets are used in sports (e.g. baseball, cricket, etc.) as well as of walking aids (e.g. walking stick). Hence, the categories (e.g. weapons) overlap and combined to form a system of network. Such a combination categories will make a network of 'sporting equipment', 'walking aid' and using a baseball bat as a walking stick, thus producing novelty.

It had been argued already that knowledge is stored as networks of linked ideas. As information processing usually involves linking elements from within the same network, it produces no novelty. By contrast, when two networks are linked via two or three relations, variable results are produced. However, in extreme situations which involve linking high order categories with many levels of lower order categories, novelty must exist (Cropley, 2001). Thus creative thinking must involve the linking of networks of ideas in such a way that something new emerges. While this may be a feature of some problem solving, it is by no means the feature of all problem solving.

4.9 Lateral Thinking

This section seeks to explore the concept of lateral thinking and relating it to creativity and to problem solving. Lateral thinking was a concept introduced by De Bono (1967). He described it as:

> *"Lateral thinking is closely related to insight, creativity and humour. All four processes have the same basis. But whereas insight, creativity and humour can only be prayed for, lateral thinking is a more deliberate process. It is as definite a way of using the mind as logical thinking – but a very different way."* (De Bono, 1970, p. 9)

Is lateral thinking merely the same thing as creative thinking? De Bono (undated)would say 'no'. While lateral thinking *may* be a creative process, there are differences. For example, lateral, thinking may or may not come up with novelty. De Bono invented several ways of defining lateral thinking, ranging from technical to illustrative. For example,

> *"You cannot dig a hole in a different place by digging the same hole deeper."* (De Bono, 1970, p. 12)

This means that trying harder in the same direction may not be as useful as changing direction. In more general terms, he suggested that:

> *"Lateral thinking is for changing concepts and perceptions."* (De Bono, undated)

Certain perceptions, concepts and boundaries are assumed in most situations but lateral thinking is concerned not with playing with the existing perceptions, concepts and boundaries but with seeking to change those very pieces. Where we organise the external world into the pieces we can then 'process'.

> *"The brain as a self-organising information system forms asymmetric patterns. In such systems there is a mathematical need for moving across patterns. The tools and processes of lateral thinking are designed to achieve such 'lateral' movement. The tools are based on an understanding of self-organising information systems."* (De Bono, undated)

> *"In any self-organising system there is a need to escape from a local optimum in order to move towards a more global optimum. The techniques of lateral thinking, such as provocation, are designed to help that change."* (De Bono, undated)

De Bono identified four critical factors associated with lateral thinking:

(1) Recognise dominant ideas that polarise perception of a problem;
(2) Searching for different ways of looking at things;
(3) Relaxation of rigid control of thinking;
(4) Use of chance to encourage other ideas.

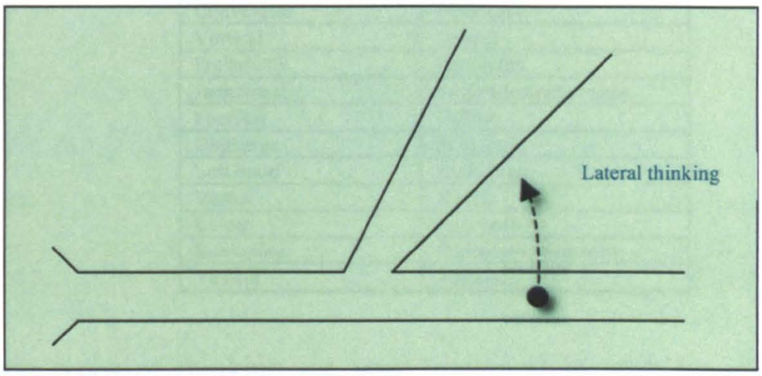
De Bono (1970) argued that lateral thinking uses information not only for its own sake but provocatively in order to bring about re-patterning (De Bono, 1970). While conflict of ideas can assist lateral thinking, he asserted that changing ideas is not from outside by conflict but by internal rearrangement of available information.

De Bono (1992) contended that the mind operates by creating patterns out of its surroundings. As the patterns form, it is easy to recognise them, react with them, and use them. Once they are used, they become more firmly established. This is the best way to handle information. Creativity involves restructuring of patterns, and lateral thinking involves the restructuring and production of new patterns. De Bono 1992 (see Figure 4.6) described lateral thinking (p. 53) as:

> *"The true technical description of lateral thinking is based on a consideration of a self-organizing pattern-making information system: cutting across patterns in a self-organizing information system."* (De Bono, 1992, p. 53)

Figure 4. 6 **The description of lateral thinking from De Bono's point of view**

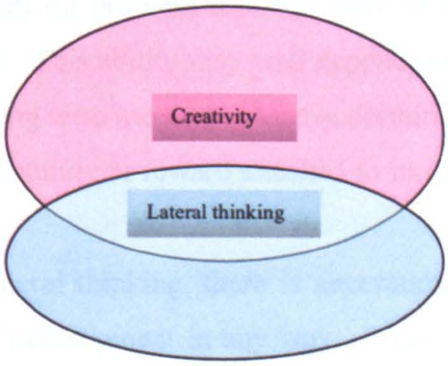
(Source: De Bono, 1992, p. 54)



In his analysis, De Bono (1970) argued that lateral thinking and creativity are closely related (see Figure 4.7). De Bono (1992) asserted that relationship between two types of thinking is "a matter of opinion" (p. 55). But they are different, creativity often describes the *results* but lateral thinking describes a *process*. Lateral thinking is concerned with librating the mind from old ideas (escape from dominance old ideas) and the stimulation of new ideas.

Figure 4. 7 **Relationship between creativity and lateral thinking**

(Source: De Bono, 1992, p. 55)



Much of thinking done in education emphasises the skills of analysis by teaching students how to understand claims, follow or create a logical argument, figure out the answer, eliminate the incorrect paths and focus on a correct one. However, there is another kind of thinking, one that focuses on exploring ideas, generating possibilities, looking for many right answers rather than just one. Both of these kinds of thinking are vital to a successful working life. Table 4.3 below will differentiate these two kinds of thinking like this:

Table 4. 3 **Difference between critical and creative thinking**
(Source: Harris, 1998)

Critical Thinking	Creative Thinking
Analytic	Generative
Convergent	Divergent
Vertical	Lateral
Probability	Possibility
Judgement	Suspended judgement
Focused	Diffuse
Objective	Subjective
Left brain	Right brain
Verbal	Visual
Linear	Associative
Reasoning	Richness and novelty
Yes but	Yes and

Both of these types of thinking are very important in problem-solving activity. First, analysing the problem must take place; then generate possible solutions. Selection and implementation of the solution is also considered as the next step. The final stage is evaluation of the best solution to reveal alteration between two types of thinking, critical and creative. In practice, both types of thinking operate together much of the time and are not independent of each other.

Perhaps lateral thinking can best be described as the ability to step outside the given frame of reference. Sometimes, this will lead to creativity in the sense that something new will be generated. It seems logical to assume that the ability to demonstrate lateral thinking will be important for problem solving where there is a need to step outside the given frame of reference. This ability may well depend on the way links that can be used and perhaps created in long term memory. Almost certainly, the greatest hindrance to this ability is the lack of opportunity or reward attached to its use.

In both creativity and lateral thinking, there is uncertainty about whether these abilities are innate or capable of development in any way. There is the same ambiguity about a range of characteristics that are often described as cognitive styles. Are these the ways that individuals prefer to learn or are they using these styles because that is the way their brain works best? The next section looks very briefly at the convergent/divergent cognitive style in that this is related to creativity, lateral thinking and, more importantly, is likely to be related to problem-solving ability.

4.10 Cognitive Styles

> *"The concept that each of us perceives, interacts, and responds in a unique way either because of genetics or nurturance poses dramatic implications for instructional delivery and lesson planning. Although, no definition is commonly accepted, researchers of style agree that students learn in different ways. Again labels, such as modalities, learning channels, processing styles, left/right brain hemispheres, are used synonymously by theorists."* (Doherty and Evans, 1990, p. 37)

Learning takes place in essentially the same way for all learners in the sense that new information is selected by the perception filter, processed in the working memory and stored in long term memory. However, individuals will make the selection in their own ways. There are differences in working memory capacity and individuals will store new information in their own idiosyncratic way. However, alongside the general common pattern of learning, it is important to recognise that different styles of learning do exist. Some may derive from genetic differences while others will reflect preferences. Perhaps most involve a bit of both.

Considerable work has been conducted in relation to these cognitive styles, particularly in science education. For example, it is known that being field-independent gives an almost universal advantage in assessment (see Danili, 2004, for a review of this area). In this study, only the convergency/divergency style will be considered in that this may have a specific relationship to the way long term memory works in both storing and accessing information and, thus, may have a particular impact on problem solving.

Bahar (1999, p. 32) noted that, whenever individuals encounter new information, "they have different ways of selecting, perceiving, and processing that information". This is related to what is already known to them and their learning style as well. The interrelationship between cognitive style and psychological differentiation gives a good sign of the differences which exist between different individuals in cognitive structure and 'psychological individuality', as noted by Witkin (1974). Cross (1976) stated that each individual has his/her own style for receiving, absorbing, and organising information into a good pattern in the mind. Thus, students are varied in their learning style. In addition, Saracko (1997) pointed out that cognitive styles identify how individuals respond to different situations. They use their own style for perceiving, remembering, thinking, and problem solving to learn based on their attitudes, preferences, or habitual strategies.

Messick (1993) brought this all together when he stated that:

> *"Cognitive styles are characteristic modes of perceiving, remembering, thinking, problem solving, decision making that are reflective of information processing regularities that develop in congenial ways."*

As a subject, *cognitive style* has several aspects of 'differential psychology' associated with individual differences in learner and learning environment. The basic aspects of individual's psychology are: *affect* or feeling, *behaviour* or doing, and *cognition* or knowing. The three elements are structured by an individual's personal psychology: cognitive style. This in turn, reflects that the person builds a generalised method to learning. The combination of cognitive styles and learning strategies to contribute to an individual's psychology is called personal *learning style*. Riding and Rayner (1998, p. 7) defined cognitive style and learning strategy as "the way in which the individual person thinks" and "those processes which are used by the learner to respond to the demands of a learning activity".

In the 1960s, Witkin (1974) introduced the term cognitive style to describe the concept that individuals constantly reveal stylistic preferences for the ways in which they organise stimuli and construct meanings for themselves out of their experiences. Cognitive styles comprise variables such as *field-dependent/field-independent, convergent/divergent,* and *right-brained/left-brained* (Hsiao, undated). Only the convergent/divergent style will be considered here.

4.11 Convergent / Divergent Cognitive Style

The convergent/divergent cognitive style originated from Hudson's work (1966). Studies by Getzels and Jackson (1962) on intelligence formed a background for Hudson. They found two learning groups which they called *'High IQ'* learners and *'High Creative'* learners. The former group gained high scores in intelligence tests although, learners were relatively weak at creativity tests. By contrast, the later group, gained relatively low scores in intelligence test but they were good at the creativity tests. Hudson (1966) gave them another name, a *converger* and a *diverger*, respectively.

He created another two new tests, which he called *open-ended* tests. The first deals with meaning of words (e.g. "How many meanings can you think of for each following words?"). The second is concerned with the uses of subjects (e.g. "How many uses can you think of for each of the following?"). Hudson defined the converger as one who scores better in intelligence tests than open-ended tests; the diverger is the reverse. In addition, there were what he called '*all-rounders*' who are equally good or bad in both types of tests. Hudson (1966;1968) argued that the convergence/divergence dimension is "a measure of bias (of the test), not a level of ability" (Bahar, 1999, p. 40).

Convergent thinkers are distinguished by their comparatively high scores in problems with one accepted answer (e.g. intelligence tests) and low scores in problems requiring more than one answer or open-ended problems (e.g. divergent thinking tests). On the contrary, divergent thinkers have the reverse scores in both tests. In sense of this finding, divergent thinkers can easily find a variety of alternative answers for a problem, while, convergent thinkers focus on one answer.

Convergent thinkers are described by Cropley (2001, p. 32) as:

> *"Oriented towards deriving the single best (or correct) answer to a given question."*
>
> *"Involved processes like shifting perspective, transforming or producing multiple answers from the available information and thus favours production of novelty."*

In the light of these definitions, convergent thinking is effective (accuracy and correctness) in situations where a 'ready-made' answer exists and needs only to be recalled from stored information. Therefore, convergent thinking seeks to recognise the familiar, reapply known strategies, and preserve the already known without producing novelty. Divergent thinking, by contrast, produces answers which may never have existed before (Cropley, 2001).

It is important to recognise that they are styles and one is not better than the other. Society needs both. For example, a brainstorming committee needs the divergers while the convergers on the committee are essential to bring things together to form a conclusion.

4.12 Convergent/Divergent, Critical Thinking and Creative Thinking

Critical thinking may be linking to convergent/divergent thinking (Guilford 1956). Convergent thinking seeks to ascertain basic knowledge and understanding. Divergent thinking requires students to process information creatively. Convergent thinking tends to align with the first three levels of Blooms' Taxonomy of Learning Objectives while divergent thinking relates to the later three levels. On the other hand, synthesis considers two steps. The first step is creating a variety of alternatives (divergence). The second step is combining elements into a unique product (convergence).

> *"A great deal of the recent work connected with divergent thinking has been reported by the authors concerned as involving investigation of creativity. However, in most cases, the independent variable has really been the tendency towards divergent thinking; to call such a tendency 'creativity' is of doubtful validity."* (Cropley, 1967, p. 7)

Clearly, Cropley (1967) is expressing 'disquiet' over the use of the world 'creativity' when he argued that 'divergency' is the more ideas are generated. Indeed, it has already been stressed that is difficult to neatly separate creativity, critical thinking and lateral thinking. In the literature, however, tests of divergent thinking tended to become "synonymous with creativity tests" (Bahar, 1999, p. 41).

Several other researchers (e.g. Nuttal, 1972; Bennett, 1973; Runco, 1986) have argued that divergency is not the same as creativity. For example, Runco (1986) viewed divergent thinking is one component of creativity. Bahar (1999) outlined the characteristics of convergent/divergent thinking (see Table 4.4).

Table 4. 4 General characteristics of convergent/divergent thinkers

(Source: Bahar, 1999, p. 42)

Cognitive styles	Characteristics
Convergers	❖ Higher performance in intelligence tests. ❖ Good at the practical application of ideas. ❖ Specialised in physical sciences 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.

Little research has been done on the relationship between the convergent/divergent cognitive styles and performance in science. Convergers tend to choose science subjects and Johnstone and Al-Naeme (1995) found that most science teaching is convergent in emphasis: there is a focus on one unique answer. However, Hudson (1966) and Bahar (1999) revealed that biology attracts both convergers and divergers. Hence, Bahar (1999, p. 44) stated that:

> *"Biology might be one of the science branches in which students might cope equally well with a convergent or a divergent bias".*

In very recent work, it has been shown that divergers tend to perform best in many tests and examinations in the sciences and it seems to be generally true that convergers never out-perform their divergent colleagues in science subjects (Danili, 2004).

If being divergent means that the person is able to create and/or use more links in long term memory, then it might be expected that divergers would out-perform also in problems-solving tasks. This will be explored in this study.

Chapter Five

Looking at Cognitive Structure

5.1 Introduction

Problem solving can be seen as one aspect of learning. This chapter seeks to draw together some of the findings from the study of learning which have a direct relevance to the processes involved in problem solving, especially when thinking of the way long term memory is organised and the way this organisation of knowledge and understanding may influence problem-solving success. Of course, there is considerable difficulty in gaining evidence about the way long term memory works, with inference from test performance being the main way forward. The chapter goes on to outline some of the approaches which have been used and to discuss other possible ways forward.

5.2 The Importance of Learning

According to Driscoll (1994), the study of learning is derived essentially from two sources. The first concerns the nature of knowledge or how we come to know things. The second concerns how that knowledge is represented in the mind. More specifically, new knowledge gains meaning when it can be substantively related to a framework of existing knowledge rather than being processed and filed in a way where it is unrelated to any network of ideas. Semantic network models (see chapter 3) support this framework.

For meaningful learning, the learner must pay attention to the relationship between concepts. A semantic network can be considered as consisting of hierarchically arranged nodes that contain concepts, items or pictures. The relationships between nodes or concepts are indicated by linking words and some kind of directional link to describe the direction of the relationship. It is possible to conceive of networks of concepts where links do not only connect to adjacent concepts but are also linked to concepts that are peripheral or newly known. The resulting web of concepts increases the number of relationships that connect new information to existing concepts thereby increasing the stability of the new information.

> *"Learning involves the acquisition and modification of knowledge, skills, strategies, beliefs, attitudes, and behaviours. People learn cognitive, linguistic, motor, and social skills, and these can take many forms. At a simple level, children learn to solve 2+2 = ?, recognize d in the word daddy, tie their shoes, and play with other children. At a more complex level, students learn to solve long division problems, write term papers, ride a bicycle, and work cooperatively on a group project."* (Schunk, 2004, p. 1)

The whole area of learning has fascinated people from the earliest times. However, in recent times, psychologists have constructed theories to explain learning and cognition (Leahey and Harris, 1993). Unfortunately, there is no one unified definition of 'learning' that is accepted by theorists, researchers, and practitioners (Schunk, 2004).

5.3 What is Learning?

Although there are many proposed definitions of learning, most psychologists and educators tend to agree that learning is "a process by which behaviour is either modified or changed through experience or training" (Hamchek, 1995, p. 228). In the light of this, definition, the learning either could be obvious as an observed outcome in an action form (e.g. learning to ride a bike, to do subtraction 6 from 10, etc.) or unobvious as an internal hidden change in attitudes, feelings, and intellectual processes. Learning can also be *improvement* in behaviour. In that sense, with time a person becomes more proficient at whatever was learned. This does not mean the behaviour of the learner improves in an obvious way. For example, a student could learn to be a competent artist in an observable manner, or to be honest and confident in their abilities in unobvious manner (Hamchek, 1995).

Schunk (2004, p. 2) later provided another definition, which is consistent with nature of learning and captures the central meanings of learning:

> *"Learning is an enduring change in behaviour, or in the capacity to behave in a given fashion, which results from practice or other form of experience."*

He emphasises three criteria: the change is not temporary and this eliminates situations where, when "the cause is removed, the behaviour is returned to its original state" (Schunk, 2004, p. 2). The behaviour change (or capacity for behaviour change) is noted and this takes place by means of practice or experience. This includes formal school or university type learning as well as the wider range of informal learning.

An understanding of biology is important to the psychology of learning in two ways. Learning must involve some change to the nervous system of the organism, as was discussed in Chapter 3. Philosopher-physicians tried to use physiology theories to work out learning theories such as epistemology (concerned with the nature of human knowledge). Thinking and memory theory could be described as relating to the specialised functions of the brain. Such theories were founded in the early twentieth century search for the neural trace of each memory. In the 1990s, the "Decade of the Brain", real progress was made on discovering the neural bases of learning and cognition.

In general, the cognitive process of acquiring skill or knowledge is a form of definition for learning. This might suggest that having a unified definition seems to be difficult.

5.4 Piaget and Cognitive Development Psychology

Recently, several changes in educational thinking have greatly affected the manner in which primary and secondary school teachers are trained. These changes are most appropriately described as efforts to improve students' learning. One underlying theme that often appears throughout the restructuring effort is the idea of constructivism. This approach to learning emphasises the personal construction of human knowledge as opposed to the transmission of knowledge from one person to the next. The current view of constructivism has a strong basis in cognitive approaches to learning and draws heavily upon the research of learning researchers like Jean Piaget and David Ausubel. The contributions of these researchers, along with the ideas of others, have laid the foundation for many of the recent changes that have occurred in science education (anon, undated).

By means of acute observation, Piaget postulated four levels of intellectual growth through which all humans progress: the sensory motor (sensorimotor), preoperational, concrete operational, and formal operational levels. The final two levels, or stages, are of particular importance to middle and secondary science educators because most students of that level operate at one of these two stages. Students at the concrete operational stage have the ability to think logically and concretely about objects and events. Students at the formal operational stage have the ability to think more abstractly and hypothetically about complex concepts and ideas (anon, undated).

One of Piaget's major contributions (Piaget, 1952) was to see that each person constructs his/her own understanding of the world around. This personal construction must reflect the learning experiences but will also, perhaps, be related to the way the links in the person's long term memory function. It raises questions about the architecture of the long term memory. This may be fixed, with knowledge and understanding being imposed onto this structure. However, can new links be formed or is it the effective activation of links which makes knowledge meaningful?

5.5 Ausubel and Meaningful Learning Model

Whereas Piaget placed an emphasis on the learner's personal construction of knowledge, Ausubel (1969) emphasised the importance of *reception learning* which is based on the idea that most of what is learned is acquired through the transmission of ideas and not through discovery. Ausubel believed that reception learning was an important means of acquiring certain discipline-based concepts as long as that learning made meaningful connections between new information and the learner's pre-existing cognitive structures.

Ausubel's emphasis on reception learning has affected the way in which certain scientific concepts are approached by science teachers. Many educators recognise the significance of allowing students to learn from information that has been organised by others as long as it has meaning to the students' own internal cognitive structures. This recognition of reception learning as an effective teaching method has placed less emphasis on discovery learning as the only way for students to construct personal meaning since students cannot be expected to discover all important scientific ideas on their own. Ausubel's idea of reception learning holds a vital part in the learning of science (Ausubel, 1968;1969).

The primary idea of Ausubel's model is that the learning of new knowledge is dependent on what is *already known*. In other words, construction of knowledge begins with our observation and recognition of events and objects through concepts we already possess. A person learns by constructing a network of concepts and adding to them. New knowledge must interact with the learner's knowledge structure. Rote learning is fine for remembering sequences of objects (e.g. lists of structures) but does not help the learner in understanding the relationships between the objects. Therefore, meaningful learning involves recognition of links between concepts (Ausubel *et al.*, 1978).

Ausubel proposed the notion of an *advanced organiser* as a way to help students to link prior knowledge with new material or concepts. Ausubel's model of learning claimed that new concepts to be learned could be incorporated into more inclusive concepts or ideas. These more inclusive concepts or ideas are advanced organisers. These can be verbal phrases (the paragraph you are about to read is about genes), or a graphic. In any case, the advanced organiser is designed to provide what cognitive psychologists called the 'mental scaffolding' that is needed to learn new information (Ausubel *et al.*, 1978) (see Table 5.1).

Table 5. 1 Meaningful learning contrasted with rote learning

(Source: anon, undated)

Type of Learning	Characteristics
Meaningful Learning	o Non-arbitrary, non-verbatim, substantive incorporation of new knowledge into cognitive structure. o Deliberate effort to link new knowledge with higher order concepts in cognitive structure. o Learning related to experience with events and objects. o Affective commitment to relate new knowledge to prior learning.
Rote Learning	• Arbitrary, verbatim, non-substantive incorporation of new knowledge into cognitive structure. • No effort to integrate new knowledge with existing concepts in cognitive structure. • Learning not related to experience with events and objects. • No affective commitment to relate new knowledge to prior learning.

Ausubel (1978) believed that learning proceeds in a top down, or deductive manner. Ausubel's model consists of three phases: presentation of an advanced organiser, presentation of a learning task or material, and strengthening the cognitive organisation. The main elements of Ausubel's model are shown in Table 5.2.

Table 5. 2 Ausubel's Model of Learning

(Source: anon, undated)

Phase one: Advance organiser	*Phase two*: Presentation of learning task or material	*Phase three*: Strengthening cognitive organisation
o Clarify aim of the lesson. o Present the organiser. o Relate organiser to student's knowledge.	• Make the organisation of the new material explicit. • Make logical order of learning material explicit. • Present material and engage students in meaningful learning activities.	o Relate new information to advanced organiser. o Promote active reception learning.

5.6 Problem Solving and Learning Models

> *"Increasing the problem solving abilities of students continues to be a major goal of mathematics and science teachers. However, students (and thus teachers) continue to be criticised for their lack of problem solving proficiency."* (Stewart, 1982)

Stewart's observation does reflect a real difficulty. For the new student who has just started to study a science discipline, there may be insufficient background knowledge to make problem solving an easy process. Not only knowledge but, specifically, procedural knowledge may be required to solve a problem successfully. For instance, in terms of understanding of correct genetics conceptual knowledge, there are series of steps and ultimate answers to the problem to be justified by the students (Stewart, 1982). Knowledge of the steps that students use to solve common problems and conceptual knowledge that they use to justify their procedures would be useful.

In science education, two dominant models have influenced research on learning and problem solving. Piagetian researchers such as Lawson (1975;1979) argued that the developmental stage of students can be used to account for their success or failure with particular science content and problem solving (Stewart, 1982). On the other hand, Ausubel influenced researchers such as Novak (1977) claimed that relevant prior conceptual knowledge is the most important factor in learning science content. It is also important in using that knowledge to solve problems. Although, Stewart (1982) asserted that the relationship between using problem-solving strategies and conceptual knowledge is important, this relationship has not been examined in science education research yet.

To assess how much knowledge the students' have in their minds, Stewart (1982) involved 'paper-and-pencil' problem solving and clinical interviews. All in all, this research has emphasised the important influence of relevant knowledge on problem solving.

The Piagetian perspective leads to arguments that certain levels of thinking are required for specific problem-solving tasks. For example, to solve genetics problems, the students must be taught formally (using Piaget's word, as in *formal* thinking). The concern for mental operations expressed by Piagetians has been described in the context of genetics in this statement:

> *"... even after careful and thorough instruction, some students can accurately reproduce content information and solve problems when the data and methods are replicas of familiar problems, but become perplexed and cannot develop solutions when required to apply abstractions and reasoning to unfamiliar but related genetics problems."* (Piagetian researchers cited by Stewart, 1982)

Stewart (1982) went on to argue that:

> *"Little detailed analysis is being done on problem solving in particular content domains where conceptual knowledge and problem solving strategies are viewed simultaneously."*

At the same time Stewart (1982) noted the small correlation observed between success on selected Piagetian tasks and success in genetics. That suggests that the Piagetian model may be poor in explaining problem-solving abilities.

According to Ausubel's learning model, problem solving is a special case of meaningful learning. Therefore, any instructional system aimed at enhancing problem-solving abilities should be designed in such a way as to promote meaningful learning. To engage in meaningful learning, students must identify specifically relevant concepts and recognise irrelevant information.

There is one extreme end which is *rote learning* where learners try to learn by "placing information in memory by repetition and in isolation from any other learned material" (Johnstone *et al.*, 1998) and the links are simply not there in long term memory. Thus, success in problem solving which is dependant on making these connections is very difficult. The other extreme is *meaningful learning* where "new information is attached to existing learning, making it richer, more interconnected and accessible through many cross references" (Johnstone *et al.*, 1998). The presence of such links is likely to make problem solving much more straightforward.

Overall, Ausubel emphasises the importance of prior knowledge as one of the key factors influencing problem solving. This is to be seen in the sense in which the knowledge related to the problem to be solved actually relates meaningfully to what is already known. Thus, Ausubel seems to offer insights into problem-solving ability more than Piaget.

5.7 Gaining Evidence About Long Term Structures

How it is possible to explore the nature of the process of problem solving in students' minds and getting into the ideas stored in student's cognitive structure and long term memory? 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? How is it possible to find the key factors influencing success in problem solving?

These are all difficult questions and it has to be recognised that gaining insights into the way information is stored and linked in long term memory will not be an easy task. However, there are several techniques reported in the literature to test the cognitive structure of students. In this study, these methods will be used: Word Association Test, Concept Map, and Structural Communication Grid. In addition, the Perry scheme (based on Perry, 1999) will be used to explore students perceptions of learning. Other new approaches will also be developed for this study.

The four approaches described by others will be discussed first and then some further approaches will be outlined.

5.8 Word Association Test (WAT)

A Word Association Test (WAT) is "one of the commonest and oldest methods for investigating cognitive structure" of learners (Bahar *et al.*, 1999, p. 72). It can be used as a "tool to elicit the associations students have formed between concepts" (Bahar *et al.*, 1999, p. 72). In the Word Association Test, semantic proximity of the stimulus words is measured by the degree of overlap of response hierarchies (Bahar *et al.*, 1999). The subject is asked to give a series of one-word responses in a fixed time to the given stimulus words. It is assumed that the Word Association Test reveals the order of the responses retrieved from long term memory.

Several research studies (e.g. Bahar and Hansell, 2000) suggested "a great regularity in semantic memory structure". Retrieval of concepts or categories takes time and, therefore, concepts closer together in the hierarchy and in meaning require less time and *vice versa.*

This is called 'semantic relatedness or semantic distance effect'. That means if two concepts are close in semantic memory (distance) or closely related, the retrieval of information is faster from the mental search process. The relationship of semantic relatedness to the retrieval of concepts shows the importance of ordering students' responses to each stimulus word.

In practice, students are given a word or phrase and asked to write down as many ideas they can think of related to the word or phrase in a fixed time (usually 30 seconds). Often, this is repeated for ten words or phrases, each of which is related to the concept under consideration. From the data obtained, some kind of map (for an individual student or the whole class group) can be developed which shows how strongly the ideas are related. The exercise is mentally exhausting for students because of the insistent time pressure and demand to write down as many words or ideas that come to mind (see Appendix D & E).

5.9 Concept Map (CM)

The Concept Map can be thought of as a pictorial representation of ideas and their inter-relationships, as held in long term memory.

> *"Concept mapping has become increasingly useful as a research tool and an instructional technique to facilitate meaningful learning."* (Novak *et al.*, 1983)

In the 1970s, Novak outlined the potential use of Concept Maps for the improvement of teaching and meaningful learning (Novak and Gowin, 1984). Novak and his research group developed Concept Maps as a means of representing frameworks for interrelationships between concepts and propositions (Novak and Gowin, 1984). They saw Concept Maps as hierarchical (see chapter three), with the more general ideas at the top. They suggested that Concept Maps can be considered as a tool for identifying what the learner already knows about a subject area.

However, Concept Maps can perhaps be used to explore (or perhaps develop) the structure and organisation of an individual's knowledge:

> *"Concept Maps have been proposed as a means to facilitate students' formation of links between content areas."* (Nicoll *et al.*, 2001b)

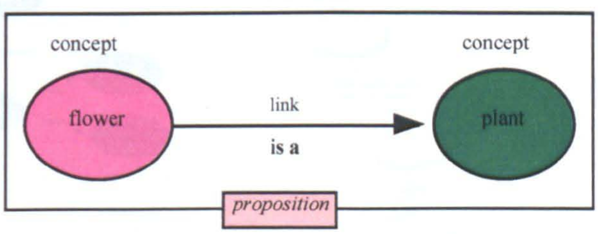
Conventionally, science in general has been considered very hard for students to understand. It is possible to attribute part of this difficulty to students' lack of connections between concept areas. For instance, biology textbooks are divided into units, which are further divided into chapters. While this helps to organise the material in a textbook, it may hinder students in making connection.

The Concept Map is considered as a 'powerful tool' to effect conceptual change in science classrooms. It is argued that Concept Maps are:

> *"A very visual method of helping students to organize their own thinking, they appeal to a different type of student than do other organizational methods, such as outlines. Concept maps have been hailed as a powerful tool for helping students link together material in disciplines such as biology."* (Nicoll *et al*., 2001b)

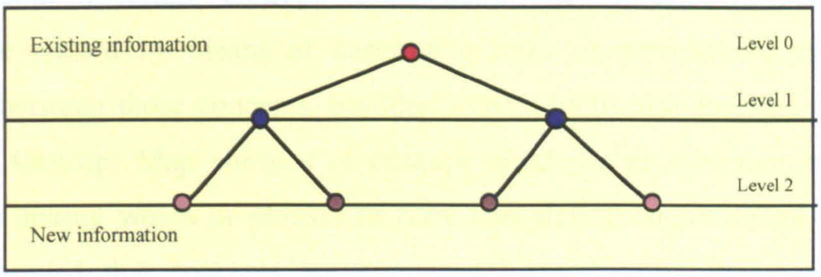
Nicoll *et al*. (2001a) asserted that Concept Maps represent students' knowledge structures and meanings in a particular domain. They contended that these maps are built by placing terms and ideas that represent the concepts to be mapped in structures called nodes. The nodes are then linked together into *propositions* (see Figure 5.1) to show how students link or connect the concepts. The 'map' created by each student gave the educators and students a visual representation of the student's prior knowledge and concept understanding. Brown (2003) asserted that "concept mapping became a way for students to visually organize their knowledge and understanding of a topic".

Figure 5. 1 A proposition



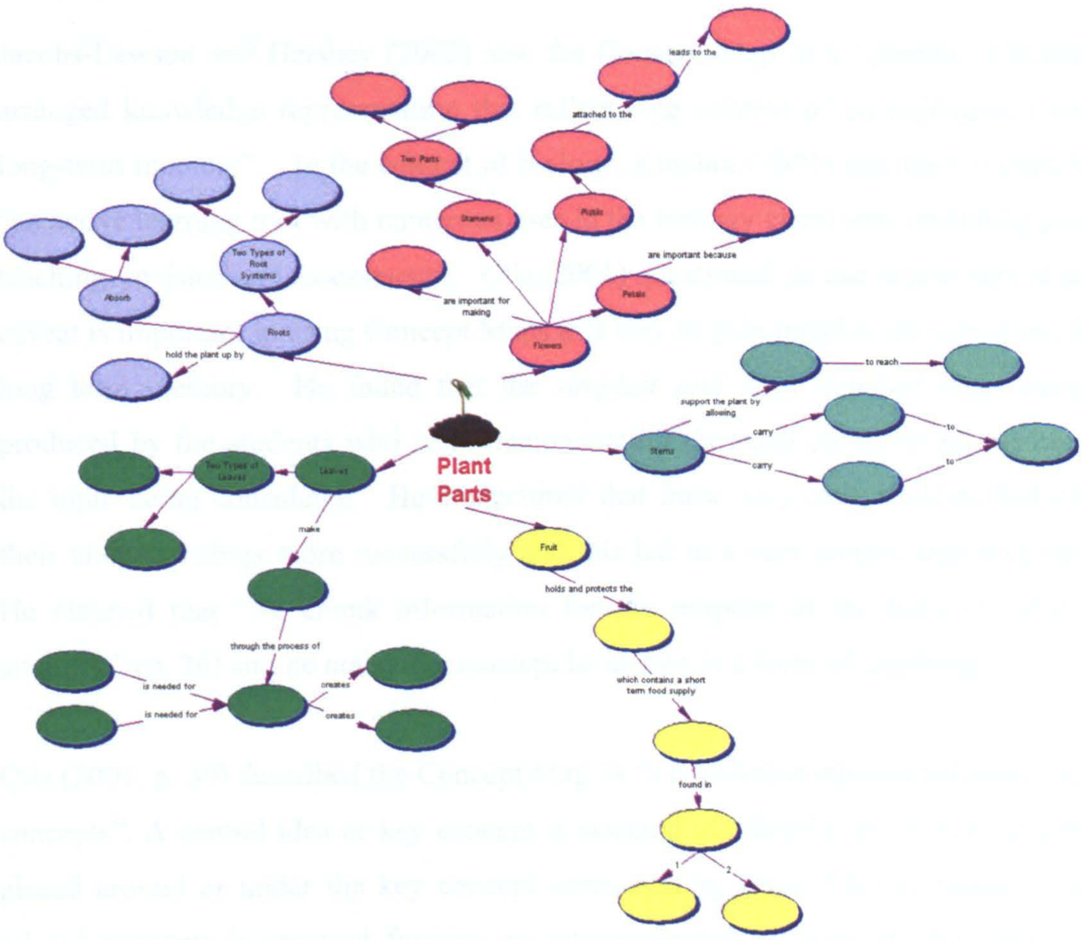
Otis (2001) taught concept mapping by placing the key concept or idea in the middle of the page. He called this the central node. Based on direct associations, branches are drawn from the central node to related nodes; call them 'level one nodes'. The number of level one nodes will vary from one key concept to another, and from one individual to another. Branching continues from each of the level one nodes to concepts directly related to them to level two nodes. The procedure is continued in this fashion expanding to level three, level four,… until the question has been adequately answered or the mapper's knowledge has been exhausted (see Figure 5.2).

Figure 5. 2 **Levels of knowledge network**



An example of Concept Map is presented in Figure 5.3. In this figure, each different color indicates a particular part of plant.

Figure 5. 3 **An example of Concept Map**
(Source: Anon, undated)



Freeman and Jessup (2004) supported the Novak ideas of Concept Maps when they asserted that:

> *"Concept mapping is a technique to let one person convey meaning and relationships to another person in a visual format, and concept maps have been shown to foster a joint understanding between two individuals viewing the same map."*

Zele *et al.* (2004) contended that Concept Maps represent a person's "structural knowledge about a certain concept or subject". They asserted that crucial terms (concepts) are related by means of descriptive links or propositions that show the relationships between those concepts. Stoddart *et al.* (2000) also asserted that the basic element of a Concept Map consists of concept words or phrases that are connected together with linking words or phrases to form complete thoughts called propositions. Hsu (2004) argued that concepts are organised hierarchically: the more general or inclusive concepts being placed at the top of the map, and the more specific or less inclusive concepts at the lower levels. The combination of two concepts and a labelled line is called a proposition or *concept link.* Cross links are used to indicate relationships among the concepts that are related to each other.

Jacobs-Lawson and Hershey (2002) saw the Concept Map as a "graphic, hierarchically arranged knowledge representation that reflects the content of an individual's semantic long-term memory". In the context of biology, Kinchin (2001) saw the Concept Map as "an active learning tool with numerous uses in the biology classroom, including planning, teaching, revision and assessment". Otis (2001) questioned its use in assessment and this caveat is important in using Concept Maps as a way to gain insights into structures held in long term memory. He found that the *simplest and least detailed* maps were often produced by the students who were demonstrating the *most complete understanding* of the topic being considered. He conjectured that these very able students had chunked their understandings more successfully and this led to a very simple cognitive structure. He claimed that "we chunk information for the purpose of the holding more within attention" (p. 26) and he noted that concept formation is a form of chunking.

Otis (2001, p. 30) described the Concept Map as "a non-linear representations of facts and concepts". A central idea or key concept is selected to related facts or concepts are then placed around or under the key concept connected by lines. This branching pattern of related concepts is repeated forming an interconnected network of ideas and concepts describing the key concepts.

According to Novak (1984), Concept Maps represent meaningful relationships between concepts in the form of propositions. These propositions are concepts connected by words in a semantic unit. This means that a properly constructed Concept Map could be read as a series of sentences describing the concept. He laid stress on the linking words; *is*, *for*, *contains*, *breaks down*, *eats*, etc. that add additional meaning and precision to the concepts being described. However, the interpretation of Concept Maps, in particular as an assessment tool, is open to all kinds of criticisms (see Otis, 2001) and it is easy to see how difficult it is to interpret the significance of linking words in any kind of formal assessment sense. According to Otis (2001), we transform our perceptions into concepts. Then, we create understanding by making links between concepts.

> *"A concept is an organising structure, a label, an abstraction, a condensing of many thoughts to a single one. This label continues to be an anchor that holds together all of the ideas that become linked and subsequently filed."* (Otis, 2001, p. 48)

The fundamental question is the extent to which the Concept Map as drawn by the student reflects the way their knowledge is actually organised in long term memory. Nonetheless, as a possible tool to explore the long term memory, the drawing of concept maps may be useful but they must be interpreted with caution.

5.10 Structural Communication Grid (SCG)

The original work of Egan (1970) developed the idea of the Structural Communication Grid (SCG) which had been used by many researchers (Johnstone *et al.*, 2000). Bahar and Hansell (2000) noted that Structural Communication Grids are "powerful assessment tools and they have been used by several researchers as a method of diagnostic and summative testing". In order to assess students' understanding, Structural Communication Grids have been used to test the "sub-concepts and linkages between the ideas" (Bahar and Hansell, 2000) held by students' minds. The diagram (Figure 5.2) below shows a basic structure of Structural Communication Grid presented in the study.

Figure 5. 4 An example of Structural Communication Grid

A	B	C ....
D	E	F ....
G	H	I ....

In the grid questions, the data are presented in the form of a numbered grid. The grid has no significance other than to hold an array of information.

The contents of the boxes can be words, phrases, pictures, equations, definitions, numbers, formulas, and so on. Many questions can be asked and there may be one or more correct answers placed in the grid. Also, some answers to one question may be answers to other questions. Strictly speaking, the questions should be related to the same topic to present them in a logical sequence. When the students are confronted with this kind of test, they do not know how many boxes are related to each question. They have to consider the contents of each box and decide which box or boxes is part of the answer to the question asked. This shows the ability of students to select relevant from irrelevant to answer the questions (Bahar and Hansell, 2000). For clarity, see Appendix E.

5.11 The Perry Scheme

Nearly all the existing psychological work on epistemological beliefs can be traced to two longitudinal studies by William Perry (1970) that began in the early 1950s. Perry's scheme provides a model of how students view knowledge. This scheme has served as a heuristic for understanding how college students make meaning of their educational experiences, and as a platform for multiple lines of research on epistemological beliefs (Hofer and Pintrich, 1997).

Perry carried out a series of intensive interviews with college students at Harvard University (Katung *et al.*, 1999). He identified a sequence of so called positions which represent ways in which students view themselves and their learning and how they can:

- Make meaning of their world;
- Interpret and make sense of the classroom environment;
- View knowledge and the process of learning;
- Understand the roles of the teacher and the students in this process.

(Katung *et al.*, 1999)

This gives insight into the way in which students seem to progress as they move through an undergraduate degree. The scheme has been described as a "continuum of developmental stages characterised by ways of thinking and behavioural patterns" (Katung *et al.*, 1999).

The positions identified by Perry are (Katung *et al.*, 1999):

(1)	*The world is seen in dualistic terms of good and bad: right and wrong answers exist to every problem in the absolute sense. It is the role of authority to teach the right answers to students. 'Rightness in exams is assessed by quantitative means'.*
(2)	*The student perceives diversity of opinion and uncertainty and treats them as unwarranted confusion created by poorly qualified authorities who set exercises so that students can learn to find the answers themselves.*
(3)	*The student accepts diversity and uncertainty as legitimate, but still temporary in areas where authority hasn't found the answers yet. He remains puzzled by the assessment standards.*
(4) a.	*The student perceives diversity and uncertainty to be extensive but considered legitimate, everyone has the right to one's own opinions but authority operates in a right and wrong system.*
(4) b.	*The student recognises qualitative, contextual, relativistic reasoning, but requires authority to tell them 'what they want' and to 'think how they want'.*
(5)	*The student perceives all knowledge and values as contextual and relativistic: however, a right/wrong value system can still operate within certain contexts.*
(6)	*The necessity for making some form of commitment within a relativistic world.*
(7)	*Some form of commitment is made in an area.*
(8)	*The implications of commitment and issues of responsibility are felt.*
(9)	*The student experiences the affirmation of identity among multiple responsibilities, and commitment is recognised as an ongoing activity through which life style is expressed.*
	(Katung *et al.*, 1999)

Although he described nine positions, in practice, there are 10, with position 4 being sub-divided. Mackenzie *et al.* (2003) had described how these positions reflect the persons' way of thinking about the world, self, knowledge, and how learning takes place. The positions are a hierarchical sequence in which individuals moved from relatively simple ways of perceiving and evaluating knowledge and the world. The student moves from a simple dualism type of approach to positions which are contextual and relativistic. Mackenzie *et al.* (2003) stated that "knowledge is seen as not absolute, and the student copes with this uncertainty by taking into account the settings in which decisions are made".

The first five positions are related to epistemological and intellectual development and the last four are related to ethical and moral issues (Katung *et al.,* 1999). The nine positions seem to occur in an invariant sequence. Movement along the continuum reflects an increasing maturity of thought. Each position serves as a necessary building block for the position to come and each one contains the qualities of the previous ones. The problem is Perry's model is quite complicated and there have been several attempts to simplify it.

Phillips *et al.*, (1998) found that, for most studies involving undergraduates, the first six positions are the most useful. In summary these are:

- Positions 1 and 2, defined as '*dualist*'. The student thinks in terms of right and wrong as a certain knowledge.
- Positions 3 and 4, defined as '*multiplist*'. The students' views are more complex. They understand that conflict of ideas and uncertainty are legitimate among different research schools. Thus, there are many good answers to a scientific problem.
- Positions 5 and 6, defined as '*relativist*'. The students understand that knowledge has a context. Hence, social issues might be a determining factor and scientist does not work in an 'ethical vacuum'.

Finster (1989) described the remaining Perry positions as:

- Positions 7-9, defined as *'commitment in relativism'*. The students are moving through positions 7-9 to make the commitments recognised as necessary in position 6. The students at positions 8 and 9 recognize the implication and responsibilities of commitment.

Johnstone (1998) adapted the Perry scheme into one that recognises three main positions which they are labelled A, B and C (Table 5.3).

Table 5. 3 Illustration of the Johnstone's categorisations of the Perry positions
(Source : Selepeng, 2000, p. 34)

Category / Position	Dualism	Multiplicity	Relativism	Commitment in Relativism
A	1 & 2			
B		3 & 4a		
C			4b & 5	6, 7, 8 & 9

There are four areas of possible application for Perry measurement scheme (Al-Shibli, 2003):

- The role of lecturers.
- The role of students.
- The view of knowledge.
- The view of exams.

The simplified model with three positions and four areas are described in Table 5.4.

Table 5. 4 **Description of 'Positions' in three-stage version of Perry scheme of entellectual development**
(Source: Mackenzie *et al.*, 2003)

Perceptions of:	*Student in Position 'A'*	*Student in Position 'B'*	*Student in Position 'C'*
Student's role	▪ Passively accepts	▪ Realises that some responsibility rests with the student. But what? And How?	▪ Sees students as source of knowledge or is confident of finding it. ▪ Discusses, and makes own decisions.
Role of lecturer or member of staff	▪ Authority, giving facts and know-how.	▪ Authority. ▪ Where there are controversies, wants guidance as to which view is favoured by staff	▪ Authority among authorities. ▪ Values views of peers. ▪ Member of staff as facilitator.
Nature of knowledge	▪ Factual; black and white; clear objectives; non-controversial; expectations unwelcome.	▪ Admits 'black and white' approach not always appropriate. ▪ Feels insecure in the uncertainties this creates	▪ Wants to explore contexts; seeks interconnections; enjoys creativity; scholarly work.
Student's task in examinations and assessments	▪ Regurgitation of 'facts'. ▪ Exams are objective. ▪ Hard work will be rewarded.	▪ Quantity is more important than quality. ▪ Wants to demonstrate maximum knowledge.	▪ Quality is more important than quantity. ▪ Wants room to express own ideas and views.

5.12 Other Techniques

Three other approaches will be used in this study, all seeking to offer insights into the way knowledge is structured in long term memory.

Lateral Thinking Test (LT): Lateral thinking has been discussed and described in terms of the ability to step outside a frame of reference. The aim in this will be to devise a short test where students are offered opportunities to demonstrate this skill in solving problems and to see whether the students who are best at this are also the more successful in solving a biology problem.

Ranking Test (RA): The idea behind this is that students will be offered a set of statements and invited to place them in an order according to some biological criteria. The hypothesis is that the students who have their ideas best linked in long term memory will be able to see the 'right' order more easily.

True-False Tests (T-F): It can be used in order to see quickly if students possess the correct information in long term memory. It is recognised that the element of guesswork will be high but the method is very fast. This factor will be important in that gaining access to university students for a long period of time is not easy.

5.13 Summary

It is planned to explore the information held in long term memory and how it is linked by seven methods outlined below. Of course, it is not possible to be certain if any of these individual methods will offer an accurate way of exploring long term memory. It is hoped, however, that by using all seven, some kind of reliable and meaningful picture might emerge: the insights offered by any one method can be matched against the insights offered by others.

(1) **A Word Association Test** can be used to reveal links that the students have made between the topic being assessed and other knowledge. It can also offer a picture of the strengths of links held between ideas.

(2) **Concept Map** can be used to explore prior knowledge and misconceptions, to encourage meaningful learning, to improve students' achievement, and, perhaps, to explore understanding of the knowledge.

(3) **Structural Communication Grid** is a method of assessment which can offer insights into understanding. The patterns of choices and omissions can reveal areas of strengths and weakness.

(4) **The Perry scheme** offers a language to explore aspects of attitudes towards learning. This can be used to develop assessments of student attitudes and to see how these relate to problem solving success.

(5) **The Lateral Thinking Test** is used to test the extent to which students' can form and use links between nodes of knowledge. In particular, it tests the ability of students to create or apply such links, this perhaps being summarised as the *accessibility* of links.

(6) **The Ranking Test** is used to explore the way ideas are linked in an ordered sense. It is thought that this ability may be related to student capacity to form and use links between concepts.

(7) **True-False Test** is used to measure the factual knowledge (nodes) and how much knowledge students have in their minds.

Chapter Six

Problem Solving Units

6.1 The Need for Problem Solving

Problem solving has become one of the most important lines of investigation in the field of science education in all science subjects, although work on open-ended problems in biology is still very limited. Lavoie (1993) contended that cognitive science offers a direction for science education research concerned with improving thinking and learning skills. However, it is acknowledged that the scope of problem solving has been too limited. Thus, for example, in looking at the school scene,

> *"While it has been established that the skill of problem solving has received a high profile in Scottish education as well as in other systems, it has also been noted that the type of problems that are usually under consideration are those which could be described as algorithms. In life, however, problems tend to be much more open-ended, less quantitative and less well defined."* (Yang, 2000, p. 33)

Facilitating the students' development of analytical and logical thinking skills is a high priority in modern science education. Such cognitive skills as analysing, hypothesising, manipulating variables, designing experiments, predicting, interpreting results, and evaluating of alternative solutions are all important skills to successful science learning (Hurst and Milkent, 1996). Smith (1991) in his book *Toward a Unified Theory of Problem Solving: Views from the Content Domains* defined problem solving as a "task that requires analysis and reasoning toward a goal (the 'solution')" (p. 14). Biology students in areas like genetics and ecology are often asked to predict outcomes resulting from interactions of multiple variables within a dynamic system. The development of effective predictive reasoning strategies can be considered as fundamental to learning in these two content areas. Research into how such skills are acquired and used has potential instructional benefits.

To explore how students approach problems in biology that are not algorithmic in nature, it is necessary to develop a set of problems that could be used with university students and which would allow exploration of the processes of problem solving. This chapter looks at the development of a set of more open-ended problems in biology for use with the first year biology students. The context of the course is described and the way the themes were selected is outlined.

6.2 Overview of the Course

The two Level-1 Biology modules (known as 1X and 1Y) are designed to provide a broad coverage of modern biology. Biology-1X runs in weeks 1-12 of the session October-January 2002-2003 while Biology-1Y runs weeks 14-25 of the next session February-May (Faculty of Biomedical and Life Sciences (FBLS), 2002-2003).

A compulsory lecture course forms the central core of both modules. The lectures provide students with a guide to what information students need to know, teach the main themes and explain difficult concepts. The overall aims of the course are set out as:

- *"To provide a broad-based understanding of modern biology in those areas selected for study.*
- *To provide the knowledge appropriate for continuing studies in biological subjects.*
- *To encourage the acquisition of general scientific skills relating to the systematic assembly, critical analysis, interpretation and discussion of factual information and data.*
- *To encourage a positive and inquisitive attitude to the personal investigation of science.*
- *To have obtained an overview of the basic concepts of biology and to have experienced the range of Biological subjects in which Glasgow offers Honours degrees and so be able to make informed choices for level-2 courses."*

(Faculty of Biomedical and Life Sciences, 2002-2003, p. 3)

6.3 The Preliminary and Main Study

The study was conducted over a 2-year period with first year students in the Faculty of Biomedical and Life Sciences at Glasgow University. The work was carried out during laboratory time, fitting in with other elements of the course. The number of students involved is shown in Table 6.1.

Table 6.1 Number of students involved in the study

The Experiments	Preliminary study		Experiments		
	1 (1X)	2 (1Y)	First Stage	Second Stage	Third Stage
Number of students	342	182	644	644	525

The preliminary study was designed to look at areas students perceived as difficult in the biology course. At that stage, problem units were devised, partly reflecting areas of perceived difficulty and partly reflecting the requirements as seen by staff in the Faculty. Three sets of experiments then followed over nearly a two year period. In these, a wide range of measurements were made with first year students, all relating to their performance in the problems.

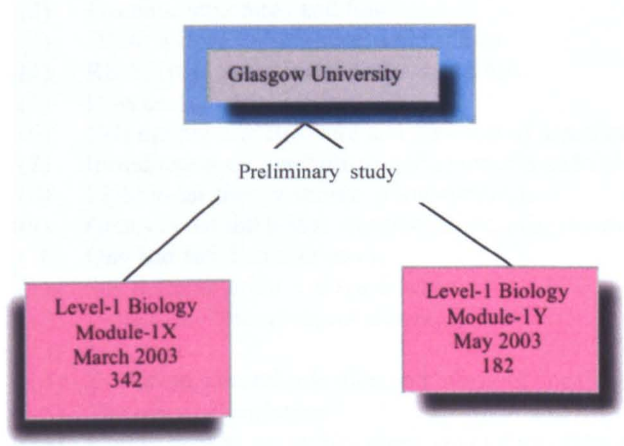
The theoretical framework underpinning this study is based on information processing. This considers input of knowledge, how it is processed, passed through a perception filter to working memory then stored in long term memory. Information processing also looks at how knowledge is represented and stored in long term memory and how ideas and information are linked together in long term memory. Specifically, this research seeks to offer insights on how declarative knowledge is structured and linked in long term memory. Various psychological and educational assessment tools were used with undergraduates to collect the data, based on the theoretical framework and research questions. These will be described later.

Ethical approval for conducting these tests was obtained from the Faculty Ethics Committee. In addition, permission was obtained from the Faculty of Biomedical and Life Sciences. Finally, permission was obtained from the students. Respondents were guaranteed confidentially and anonymity. They were informed that it was hoped that their participation would help future course planning.

6.4 The Preliminary Study

The aim of this study was to find out what are the most difficult topics in Level-1 Biology module. Two surveys were applied, each at the end of modules 1X (March 2003) and 1Y (May 2003) respectively. Samples were 342 and 182 students for the two surveys (see Figure 6.1). Topics for the problem units were influenced by the topics which were found to be difficult for students, the idea being that such units would benefit students.

Figure 6. 1 The preliminary study



Surveys and questionnaires are known to be useful ways to collect data quickly (see Reid, 2003). However, care needs to be taken to develop surveys which are likely to be give reliable and valid information. Sirhan (2000) used the survey method to pin-point the difficulties in a university chemistry course and compared his results with performance in these topics in the formal examinations. He found close matching of perceived difficulties with actual difficulties. This gives strong evidence of validity. With large numbers and a clearly presented survey, reliability is also usually assured (Reid, 2003).

In the surveys, the students were given a list of topics which they had been taught and instructed to mark each as: *Easy*, *Moderate*, or *Difficult*. They were also invited to write their comments where topics were thought to be difficult. In addition, another space was provided to write extra comments about the laboratories in biology, if they wished. The overall aims of module 1X are to provide:

- Knowledge of the structure and functions of cells, genes and biological molecules which forms the basis for further studies in biological sciences.
- An understanding of the molecular basis of living organisms: how genes encode proteins and how proteins determine cellular activities.
- An appreciation of how the techniques of molecular biology are being used in scientific and medical research and in industrial applications.
- Knowledge of plants and biotechnology which forms a basis for further studies in biological sciences.
- An understanding of how green plants function efficiently to capture and store solar energy, a process upon which all life on this planet depends.
- A basic knowledge of different types of microorganisms and how they affect our health.
- A critical awareness of: the evidence for evolution as the basis for the diversity of living organisms, and the mechanisms by which evolution is thought to have occurred.
- An appreciation of the range of problems encountered during the development of a plant from a seed to a fully functioning mature organism in a terrestrial environment, and of how the mechanisms involved in solving these problems have been elucidated in physiological and molecular studies. (Course Information Document, 2002-2003, p. 13)

The biology course at Level-1X consists of number of topics listed as below:

(1) Introduction to cells, atoms, and molecules.
(2) Proteins: structures and functions
(3) DNA: a store of biological information
(4) RNA: How genes are expressed as RNA.
(5) How cells make proteins.
(6) Cell membrane: structure and function of membranes.
(7) Introduction to metabolism, mitochondria and chloroplasts.
(8) Light as an energy source: photosynthesis.
(9) Genes in action: genes, chromosomes, mitosis, and meiosis.
(10) One and two factor crosses.
(11) Sex determination and sex linkage.
(12) Genetic and chromosome diseases.
(13) Microbes.
(14) Evolution, natural selection and origin of species.
(15) The story of evolution.
(16) Plants: light as an environmental signal and Nitrogen metabolism.
(17) How plants fix Nitrogen.
(18) Physiology of plants.

The overall aims of the Level-1Y module are to provide:

- A basic knowledge and understanding of the principles and biotechnology as they relate to plants and microorganisms with specific examples of genetically engineered plants and a discussion of the ethical questions involved.
- A broad understanding of animal form and function, laying particular emphasis on the anatomy and physiology of vertebrates especially humans.
- Information on human nutritional requirements, on how food is digested and absorbed by the body, and on how common health problems may be avoided or delayed by dietary management.
- A basic knowledge of the mammalian circulatory system and the way in which oxygen and carbon dioxide are carried to and from the tissues.
- An understanding of the composition of blood.
- A review of the different components of the body's defences against infection and an understanding of the immune response to selected pathogens and organ transplants.
- An appreciation of the structure and function of the mammalian kidney and the role it plays in homeostasis.
- An understanding of the process of chemical signalling within the body, with particular reference to the hormones produced by the pituitary.
- An appreciation of the advantages and disadvantages of both sexual and asexual reproduction and a basic knowledge and understanding of reproduction in humans.
- Provide an account of an explanation for the distribution, diversity and historical sequence of living organisms.
- Discuss the diversity of life cycles and reproductive behaviour as key features in the process of natural selection.
- Analyse how living organisms interact with their environments.

(Course Information Document, 2002-2003, p. 22)

The biology course at Level-1Y consists of number topics listed as below:

(1) Plant form and function
(2) Animal form and function: nutrition, transport and gas exchange.
(3) Animal form and function: the body's defences.
(4) Animal form and function: controlling the internal environment.
(5) Chemical signals and hormones.
(6) Reproduction.
(7) Communication science.
(8) Ecosystems.
(9) Biodiversity and conservation.

The surveys and their results are shown in full in Appendix A & B.

6.5 Analysis and Results (Module 1X)

The number of responses for each criterion in each topic were recorded and the percentages calculated. The most difficult topics are now listed and typical students comments are summarised in Table 6.2.

Table 6.2 **The most difficult topics in biology-1X**

No.	Topic Name	Percentage (%)
1	The dark-reactions of photosynthesis	21.1
2	The light-reactions of photosynthesis	17.5
3	Phytochrome and germination	15.2

The following information on biological concepts and definitions are extracted from Level-1 Biology modules 2002-2003, and Biology (text-book) for Campbell (2002, 6th edition) the recommended text-book for the course.

(1) To understand how plants use solar energy to fix atmospheric CO_2 into carbohydrates. Light and dark-reactions of photosynthesis are described in biology-1X. The light-reactions of photosynthesis, reveal the function of chlorophyll and caretonoids, how ATP and $NADPH_2$ are made, and how O_2 is evolved. The dark-reactions of photosynthesis reveal how the 'Calvin Cycle' was discovered, the basic reactions in C_3, C_4 and CAM metabolism, and the central role of RUBISCO. All reactions of photosynthesis not directly dependent upon light are known as the dark-reactions. They occur whether there is light present or not. The dark-reactions are metabolic steps called Calvin Cycle that occurs in the part of the chloroplast known as the *stroma*. Dark-reactions begins by incorporating from the air into organic molecules already present in the chloroplast. The purpose of dark-reactions is to take the energy from ATP and energised electrons and hydrogen ions from NADPH and add them to CO_2 to make glucose or sugar.

(2) All reactions of photosynthesis that are directly dependent upon light are known as the light-reactions. The light-reactions occur in the part of the cell known as the thylakoids (stacks of thylakoids are known as grana). Many chlorophyll molecules are found embedded into the membranes of the thylakoids. The purpose of the light-reactions is to convert light energy into chemical energy in the form of ATP and NADPH.

(3) Phytochrome and germination: Phytochromes are a family of plant pigments and a class of light receptors (mostly absorbing red lights) in plants. These photoreceptors regulate many of plant's responses to light throughout its life, including seed germination. As seed matures, it dehydrates and enters a phase referred to as dormancy 'to sleep", a condition of extremely low metabolic rate and suspension of growth and development. Conditions required to break dormancy vary between plant species. Some seeds germinate as soon as they are in suitable environment.

Students were invited to make comments where they found the topic difficult. Here is a summary of the most frequent comments almost all of which were negative in tone.

(1) The dark-reactions of photosynthesis (21.1 %)

Hard to see how they were linked	New topic-briefly were covered
Too many details to learn	Textbook support was poor
Not enough information	Not much in lecture notes
Confusing	Complicated for Red Light
Not very well taught	Lots of details
Difficult to understand	Taught previously, but now taught in different way using different terms
Complex	The mechanisms of these reactions were complex and processes were difficult to understand
Lots of learning	
Difficult to grasp concepts	
A lot of information were given	

In this topic students found it difficult to understand and grasp the concepts. Understanding seems a problem and they identified the problem as there being too much detail, yet not enough information. Together with the comments relating to linking ideas, it suggests that this is a topic where the amount of detail was obscuring the fundamental ideas, a classic case of information overload.

(2) The light reactions of photosynthesis (17.5%)		
Hard to see how they were linked Too many details to learn Not enough information Taught previously, but now taught in different way by using different terms Confusing The mechanisms of these reactions were complex and processes were difficult to understand Not very well taught Difficult to understand Complex		Lots of learning Difficult to grasp concepts A lot of information was given New topic-briefly covered Textbook support was poor Not well explained Don't much like photosynthesis on Near Red Light Confusing with terminology Too complicated Very vague

The comments are similar although the information overload seems more acute. There seem to be added complications with terminology, and the combination of the topic being seems as too complicated and vague. It is impossible to link ideas meaningfully when the amount of information is simply too high. The students could not see the key points and relate others to them.

(3) Phytochrome and germination (15.2 %)		
Very complicated Not well explained A lot of information Not enough time were giving Confusing New topic		Difficult Plants are tricky Too much to remember terms and fast getting lost Plant material covered in lectures was very dry and difficult to get a grasp of

The students are explicit in showing negative attitudes towards plant topics. However, the other comments were similar, suggesting a situation high in information. The 'too much to remember' and 'getting lost' comment are typical of learners who are being overwhelmed and cannot see the key issues as a rationalising framework.

6.6 Analysis and Results (Module 1Y)

The number of responses for each criterion in each topic were recorded and the percentages calculated. The most difficult topics are now listed and students comments are summarised in Table 6.3.

Table 6. 3 The most difficult topics in biology-1Y

No.	Topic Name	Percentage (%)
1	Cell mediated immunity	28.8
2	Antibodies	26.1
3	The immunological armoury	23.3
4	Arabidopsis, gene function	18.3
5	Gene expression in plant growth	17.8

The following information on biological concepts and definitions are extracted from Level-1 Biology modules 2002-2003, and Biology (text-book) for Campbell (2002, 6^{th} edition) the recommended text-book for the course.

(1) Cell-mediated immunity response is the branch of acquired immunity that involves the activation of cytotoxic T cells, which defend against infected cells, cancer cells, transplanted cells and active and passive immunisation.

(2) Antibodies: Proteins secreted by plasma cells (differentiated B cells) that binds to a particular antigen and marks it for elimination; also called immunoglobulin. All antibody molecules have the same Y-shaped structure and in their monomer form consist of two identical heavy chains and two identical light chains joined by disulfide bridges.

(3) The immunological armoury: It has many forms: Innate immunity provides broad defenses against infection as external defenses. External defenses as intact skin and mucous membranes from physical barriers that bar the entry of microorganisms and viruses. Internal cellular and chemical defenses: phagocytic cells ingest microbes that penetrate external innate defenses and help trigger an inflammatory response. In acquired immunity, lymphocytes provide specific defenses against infection: Antigen recognition by lymphocytes: receptors on lymphocytes bind specifically to small regions of an antigen. B cells recognise intact antigens. T cells recognise small antigen fragments.

(4) *Arabidopsis* is excellent for plant molecular biology and genetics: mutant characterisation and genome analysis provide information on gene function. *Arabidopsis thaliana* (or thale cress or mouse eared cress as it is commonly known) is a small flowering plant that is widely used by plant science researches as a model organism to study many aspects of plant biology in the same way that mice are used to help the researchers to learn about the workings of the human body.

(5) Gene expression: Gene is a discrete unit of hereditary information consisting of a specific nucleotide sequence in DNA (or RNA, in some viruses). Gene expression underlies plant growth, development and responses to the environment. It plays an important role in cell differentiation, development, and pathological behaviour. DNA microarrays offer biologists the remarkable ability to monitor the expression levels of thousands of genes in a cell simultaneously. Many genes are differentially expressed: spatially, temporally or in response to e.g. light, low temperature or touch.

Students were invited to make comments where they found the topic difficult. This section is a summary of the most frequent typical comments almost all of which were negative in tone.

(1) Cell mediated immunity (28.8 %)	
Not well explained and run too fast The lecturer needs to update his methods and how to use Campbell text-book Having a bit of irrelevant words on an overhead is no use at the last Complicated lectures	Concepts were poorly explained Notes provided weren't enough, just keywords which were hard to relate to the lectures Overheads were poor and explanation was brief Very detailed and lecturer went very quickly Too much information was given

The feature of the student comments seems to reflect that they could not cope with the pace or the language. The amount of information was too high and they could not grasp the concepts involved.

(2) Antibodies (26.1 %)	
Not well explained and run too fast The lecturer needed to update his methods and how to use Campbell text-book Having a bit of irrelevant words on an overhead is no use at the last Concepts were poorly explained Notes provided weren't enough, just keywords which were hard to relate to the lectures	Confusing Chemistry was difficult Overheads were poor and explanation was brief Difficult to learn structures of antibodies Very detailed and lecturer went very quickly Too much information was given

The underlying chemistry ideas were causing problems and, again, the pace and information load led to poor understanding.

(3) The immunological armory (23.3 %)	
Not well explained and ran too fast The lecturer needed to update his methods and how to use Campbell text-book. Having a bit of irrelevant words on an overhead is no use at the last Concepts were poorly explained Random words were used	Notes provided weren't enough, just keywords which were hard to relate to the lectures Complicated and some concepts were difficult to grasp Confusing Overheads were poor and explanation was brief Very detailed and lecturer went very quickly Too much information was given

The same pattern of problems is also evident here. In the last three topics, the overload of information coming at the students is too fast, with language difficulties and lack of background knowledge. These are all characteristics which lead to poor understanding and student disillusionment. Overall, information overload allows the learner no way to develop sound understanding. The only solution is to resort to memorisation or simply give up.

(4) Arabidopsis, gene function (18.3 %)	
Not fully explained	Topics are boring and hard to conceive
Was difficult to understand	Plant work was hard
Confusing	Very boring
Lectures were not engaging and accessible	Difficult because content was quite dry

In both topics (4) and (5), there is evidence of pre-conceived ideas of difficulty. This can often lead to statements expressing boredom. Clearly, the students were not able to engage with the subject matter and were left in a state of confusion.

(5) Gene expression in plant growth (17.8 %)	
Genes were difficult	Topics were boring and hard to conceive
Not fully explained	Plant work was hard
Was difficult to understand	Very boring
Confusing	Difficult because the content was quite dry
Lectures were not engaging and not accessible	

6.7 Criteria and Description of Units

In designing these units, several factors were considered. The topics of the problems had to reflect themes and objectives of the modules in the biology course at level-1. The topics chosen also took into account the areas where students were indicating difficulties. A large number of units was devised but the choice of the ones used in this study also took into account the wishes of the faculty staff.

Open-ended problems tend to be the most frequently encountered in life. Several studies concluded that the ability of students to apply scientific knowledge to their real-life problems is very important. Hence, the research also considered social issues and real-life problems as factors in deciding which subjects would be chosen.

The Faculty of Biomedical and Life Sciences wished to have problem-based units in biology course. Group work allowed for many useful skills to be developed as well as giving the students an unthreatening experience in problem solving with open-ended problems in biology. However, in order to explore cognitive aspects of problem solving, individual problems were required. To meet these contradictory needs, a set of group-based problems were devised. These were used to develop confidence and many desirable skills (like team working, verbal communication). Performance in these units was not assessed. One unit was then used on an individual basis, it being designed to have a similar format. Success in this unit was assessed and related to several cognitive measures.

The group problems were deliberately designed to be quite difficult so the students could not satisfactorily solve them on an individual basis. In addition, they were designed in such a way that they moved beyond the recall of rote knowledge and required enough knowledge to be applied and discussed.

The only way students can solve problems is to use their own previous knowledge held in long term memory. If the students do not have sufficient background or face difficulties in making connections between concepts, solving these problems will be difficult.

The overall aim was an attempt to gain insights into the ways' students solve open-ended biology problems. This was based on how they handled the individual problem. The focus was on the way long term memory was functioning as a factor determining success for such problems. This involves much more than the recall of information. The aim was to explore how concepts and linkages between concepts might influence success in solving problems. It was also important to look for any other factors relating to long term memory.

6.8 The Units

The problem-solving exercises were called "UNITS", this word being neutral, hopefully not causing students to have unnecessary concerns. Students were told that performance in the units was unrelated with examination marks and answers obtained were not exactly "right" or "wrong". It was hoped that this would encourage genuinely open discussion which would provide useful insights into problem solving.

It was critical to use careful design and layout, to minimise any difficulties during solving the problems. Accurate and careful structuring of questions was employed and diagrams and tables were used wherever appropriate. Great care was taken to use language that was appropriate to students in terms of biological ideas.

Because of the need to use the units with students at the right stage of their course (so that the unit theme fitted in with topics being studied), formal pre-testing of the units was not possible but the units were scrutinised by a small group postgraduate research students in the Centre for Science Education and several experienced biology staff. Minor adjustments were then made to them.

To minimise confusion when students were solving the problems, each unit was laid out in the same way: the title, the use of boxes and shading to guide the instructions of task on one side of A4 paper. In addition, space was specifically set aside to encourage students to write notes or calculations whenever needed during problem solving. This was mentioned several times on the question and answer sheets to encourage students to talk and write in a group. Each unit had a separate "answer sheet" which was completed by each group, sharing their answers and their working.

Each unit began with basic and introductory information. Usually, there was a strong biological component linked where appropriate to a numerical component and ethical component. The units had the following features:

- Recognition of key biological terms and an ability to define them.
- Extraction of precise information from experimental data.
- Simple arithmetical calculations.
- The interpretation of numerical and graphical data.
- The design of simple experiments.
- Expressing views supported by evidence.

All students completed one unit *A Model Organism* and then one of *The Chicken Run* or MMR Vaccine. These three units were completed with students working as groups. The use of these units was decided by faculty staff to suit the needs of students. At this point, students completed a unit on an individual basis and this unit was used for the study: *Forests that Need Fires*. This procedure was followed only in the first and third stages of experiment (see Table 6.4).

Table 6.4 Experimental plan

Experiment	Approximate Time (minutes)
Introductory explanation	15
First group discussion ***A Model Organism*** (all students did it)	45
Second group discussion Either ***The Chicken Run*** or ***MMR Vaccine***	30
Individual problem (All students did it) ***Forests that Need Fires***	20
Educational tests	20
Total	130

Students also took a series of educational tests as described in chapter 5. Different groups took different tests simply because it was not possible to ask all students to complete all tests on grounds of excessive time demand. In the second experiment, which involved the same students as the first experiment, only educational tests were used.

Tutor guides were prepared for the staff of Biology Department to aid them to administer the problems sessions. These offered an outline of the aims of the units and how to run them with student groups, as well as indicating likely possible answers. All tutor guides with the units are shown in full in Appendix C.

6.9 The Four Units Used

To illustrate the style of the problem units, one unit is shown here in full. This unit is entitled, *Forests that Need Fires*. Some plants can survive in severe conditions such as natural fires. Indeed, some trees such as pines cannot survive without periodic fires. Their cones open and their seeds germinate only after they have been exposed to fire. This observation led to the development of the unit. After an introductory exercise to make the student think about temperature ranges, the student is taken through a series of questions. This was the unit used on an individual basis.

The other problem units are then described briefly and are shown in full in Appendix C.

Unit 3

Forests that Need Fires

Matriculation Number: ....

Introduction

Forest fires are common especially in countries like Australia and USA where there are extended dry seasons. These fires, although they are now often caused by humans, have probably been a feature of such habitats for a sufficient time that plants and animals have evolved alongside fire and may show particular adaptations to it as an ecological factor.

You will be working individually.
Think about possible answers to the questions below.
Write your answers in the spaces on the sheets.

This exercise has four parts.

Part One

Temperature

(1) From the list of temperatures, choose the right one for each of the four situations:

1. Coal fire	......	(A) 10,000-15,000°C
2. Boiling water	......	(B) 5,500-6,000°C
3. Surface of the sun	......	(C) 900-11,000°C
4. A grassland fire	......	(D) 700-900°C
		(E) 100°C
		(F) 90°C

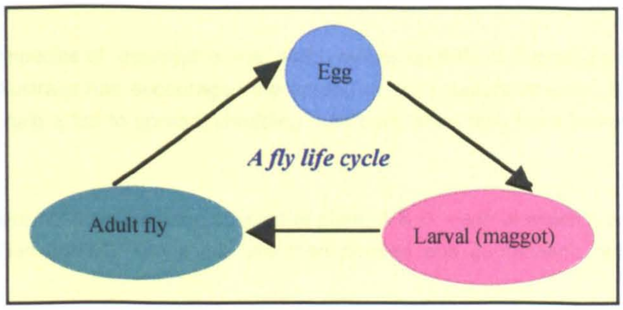
Write letters here

Part Two

Biology of the plant

Describe adaptations of a plant adapted to fire

If the life cycle of a fly is:



(1) Draw a diagram showing the life cycle of a plant, starting with the seed in the box below:

(2) Suggest how plants might protect themselves against fire.

....

....

....

(3) What stage of the plant life cycle might benefit from fire and why?

....

....

....

Part Three

Seed germination: Interpret data and design an experiment

Fires are a natural way of clearing old growth, causing organic matter to decompose rapidly into mineral components which fuel rapid plant growth, and recycling essential nutrients, especially nitrogen. Some species of trees also survive periodic blazes. The cones of Lodgepole and jack pines open and their seeds germinate only after they have been exposed to fire.

There are approximately 700 species of `eucalyptus tree, which makes up 90% of Australia's forests. At least 20,000 years of human grass burning in Australia has encouraged the spread of fire resistant species. Some eucalyptus species are largely fire-resistant but can help a fire to spread, shedding their bark when they burn and releasing flammable oils from their leaves.

The table shows an experiment conducted on two species of plant, A & B, each of which has seeds placed on a dish with some dry grass, which is then burned. The seeds are then planted and germination recorded, together with that of unburned controls.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Plant Treatment</td></tr>
<tr><td>A</td><td>B</td></tr>
<tr><td rowspan="2">Treatment</td><td>Fire Treatment</td><td>Most germinate</td><td>Few germinate</td></tr>
<tr><td>No Fire (control)</td><td>None germinate</td><td>Most germinate</td></tr>
</table>

(1) Describe the pattern shown by the data.

(2) Try to explain its biological significance.

(3) Design an experiment to determine how much heat the seeds of species A can survive?

Part Four

Management strategy : How will you manage a National Park?

You are charged with managing a National Park in a habitat that experiences periodic but unpredictable occurrence of fire?

(1) What would you do when fires broke out and why?

....

....

....

....

....

....

6.10 The Group Units

A brief description of each unit is given below. The units are given in full with teachers' guides in Appendix C.

Unit 1: A Model Organism

The result of the difficulty survey showed that the students were having difficulties to grasp gene concepts and all the concepts relating to that topic. In unit 1, an important model organism: *Arabidopsis thaliana* was chosen to be as unit 1. It is discussed earlier in section 6.6. This unit has five parts including the introduction (see Table 6.5) and they are as follows:

Table 6.5 The description of the content of unit 1

	Title and goal	*Discussion*
Introduction	This part had list of terms and definitions and two discussion questions.	The purpose was to see whether students can recall the factual knowledge regarding genetics terms.
Part one	Identifying a suitable model plant species.	Searching about a model species and what is used for.
Part two	Looking at some model organisms.	Giving some examples about model organisms in another fields of biology in an attempt to lead to the characteristics of these model species in common.
Part three	Identifying a suitable model plant species.	Seek the optimum size of model organism in genetics comparing to other model organisms in another fields of biology.
Part four	Data and interpretation of *Arabidopsis thaliana*.	This part showed molecular techniques that can be used to manipulate DNA sequences.

Unit 2A: The Chicken Run

In unit 2A, students were given background about how the frozen chicken industries ship over thousand tones of chicken into some countries. Routinely in each week, they pump the meat full of water to make it weigh more thus swelling profits. The unit was developed to drive the students to think how that can happen and what are the ingredients are added to keep water preserved in chickens to give such a big weight. The ethical issues generated after that are considered. This unit has three parts (see Table 6.6) and they are as follows:

Table 6.6 The description of the content of unit 2A

	Title and goal	*Discussion*
Part one	Biological component: What do you know about the biology of the test material.	In here, trying to seek about introductory information about genetics in general.
Part two	Numerical component: Examine the data in the tables and calculate some relationships.	Calculating the percentages of tested samples was a purpose of this section.
Part three	Ethical component: Discuss the ethics of the food industry based on the evidence presented in the unit.	Seeking the ethical issues behind this kind of processes.

Unit 2B: The MMR Vaccine

In unit 2B, the students were given information about report of an MMR Expert Group established by the Scottish Executive in response to issues surrounding the alleged relationship between the combined measles, mumps, and rubella vaccine and autism. The combined measles, mumps, and rubella (MMR) vaccines were introduced into the UK childhood immunisation programme in 1988. However, speculation had surrounded MMR because of hypothesised connections to inflammatory bowel disease and autism. With a minority of parents in Scotland (now 12%) declining to have their children immunised by the age of two years, there have been calls for a change in policy to allow parents to choose between MMR and single vaccines. This unit seeks to understand whether students can response towards different aspects of questions as in Table 6.7. It has four parts including the introduction and they are as follows:

Table 6.7 The description of the content of unit 2B

	Title and goal	*Discussion*
Introduction	This part had background of MMR history and the actions being taken from the Expert Group.	
Part one	Establishing a background knowledge of basic immunological terminology.	The purpose was to see whether students can recall the factual knowledge regarding immunological terms.
Part two	Examination of data.	After presented some graphs, there are seven questions given about those graphs.
Part three	Benefits and problems associated with public immunisation programmes such as MMR.	This section more relating to social and ethical issues.

It was planned to use a second individual open-ended problem with the students but time prevented this from taking place. This was based on *photosynthesis* and is shown in full in the Appendix J.

Chapter Seven

Experimental Work: Stage One

7.1 Introduction

In his analysis, Johnstone (1993) regarded problems of type 4, 6-8 problems as open-ended (Table 7.1 shows a simplified outline of this analysis). In these, at least *two* of the three features (data, methods, goals) are incompletely known (see chapter 2). The problems used in this study aimed to fulfil these criteria.

Table 7.1 Problem classification (after Johnstone, 1993)

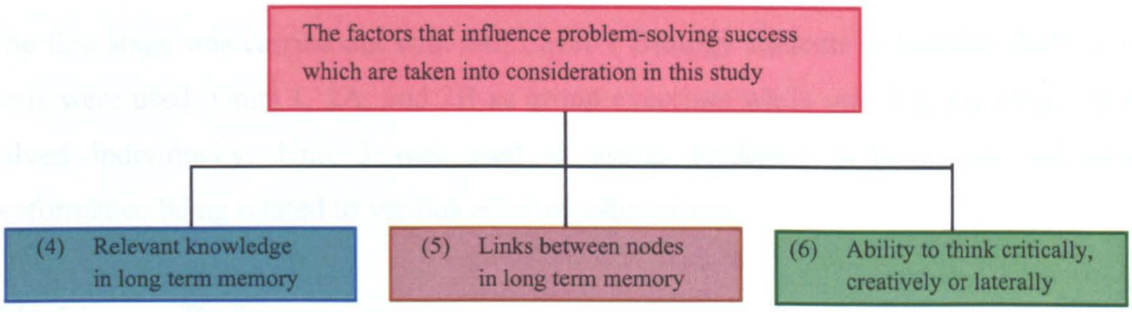
Type	Data	Methods	Goals
1	Given	Familiar	Given
2	Given	Unfamiliar	Given
3	Incomplete	Familiar	Given
4	Incomplete	Unfamiliar	Given
5	Given	Familiar	Open
6	Given	Unfamiliar	Open
7	Incomplete	Familiar	Open
8	Incomplete	Unfamiliar	Open

Yang's (2000) work indicated that success in problem solving might depend on six factors (as discussed earlier in section 2.7). She suggested that success in problem solving might depend on:

1) Working memory space.
2) Extent of field-dependency.
3) Willingness to take cognitive risks (may include confidence).
4) Relevant knowledge held in long term memory.
5) Links between nodes of knowledge in long term memory.
6) Ability or willingness to think critically, creatively or laterally.

Three of these factors are explored further in this study (see Figure 7.1).

Figure 7. 1 The three factors that are examined in this study



Factors 1 and 2 are already well established while Yang also explored factor 3. She found evidence to support factors 3 and 5 while she found implicit evidence of factor 4. She did not explore factor 6 (Reid and Yang 2002b). Here, the aim is to seek the role of factors 4, 5 and 6. Yang suggested that problem solving seems to be dependent on the functional links between what were called '*islands of knowledge*' in long term memory. Also, the knowledge seems to be chunked in long term memory as islands or nodes and the quality of links between nodes of knowledge is important too (Reid and Yang 2002b).

A reasonable hypothesis might be to suggest that success in problem solving in open ended problems might be dependant on the number of links (usable, relevant and accessible) in long term memory. Being able to chunk such links into useful units of knowledge might also be important. Another possible hypothesis might be the ability to create links in long term memory and this might be related to creativity or lateral thinking, perhaps divergency. These hypotheses formed the basis on which the development of the test material took place.

7.2 The First Stage

The first stage was carried out with 642 Level-1 Biology students in October 2003. Four units were used. Units 1, 2A, and 2B as group exercises while unit 3 is a problem to be solved individually. Unit 3 was used to assess student's performance, individual performance being related to various other measurements.

Table 7.2 The first stage

Level-1 Biology (Glasgow University)	
Date	First term (Oct 2003)
No. of teaching units	4
No. of tests	5
Total number of students (N)	642

All students undertook units 1 and 3, while about half completed unit 2A and another half completed unit 2B. The choice of the units to be used was influenced strongly by Faculty wishes, to meet their teaching requirements. The group exercises (1, 2A & 2B) were designed to develop problem-solving type skills with students as well as offer some insights into important biological themes. Specifically, they allowed the students to become accustomed to the more open style of the problem solving in biology and, therefore, to face unit 3 with a degree of confidence. Only a small number of the other three units were marked, this being less meaningful as marks reflect group performance. Marking of group units is shown in Appendix I. Table 7.3 shows the units used and number of groups and students involved in each unit.

Table 7.3 The units and the number of groups and students involved in first stage

Units	*Name of units*	*Type of work*	*Numbers involved*
1	*A Model Organism*	Group	176 groups
2A	*The Chicken Run*	Group	97 groups
2B	*MMR Vaccine*	Group	70 groups
3	*Forests that Need Fires*	Individual	642 students

Unit 3 was done individually and five short (5-10 minutes) tests were devised. Because of time, any individual student only took two tests. The tests were designed to offer insights into knowledge and links between nodes that the students brought to their attempt on unit 3. The tests are summarised in Table 7.4.

Table 7.4 The tests and measurement intentions

No.	*Tests*	*Measurement*
1	True-False test 1 (TF1)	To test the factual knowledge / nodes in long term memory
2	True-False test 2 (TF2)	
3	Word Association Test (WAT)	To test links between nodes to see if they exist in long term memory.
4	Structural Communication Grid (SCG)	To test concepts being understood by students.
5	Perry Position Questionnaire (PPQ)	To test the attitudes of students towards aspects of learning.

The first four tests (Table 7.4) were based on plant (flower) germination, of direct relevance to unit 3.

The units and the tests were completed in laboratory class time. The students come to laboratories in groups up to about 50, two laboratories being available at any time. This is shown in Table 7.5.

Table 7. 5 Schedule of the first stage in October, 2003

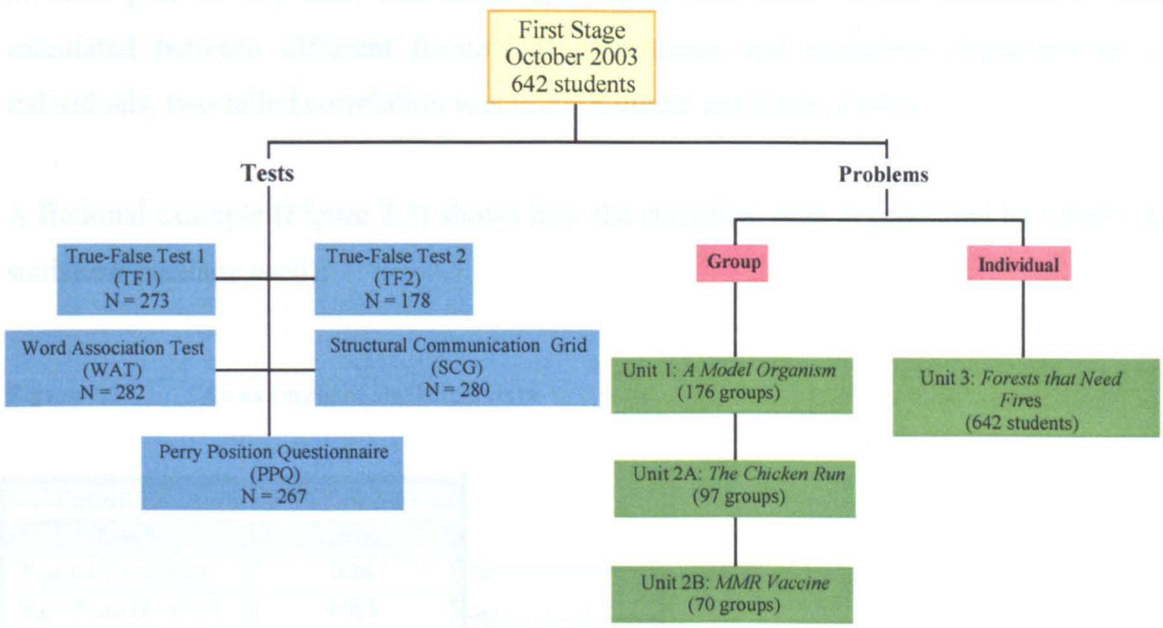
Day	*Time*	*Tests for Lab 1*	*Tests for Lab 2*	*Number of students*
Tuesday	a.m.	TF1 & SCG	TF1 & SCG	87
	p.m.	TF2 & PPQ	TF2 & PPQ	83
Wednesday	a.m.	WAT & PPQ	WAT & PPQ	91
	p.m.	WAT & TF1	WAT & TF1	91
Thursday	a.m.	TF2 & SCG	TF2 & SCG	94
	p.m.	TF1 & PPQ	TF1 & PPQ	92
Friday	a.m.	WAT & SCG	No lab classes	99
	p.m.	WAT & SCG		
TF1: True-False test 1; TF2: True-False test 2; WAT: Word Association Test; SCG: Structural Communication Grid; PPQ: Perry Position Questionnaire.				

Table 7.6 shows the number of tests applied in each laboratory session with number of students involved, and the time for each test. Finally, Figure 7.2 shows the summary of first stage and what tests and units were used at that level. In the entire project, the time available was a major constraining factor in making all measurements and applying problem-solving units.

Table 7.6 Number of tests applied in the first stage

Tests	*Number of lab sessions for each test*	*Number of students*	*Time (minutes)*
True False Test 1 (TF1)	6	273	10
True False Test 2 (TF2)	4	178	10
Word Association Test (WAT)	4	282	10
Structural Communication Grid (SCG)	6	280	10
Perry Position Questionnaire (PPQ)	6	267	5

Figure 7.2 Summary of the first stage



7.3 Statistical Analysis of Data Obtained

Pearson Correlation: The aim was to relate students' performance in unit 3 to their performance in the various tests they undertook, each student taking two out of a battery of five tests. Pearson correlation was used to test for any relationship. The Pearson correlation coefficient (r) is a parametric correlation coefficient and it is often referred to as "Pearson's product moment correlation" (Hinton *et al.*, 2004). It is defined within the range of -1 to +1. Essentially, it works out a measure of how scores of two variables vary together (their 'product') and then contrasts this with how much they vary on their own. It is devised to measure the strength or degree of a supposed linear association between two variables. Therefore, it works best when the variables are approximately normally distributed and have no outliers (Kinnear and Gray, 2000). This was checked for all the data obtained in this study – see Appendix G & H.

Pearson's correlation relies on a number of assumptions:

- The relationship between variables is linear.
- The points are evenly distributed along the straight line.
- The data are drawn from normally distributed populations.
- The data collected must be interval or ratio, from continuous distributions.

A *two-tailed* test does not assume that the correlation will be positive or negative. With a *one-tailed* test, it can be deduced beforehand that the correlation is going to be a positive or negative. When correlations were calculated between different formats of assessment in each part of any test, one-tailed correlation was used. When correlations were calculated between different formats of assessment and cognitive characteristics of individuals, two-tailed correlation was used (Kinnear and Gray, 2000).

A fictional example (Figure 7.3) shows how the statistical data is generated by SPSS (the statistical package used):

Figure 7.3 An example of statistical data

	Test 2
Test 1	
Pearson Correlation	0.26
Significant (2-tailed)	0.001
Sample (N)	273

*** Correlation is significant at the 0.01 level (2-tailed).*

The correlation coefficient is 0.26 with a p-value (2-tailed) of 0.001 (r is significant at the 0.1% level)

A conventional way of reporting these figures would be as follows:

$r = 0.26, N = 273, p < 0.001$ (2-tailed)

These results indicate that as success in test 1 increases, test 2 performance also increases, a positive correlation.

The appropriate illustrative statistic to support Pearson correlation is a scatterplot (Hinton, *et al.* 2004).

Kendall tau_b Correlation: Kendall tau_b correlation is a non-parametric correlation coefficient and labelled by Greek letter τ. It is a measure of association between two ordinal variables and takes tied ranks into account (ranking and ordered categories). It can be used for small data sets with a large number of tied ranks. Therefore, it works regardless of the distributions of the variables. In the Kendall tau_b statistic, all the scores are ranked on each variable. It assesses how well the rank ordering on the second variable matches the rank ordering on the first variable. Kendall tau_b ranges from -1 to +1 and probability is stated in a similar way to Pearson's correlation. This is used when questions in the Perry Position Questionnaire were analysed because the data are not necessarily normally distributed and there are many tied ranks (Kinnear and Gray, 2000).

7.4 Unit 3 Analysis

Before describing assessment tools and their analysis and results, the description of unit 3 answers (in red) will be shown in this section. Table 7.7 shows the scoring (in blue) of unit 3.

Unit 3
Forests that Need Fires (28 Marks)

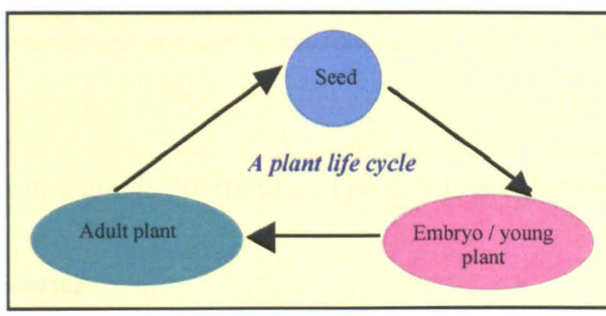
Part One
Temperature

(4 Marks)

(1) Coal fire (C) 900-11,000°C
(2) Boiling water (E) 100°C
(3) Surface of the sun (B) 5,500-15,000°C
(4) A grassland fire (D) 700-900°C

Part Two
Biology of the plant
Describe adaptations of a plant adapted to fire

(1) Draw a diagram showing the life cycle of a plant, starting with the seed. **(4 Marks)**



(2) Suggest how plants might protect themselves against fire? **(3 Marks)**

Fire resistant by producing:
- outer protective shell of seed or stem (hard coat);
- hard bark and spongy/air spaces in the bar;
- roots deep in soil or bulb below ground level.

(3) What stage of the plant life cycle might benefit from fire and why? **(4 Marks)**

1. Seedling stage or seed germination.
2. The benefits are:
a. Seed germination
b. Clearing old growth of plant.
c. Causing organic matter to decompose rapidly into mineral components that enhances rapid plant growth (produces fertile soil by recycling essential nutrients).
d. Adult plants that can survive the fire by getting more light and nutrients.

Part Three
Seed germination: Interpret data and design an experiment

(1) Describe the pattern shown by the data. **(2 Marks)**

Fire is essential for the most of plant (A) to germinate but only for few of plant (B) which means that plant (B) will be damaged if it is exposed to fire. On the other hand plant (A) will benefit from that exposure.

(2) Try to explain its biological significance. **(3 Marks)**

Plant (A) is adapted to area or habitat where fire is more common rather than plant (B) which might be rarely germinate in that kind of habitat.
What is the advantage that plants can get benefit from the effects of the fire.

(3) Design an experiment to determine how much heat the seeds of species A can survive.
(4 Marks)

This can be done by exposing the variety (certain different) number of seeds to different temperatures and compare, which will survive under these different conditions and see which is the suitable condition for them.
What is the purpose of the experiment?
What you will do? (Procedure)
What is the conclusion?

Part Four
Management strategy: How will you manage a National Park?

(1) What would you do when fires broke out and why? ***(4 Marks)***

What to do?
Stop immediately.
Part of plants could be burnt and then stopped.
Allow to burn itself out.
Why?
Need to say something about conservation.
Need to explain how fire can conserve species diversity.

The time provided for this unit is 20 minutes. The unit is divided into 5 sections:

Table 7. 7 Unit 3 scoring

Objectives for each part	Marks	Questions included
Knowledge	4	Part 1: Q1
Understanding	11	Part 2: Q 1, 2 & 3
Implication	5	Part 3: Q1 & 2
Experimental	4	Part 3: Q3
Analysis	4	Part 4: Q1
Total	28	

7.5 Assessment Tools

Each of five assessments is described briefly along with the results obtained.

7.5.1 True-False Test 1 (T-F1)

In this study, True-False test 1 was conducted to test the relevant factual knowledge or ideas (nodes) that exist in students' minds and to see if students can recall the information from long term memory. This test was applied to a sample of 273 students. It was developed carefully on the basis of Level-1 Biology module-1X about the basics of seed structure, flower structure, and germination of seed and flower. This test was devised to see if students grasp the concepts of seed structure and some parts of flowers. It was also related closely to that topic in the Higher Grade Biology text-book (Torrance, 1991), this course having been studied by most students at school. Six groups completed this test: two groups did it along with the Structural Communication Grid test (N = 87), two groups with the Perry Position Questionnaire (N = 92), and another two groups with the Word Association Test (N = 91). The time provided for this test was 10 minutes. This test marked as one mark for each sentence with a total of 12 for 12 sentences. Table 7.8 shows the results of descriptive statistics for True-False test 1. Figure 7.4 shows the test and its correct answers.

Figure 7.4 **True-False test 1 and its correct answers**

Tick whether you think each statement below is true or false

	Statement	TRUE	FALSE
1	Three main parts of a seed are: embryo, cotyledons and root.		
2	Germination is the development of a plant embryo into an independent plant with green leaves.		
3	All seeds need for germination is water, carbon dioxide and a suitable temperature.		
4	The seeds of some plants can survive exposure to fire.		
5	The germination of seeds may depend on a variety of environmental stimuli. These vary between species, but may include frost or fire.		
6	Stamens contain the flower's female sex cells (gametes).		
7	Pollen grains contain the plant's male sex cells (gametes).		
8	Cross-pollination is the transfer of pollen from an anther to a stigma in the same flower or in another flower on the same plant.		
9	Self-pollination is the transfer of pollen from an anther of one flower to a stigma in a flower on another plant of the same species.		
10	Fertilisation is the process by which the nucleus of a male sex cell (gamete) fuses with the nucleus of a female sex cell (gamete) to form a single cell called a zygote.		
11	Fertilisation in flowering plants takes place inside an ovule.		
12	If it were not for attack by wood boring insects, trees would not need thick bark.		

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	F	T	F	T	T	F	T	F	F	T	T	F

Table 7.8 **Descriptive statistics for True-False test 1**

	N	Minimum	Maximum	Mean	Std. Deviation
True-False test 1	273	3	12	8.9	1.7

Pearson correlation (see Table 7.9) was highly significant between unit 3 and the True-False test 1: 0.26 ($p < 0.001$). Other correlations are also significant (except for the Perry Position Questionnaire) and will be discussed later in subsequent sections.

Table 7. 9 **Correlation results for True-False test 1 with unit 3 and other tests**

True-False test 1 Correlations	Unit 3	Word Association Test	Structural Communication Grid
Pearson correlation (r)	0.26	0.21	0.33
Significance (2-tailed)	p < 0.001	p = 0.047	p = 0.002
Sample (N)	273	91	87

Table 7.10 Correlation results for True-False test 1 with five areas in unit 3

True-False test 1 Correlations	Knowledge	Understanding	Implication	Experiment	Analysis
Pearson correlation (r)	0.03	0.19	0.18	0.04	0.06
Significance (2-tailed)	n.s.	p = 0.002	p = 0.003	n.s.	n.s.

Correlation was used between True-False test 1 and all five areas (knowledge, understanding, implication, experiment, and analysis) in the unit 3 test (see Table 7.10). Performance in True-False test 1 is correlated significantly with two of the parts of unit 3, 'Understanding' and 'Implication'. This might suggest that implication requires basic background knowledge as measured by True-False test 1. Equally, It is possible that the recall of background knowledge is better when the knowledge is understood in its context. This conclusion is true for all subsequent correlations with other tests in the following sections.

7.5.2 True-False Test 2 (T-F2)

True-False test 2 aimed to test the recall of conceptual knowledge about functions of flowers' and seeds' parts, testing if students can link between structures and functions of flowers and seeds was another purpose. This test was applied to a sample of 178 students. It was developed carefully on the basis of Level-1 Biology module-1X about the basic definitions and functions of some of seed and flower parts. It also related closely to that topic in the Higher Grade Biology text-book (Torrance, 1991). Four groups completed this test: two groups did it with the Structural Communication Grid (N = 94), and another two groups with the Perry Position Questionnaire (N = 83). The time provided for this test was 10 minutes. This test was marked in the same way as True-False test 1. Table 7.11 shows the result of descriptive statistics for True-False test 2. Figure 7.5 shows the test and its correct answers.

Figure 7.5 **True-False test 2 and its correct answers**

Tick to show whether you think each statement below is true or false

	Statement	TRUE	FALSE
1	Anther is the structure containing embryo plant and food store formed from an ovule following fertilisation.		
2	fertilisation is a process by which a male gamete fuses with a female gamete.		
3	Fruit is the swollen region of flower's female sex organ containing ovules.		
4	Germination is the development of a plant embryo into an independent plant with green leaves.		
5	Ovary is the structure presents in a flower's anthers that contain male gamete.		
6	Ovule is the structure containing one or more seeds.		
7	Petal is the structure that protects unopened floral bud.		
8	Pollen grains are cells formed when a female gamete is fertilised by a male gamete.		
9	Pollination is a transfer of pollen grains from an anther to a stigma.		
10	Seed is the head of stamen containing pollen grains.		
11	Sepal is the brightly coloured scented structure which attracts insects to a flower.		
12	Zygote is the structure present in a flower's ovary that contains female gamete.		

Question	1	2	3	4	5	6	7	8	9	10	11	12
Answer	F	T	F	T	F	F	F	F	T	F	F	F

Table 7. 11 **Descriptive statistics for True-False test 2**

	N	Minimum	Maximum	Mean	Std. Deviation
True-False test 2	178	0	12	8.6	1.8

Pearson correlation analysis (see Table 7.12) showed a significant correlation between unit 3 and True-False test 2: 0.20 at p = 0.007. The correlation with Perry question 3 will be discussed later.

Table 7.12 **Correlation results True-False test 2 with unit 3 and other tests**

True-False test 2 Correlations	Unit 3	Structural Communication Grid	Perry 3
Pearson correlation (r)	0.20	0.51	0.23
Significance (2-tailed)	p = 0.007	p < 0.001	p < 0.022
Sample (N)	178	94	83

Table 7.13 Correlation results for True-False Test 2 with five areas in unit 3

True-False test 2 Correlations	Knowledge	Understanding	Implication	Experiment	Analysis
Pearson correlation (r)	0.01	0.24	0.10	0.05	- 0.06
Significance (2-tailed)	n.s.	p = 0.001	n.s.	n.s.	n.s.

Looking at Table 7.13, It is clear that the parts of unit 3 which correlate with True-False test 2 are 'Understanding' and, although not significantly, 'Implication'. This will be discussed later when the pattern of correlations for all the tests used are shown.

7.5.3 Word Association Test (WAT)

The Word Association Test was conducted to explore what links might exist between nodes of knowledge in long term memory. This test was carried out with a sample of 282. It is also based on the same topic as True-False test 1 and True-False test 2: germination of the plant (flower). This test was applied to four different groups: two groups took it with True-False test 1 (N = 91) and another two groups took it with the Structural Communication Grid (N = 99). The time provided for this test is 10 minutes.

At the start of this test, students were given instructions as follows:

> *"When you hear or see a word, it often makes you think of other words. In this study we should like to find out what other words are brought to your mind by some words used in plant germination.*
>
> *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 that comes to your mind in the spaces provided. Fill up as many spaces as you can. Continue in this way until you are told to turn to the next page. There are no right or wrong answers. Write as quickly as possible since you are only allowed 30 seconds for each page.*
>
> *The second and third pages of the test contained examples of responses to the stimulus (key) words "Falcon" and "Photosynthesis". To construct the Word Association Test, ten key words were provided to act as stimuli. The stimulus words selected were the most important key ideas relating to the germination topic".*

The stimulus words were *Germination*, *Seed*, *Flower*, *Fruit*, *Embryo Plant*, *Pollination*, *Dormancy*, *Ovary*, *Tree Bark*, and *Ovule*. For each stimulus word, students were required to list up to ten words which they considered to be most closely associated with that stimulus word. Students were given 30 seconds for each stimulus word. The full Word Association Test is given in Appendix D.

In the test, each stimulus word was written at the top of the response form and ten times down the side of the page so that students were encouraged to return to the stimulus word after each association.

The responses that were given to each stimulus word in a fixed time may be analysed in several ways. Because the aim was to investigate the links between nodes or ideas, the best way is to count all the responses, giving a measure of the number of links each student held. However, only relevant and valid words were accepted. For instance, stimulus word *'flower'*: if the subject responded by word 'sympathy', it was considered wrong although it is related to the flower from the students' point of view but it is not relevant to subject matter or topic on *'Germination'*. The maximum possible score was 100.

Table 7.14 shows the result of descriptive statistics of Word Association Test.

Table 7.14 Descriptive statistics for Word Association Test

	N	Minimum	Maximum	Mean	Std. Deviation
Word Association Test	282	4	33	14.5	5.6

The analysis showed that there is correlation between unit 3 (including parts of unit 3) and the Word Association Test using Pearson correlation: r = 0.20 at p = 0.001. The correlation results are shown in Table 7.15 and 16. Looking at Table 7.16, significant correlation is found between the Word Association Test with both 'Understanding' and 'Implication'. However, there is a negative correlation between this test and knowledge. This will be discussed later.

Table 7. 15 Correlation results for Word Association Test with unit 3 and other tests

Word Association Test Correlations	Unit 3	True-False test 1	Structural Communication Grid
Pearson correlation (r)	0.20	0.21	0.10
Significance (2-tailed)	p = 0.001	p = 0.047	n.s.
Sample (N)	282	91	99

Table 7.16 Correlation results for Word Association Test with five areas in unit 3

Word Association Test Correlations	Knowledge	Understanding	Implication	Experiment	Analysis
Pearson correlation (r)	- 0.14	0.19	0.14	0.02	0.12
Significance (2-tailed)	p = 0.016	p = 0.001	p = 0.018	n.s.	n.s.

This confirms that there is a link between success in unit 3 and the Word Association Test results. If the performance in the Word Association Test is a measure of the number (and accessibility) of links in long term memory, this suggests that accessible links is related to (and may be a factor) in problem-solving success in biology. Word Association Test seeks to offer a measure of the links between nodes of knowledge in long term memory. Clearly, this is related to 'Understanding' and 'Implication' as part of success in unit 3. The negative correlation with the knowledge is more difficult to explain. At face value is suggested that, the more they know the less they linked. Is more knowledge can cause confusion?

7.5.4 Structural Communication Grid (SCG)

The Grid test (Figure 7.6) was used as a technique to gain insight into students' understanding of biological concepts. In addition it is a tool to reveal the prior knowledge and concepts stored in long term memory. To prepare the grid questions for university students level, modules 1X and the Higher Grade Biology text-book (Torrance, 1991) were investigated. Here is the grid question on parts of flower.

Figure 7. 6 Structural Communication Grid

The grid below contains parts of a flower. Look at the boxes below and answer the questions that follow by using the letters provided.

(Boxes may be used as many times as you wish).

A Sepal	**B** Pollen	**C** Ovary
D Stigma	**E** Petal	**F** Anther
G Stamen	**H** Ovule	**I** Nectar

Select all the boxes which contain:

Q1 Male parts of a flower: ....

Q2 Female parts of a flower: ....

Q3 A part which protects an unopened flower: ....

Q4 A region to which pollen grains become attached: ....

Q5 Parts of a flower which attract insects: ....

Q6 Those parts of a flower which, together, will form seeds: ....

This grid test was used with six groups: two groups took this test with True-False test 1 (N = 87), another two groups took it with True-False test 2 (N = 94), and the other two groups took it with the Word Association Test (N = 99). The total number of students was 280. The grid questions on parts of flower were marked out of 6, giving equal weighting to each of the six parts. The time provided for this test was 10 minutes. Table 7.17 shows the correct answers for this test.

Table 7.17 Table of correct answers for Structural Communication Grid

Questions	Answers
Q1	B + F + G
Q2	C + D + H
Q3	A
Q4	D
Q5	E + I
Q6	B + H

Structural Communication Grid questions can be used diagnostically and, for this purpose, the answers were coded using a spreadsheet. These codes were then converted into scores. The system adopted with this test is shown in Tables 7.18-7.20.

Table 7.18 Codes for questions 1 and 2 (three correct answers)

Codes	Number of correct and wrong answers	Scores (1)
0	Nothing is correct	0
1	One is correct	0.33
2	Two are correct	0.67
3	Three are correct	1
11	One is correct & one is wrong	0.2
21	Two are correct & one is wrong	0.55
31	Three are correct & one is wrong	0.86
32	Three are correct & two are wrong	0.67
9	Anything else	0

Table 7.19 Codes for questions 3 and 4 (one correct answer)

Codes	Number of correct and wrong answers	Scores (1)
0	Nothing is correct	0
1	One is correct	1
11	One is correct & one is wrong	0.6
9	Anything else	0

Table 7. 20 Codes for questions 5 and 6 (two correct answers)

Codes	Number of correct and wrong answers	Scores (1)
0	Nothing is correct	0
1	One is correct	0.5
2	Two are correct	1
11	One is correct & one is wrong	0.35
21	Two are correct & one is wrong	0.7
9	Anything else	0

Table 7.21 shows the result of descriptive statistics.

Table 7.21 Descriptive statistics for Structural Communication Grid

	N	Minimum	Maximum	Mean	Std. Deviation
Structural Communication Grid	280	0	6.0	3.4	1.4

The analysis showed that there is significant correlation between unit 3 (including parts of unit 3) and the Structural Communication Grid: 0.25 at $p < 0.001$. The correlation results are shown in Table 7.22 and 23.

Table 7.22 Correlation results for Structural Communication Grid with unit 3 and other tests

Structural Communication Grid Correlations	Unit 3	True-False test 1	True-False test 2	Word Association Test
Pearson correlation (r)	0.25	0.33	0.51	0.10
Significance (2-tailed)	p < 0.001	p = 0.002	p < 0.001	n.s.
Sample (N)	280	87	94	99

Table 7.23 Correlation results for Structural Communication Grid with five areas in unit 3

Structural Communication Grid Correlations	Knowledge	Understanding	Implication	Experiment	Analysis
Pearson correlation (r)	- 0.03	0.30	0.21	0.04	- 0.06
Significance (2-tailed)	n.s.	p < 0.001	p = 0.027	n.s.	n.s.

Table 7.23 shows, yet again, that 'Understanding' and 'Implication' are correlated significantly with success in the Structural Communication Grid.

7.5.5 Perry Position Questionnaire (PPQ)

In this study, the Perry test (see Figure 7.7) was used to measure the students' perceptions and attitudes towards different aspects of learning. The four aspects are:

- Lecturers' role
- Students' role
- The nature of scientific knowledge
- Assessment

Each area will be considered in turn and the questions which relate to that area will be discussed individually before drawing conclusions. This scheme will show the students' position from A to C under the adapted Perry scheme. Nine questions were used (see Figure 7.7 and Table 7.24). This test was applied to six groups (N= 267): two groups did this questionnaire with True False test 1 (N= 92), another two groups did it with True False test 2 (N= 83), and the last two groups did it with the Word Association Test (N= 91).

Figure 7.7 Perry Position Questionnaire

You can describe a racing car in this way:

quick	✔	☐	☐	☐	☐	☐	slow
important	☐	☐	✔	☐	☐	☐	unimportant
safe	☐	☐	☐	☐	✔	☐	dangerous

The positions of the ticks between the word pairs show that you consider it as <u>very</u> quick, slightly more important than unimportant and <u>quite</u> dangerous.

Use the same method of ticking to show your opinions below.

Q1	In order to pass my courses, I need to study just what the lecturer tells me.							I do not have to rely totally on the lecturer. Part of my learning is to work things out myself.
Q2	I do not believe in just accepting what the lecturer says without question. Success involves thinking for myself.							I cannot be wrong if I accept what the lecturer says. If I question anything, I might end up failing.
Q3	I believe it is the job of the lecturer to supply me with all the knowledge I need.							The duty of the lecturer is not to teach me everything, but to help me to think for myself.
Q4	All one has to do in science is to memorise things.							Understanding science is the key part of science study.
Q5	I do not believe that all scientific knowledge represents the 'absolute truth'.							We cannot call anything scientific knowledge if it is not absolutely true.
Q6	In exams I prefer questions which are based on what the lecturer taught.							In exams, I like questions that give me the scope to go beyond what is taught and show my ability to think .
Q7	My studies should lead me to be able to work things out for myself.							My studies should lead me to know what to learn.
Q8	Usually, I find I learn more about a subject by discussing it with other students.							Usually, I find it more useful to work on my own.
Q9	It is a waste of time to work on problems which have no possibility of producing a clear-cut, unambiguous							I find benefit from thinking through problems where there is no clear-cut, unambiguous answer.

The questions were gathered into four groups as Table 7.24 shows that:

Table 7. 24 Perry Questions

Students Perceptions of Lecturers' Role	
Q2	I do not believe in just accepting what the lecturer says without question. Success involves thinking for myself. / I cannot be wrong if I accept what the lecturer says. If I question anything. I might end up failing.
Q3	I believe it is the job of the lecturer to supply me with all the knowledge I need. / The study of the lecturer is not to teach me everything, but to help me to think for myself.
Students Perceptions of Students' Role	
Q1	In order to pass any course, I need to study just what the lecturer tells me. / I do not have to rely totally on the lecturer. Part of my learning is to work things out of myself.
Q7	My studies should lead me to be able to work things out of myself. / My studies should lead me to know what to learn.
Q8	Usually, I find I learn more about a subject by discussing it with other students. / Usually, I find it more useful to work on my own.
Students Perceptions of the nature of Scientific Knowledge	
Q4	All one has to do in science is to memorise things. / Understanding science is the key part of science study.
Q5	I do not believe that all scientific knowledge represents the 'absolute truth'. / We cannot call anything scientific knowledge if it is not absolutely true.
Q9	It is a waste of time to work on problems, which have no possibility of producing clear-cut, ambiguous answer. / I find benefit from thinking through problems where there is no clear-cut, unambiguous answer.
Students Perceptions of Assessment	
Q6	In exams, I prefer questions which are based on what the lecturer taught. / In exams, I like questions that give me the scope to go beyond what is taught and show any ability to think.

Positions of responses for each student on each question were coded from 1 to 6 (left to right). The data obtained are not necessarily normally distributed, and are categorical or ordinal in nature. To see if the responses of the students to each question related to their performance in unit 3, Kendall's tau_b correlation was applied (see Table 7.25).

Table 7. 25 Correlation results for Perry Position Questionnaire with unit 3

Unit 3 (N = 267) Correlations	Perry Q 1	Perry Q 2	Perry Q 3	Perry Q 4	Perry Q 5	Perry Q 6	Perry Q 7	Perry Q 8	Perry Q 9
Pearson correlation (r)	0.10	- 0.02	0.06	- 0.01	- 0.03	0.05	- 0.14	0.08	- 0.02
Significance (2-tailed)	p = 0.037	n.s.	n.s.	n.s.	n.s.	n.s.	p = 0.004	n.s.	n.s.-

In two questions, there is a significant correlation which is low (see Table 7.25). Both questions relate to a willingness or desire to "to work things out for themselves" and those who hold this view are those who more successful in unit 3. This would seem to be an important observation. Perhaps, it requires this particular perception of their role as learners in order to have the willingness or confidence to approach a problem successfully. This raises the question: It is possible to develop this perception in students or is it innate ability? In Yang's work (Reid and Yang, 2002b), she found that completion of one problem enhances confidence remarkably and seem to allow students to take what was called *cognitive risks*.

This suggests that those who want to think things for themselves are those who are more successful in True-False test 2.

7.6 Conclusions

Previous work has identified some of the factors that might influence the success in problem solving. The experiment was designed to focus on factors relating to long term memory in particular: what the learner held and how the knowledge was linked were particularly important. The perceived role of students and lecturers is also an important factor to motivate students to learn in a right way. However, the student responses to the Perry questionnaire show few significant correlations with any aspect of problem solving.

Numerous measurements were made to explore links in long term memory related to how students handled problem solving.

Five tests were used: True-False test 1 and 2 aimed to test the factual knowledge in long term memory, Word Association Test aimed to measure the number and accessibility of relevant links held while Structural Communication Grid aimed to test understanding. The Perry Position Questionnaire aimed to test the attitudes of students towards aspects of learning. All the measurements show statistically significant correlations with performance in unit 3. However, only two Perry questions showed significant correlation. It seems that the students perceptions related to learning do not relate, in general, to their success in problem solving.

The key observation is that four of the tests used show highly significant correlation with the performance of individual students on the problems in unit 3. All five measurements are now related (Table 7.26) to show the overall pattern.

Table 7.26 Correlation results for unit 3 with all tests

Correlations		Unit 3	T-F 1	T-F 2	WAT	SCG
Unit 3	Pearson r Significance Sample		**0.26** $p < 0.001$ 273	**0.20** $p = 0.007$ 178	**0.20** $p = 0.001$ 282	**0.25** $p < 0.001$ 280
T-F 1	Pearson r Significance Sample			----	**0.21** $p < 0.047$ 91	**0.33** $p < 0.002$ 87
T-F 2	Pearson r Significance Sample				----	**0.51** $p < 0.001$ 94
WAT	Pearson r Significance Sample					0.20 n.s. 99
SCG	Pearson r Significance Sample					

The results indicate that performance in the problems in unit 3 is related to the performance in each of these four tests. This *suggests* that success in unit 3 may be relate to:

- Factual knowledge.
- Links between nodes of ideas.
- Understanding of ideas.

Of course, this deduction assumes the validity of each of the four tests. It also assumes that unit 3 performance and the performance in the four tests are not simply measuring some kind of general ability in biology.

The descriptive statistics of all tests are presented in Table 7.27.

Table 7.27 Descriptive statistics for all tests

	N	Minimum	Maximum	Mean	Std. Deviation
Unit 3	642	3	24	12.7	2.9
True-False test 1	273	3	12	8.9	1.7
True-False test 2	178	0	12	8.5	1.8
Word Association Test	282	4	33	14.5	5.6
Structural Communication Grid	280	0	6	3.4	1.4

The results suggest that unit 3 and all four tests were at an appropriate level of difficulty and spread the students out to a reasonable extent (see Appendix D). With such similarities in difficulty level and the size of the samples being used along with the consistent application of the all the measurements with each laboratory group (applied under strict conditions by the researcher), reliability is likely to be high (see Reid, 2003).

However, validity is much more difficult to assess. In addition, the observations might simply be related to some kind of overall biological ability: thus, if a student is good at one kind of skill in biological context, then they are likely to be good at other skills in biological contexts. This question is explored in the next experiment. In addition, the whole question of creativity and lateral thinking along with extent of divergent ability are yet to be explored. In the light of these observations, the next stage was conducted and will be discussed in the following chapter.

Chapter Eight

Experimental Work: Stage Two

8.1 The Second Stage

The second stage involved the same sample of 642 students as the first stage. The work was carried out 6 months later in April 2004. The timing was determined by possibilities of access to students. It was hoped to use another individual problem with the students as well as a battery of tests but lack of time of access to students made this impossible. Thus, more tests were applied and compared with their *previous* performance with unit 3. The outcomes from the first stage supported the idea that problem-solving success did relate to nodes of knowledge held and links between these ideas, all held in long term memory. However, it was still possible that what was being observed was simply some kind of generic ability, perhaps related to biology.

The second stage (Table 8.1) differs from the first stage in having tests without any problem units being applied before. In addition, it is related to different subject matter which was based on *Evolution.* This topic had been studied November and December 2003. Only one test was related to the content of unit 3 (*Forests that Need Fires)* and all other tests were related to the *Evolution* content. This allowed a check across content areas. If the observation from the first stage merely reflected some kind of generic biological ability, then there would be the same kind of significant correlations with tests based on another content area.

Table 8.1 **The second stage**

Level-1 Biology (Glasgow University)	
Time	Third term (April 2004)
No. of teaching units	0
No. of tests	5
Total number of students	642

These tests were devised to be short (5-10 minutes) and they were five in number. Any individual student only took two tests. The tests are summarised in Table 8.2 while Tables 8.3 and 8.4 outline the organisation of the testing procedures. Finally, Figure 8.1 shows the stage and what tests and units were used at that level.

Table 8.2 **The tests and their aims of measurement**

No.	Tests	Topic	Measurement
1	Structural Communication Grid 1 (SCG1)	Plant germination	To measure students' understanding and to show the interconnection of knowledge in their minds.
2	Structural Communication Grid 2 (SCG2)	*Evolution*	
3	Word Association Test (WAT)	*Evolution*	To test accessibility of links between ideas held in long term memory.
4	Ranking Test (RA)	*Evolution*	To test students' understanding and the links between nodes.
5	Concept Map (CM)	*Evolution*	To test the links between nodes if they exist in long term memory.

Table 8.3 **Schedule of Second stage in April (24-27/4/2004)**

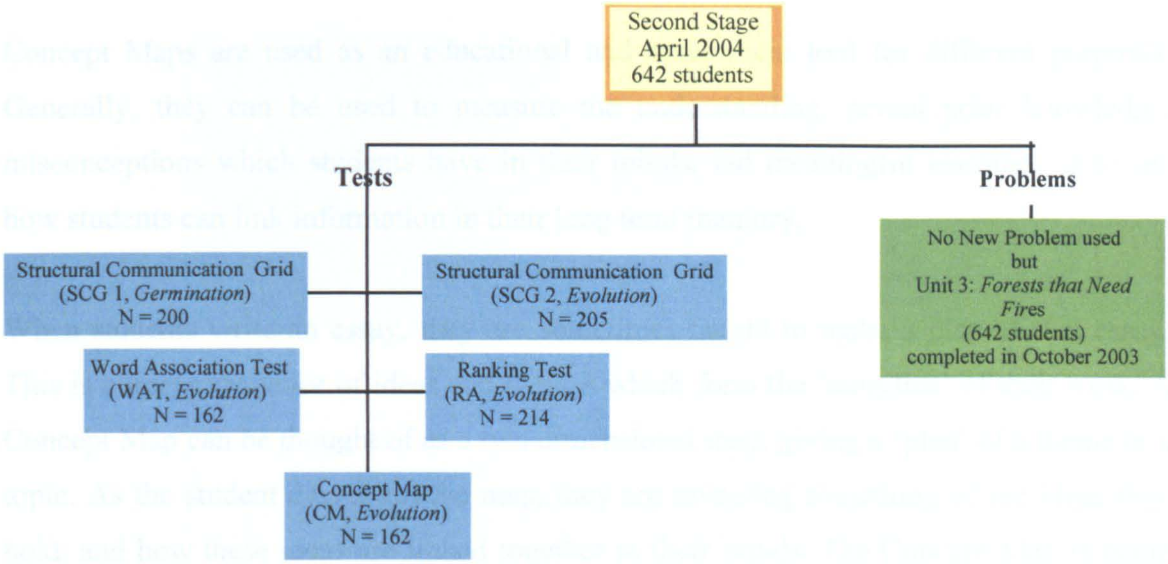
Day	*Time*	*Tests for lab 1*	*Tests for lab 2*
Tuesday	a.m.	WAT & CM	SCG1 & RA
	p.m.	WAT & CM	SCG1 & RA
Wednesday	a.m.	WAT & CM	SCG1 & RA
	p.m.	SCG2 & RA	SCG1 & SCG2
Thursday	a.m.	WAT & CM	SCG1 & SCG2
	p.m.	WAT & CM	SCG1 & SCG2
Friday	a.m.	SCG2 & RA	No lab classes
	p.m.	SCG2 & RA	

WAT: Word Association Test '*Evolution*';
CM: Concept Map '*Evolution*', SCG1:
Structural Communication Grid '*Forests that Need Fires*';
SCG2: Structural Communication Grid '*Evolution*';
RA: Ranking test '*Evolution*'.

Table 8.4 **Number of tests that applied in the second stage**

Tests	*Number of lab sessions for each test*	*Number of students*	*Time (minutes)*
WAT	5	162	10
CM	5	162	10
SCG1 (F)	6	200	10
SCG2 (E)	6	205	10
RA	6	214	5

Figure 8.1 Summary of the second stage



8.2 Assessment Tools

The aim of all the tests was to explore the linking of key ideas in long term memory. However, most of the tests explored a fresh unrelated topic, *'Evolution,'* which had been studied in late autumn of 2003. *Evolution* was chosen as a suitable topic in that it is a discrete topic of comparable size and difficulty compared to plant germination and it had been taught a few months earlier. If all the tests were measuring some kind of generic biological ability, then similar sized significant correlations would occur again with this topic. However, there is a complication. The tests were aiming to offer evidence about the links between ideas in long term memory. It is possible that students have the same pattern of links and nodes in their minds even with different subject matter.

Otis (2001) found such a pattern. He was surprised to observe that the number of nodes for a given student did not appear to fluctuate very much with complexity and variety of the scenarios he applied. He found that there is "a strong tendency for the maps of an individual to contain the same number of nodes, regardless of the scenario being mapped". If his observations reflect some kind of constant fixed architecture of the long term memory (on to which different subject matter is placed), then correlations may be difficult to interpret. Any significant correlations might be caused by this factor or might be caused by some kind of generic biological ability.

8.2.1 Concept Map (CM)

Concept Maps are used as an educational and assessment tool for different purposes. Generally, they can be used to measure the understanding, reveal prior knowledge, misconceptions which students have in their minds, aid meaningful learning, or to see how students can link information in their long term memory.

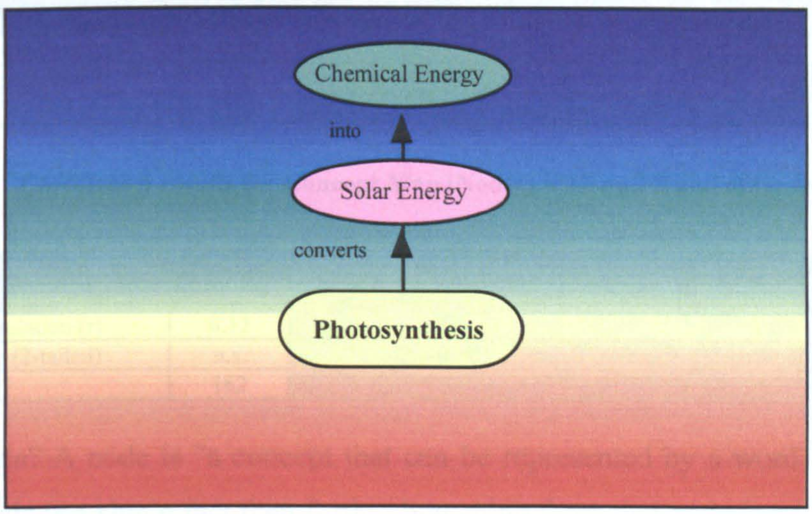
When students write an essay, they are sometimes taught to make a plan of that essay. This is a linear sequence of ideas and themes which form the 'storyline' of their work. A Concept Map can be thought of as a two dimensional map, giving a 'plan' of a theme or a topic. As the student draws out the map, they are revealing something of the ideas they hold, and how these ideas are linked together in their minds. The Concept Map is being used for that purpose here. Students are given the word *Evolution* to be placed in the middle of a sheet of paper and they generate the ideas which link to it and draw links with arrows and phrases.

Specifically, the aim of a Concept Map in this study was to explore the number of links between nodes in long term memory. 162 Level-1 biology students were shown how to draw a Concept Map, using an example on the topic of *'Photosynthesis'*. Five laboratory groups were involved and all these groups also completed a Word Association Test.

A Concept Map can be seen as, "a two dimensional representation of the creator's cognitive network" (Otis, 2001, p. 109). In order to represent a map in a two dimensional pattern, writing a concept word in the middle of the page, with the paper in landscape position allows students to have more room for expansion of their ideas and thoughts. In addition, it also allows students "to take advantage of the brain's natural tendency to chunk and link information" (Otis, 2001, p. 34).

Figure 8.2 shows the part of Concept Map that introduced the students to the idea of concept mapping. The Concept Map will be shown in full in Appendix E.

Figure 8.2 **Part of Concept Map about '*Photosynthesis*'**



Concept Maps are particularly difficult to mark (see Otis, 2001). In this experiment, a simple procedure was adopted, recognising that it had limitations. The evidence from Otis showed that the number of nodes and links does not necessarily relate to the depth of student understanding in that chunking in long term memory can simplify the map drawn. This allows the very able student to group many ideas into a single node. This is difficult to cope with in any scoring scheme. However, Otis was working with medical students where the nature of the work led to a fairly sophisticated grasp of complex themes. This was less likely in the biology curriculum. The scoring scheme was carried out simply by counting the number of valid links and nodes in each map and a total score was given for each student. Table 8.5 shows the result of descriptive statistics.

Table 8.5 **Descriptive statistics for Concept Map (Links and Nodes)**

	N	Minimum	Maximum	Mean	Std. Deviation
Concept Map (Links)	162	0	50	18.2	9.2
Concept Map (Nodes)	162	0	49	17.8	8.9

Pearson correlation was calculated between both Concept Map scores and performance in unit 3, no significant correlation being found. This was not surprising as unit 3 and the Concept Map were testing different subject matter. This is an important result because it reveals that the correlations obtained in first stage were not to be explained easily in terms of ability to solve biological problems as some kind of generic skill. However, the test results revealed very strong correlation with the Word Association Test (see Tables 8.6 & 8.7) which also was testing in the topic of *Evolution*. This is to be expected in that the two tests were measuring in the same content area.

Table 8.6 Correlation results for Concept Map (Links) with unit 3 and other tests

Concept Map (Links) Correlations	Unit 3	Concept Map (Nodes)	Word Association Test
Pearson correlation (r)	0.13	0.99	0.40
Significance (2-tailed)	n.s.	p < 0.001	p < 0.001
Sample (N)	162	162	162

Table 8.7 Correlation results for Concept Map (Nodes) with unit 3 and other tests

Concept Map (Nodes) Correlations	Unit 3	Concept Map (Links)	Word Association Test
Pearson correlation (r)	0.12	0.99	0.39
Significance (2-tailed)	n.s.	P < 0.001	p < 0.001
Sample (N)	162	162	162

What is a node? A node is "a concept that can be represented by a word or two" (Otis, 2001). If a node is a single fact then further branching from that node is not possible. It is possible to extend all networks of branching nodes to the terminus of a single fact. In practice, this is rare because that information is implicit and therefore offers little value to the mapper. A map that dependably offers one or two options at each node is close to the linear pattern of text. A map that exhibits branching patterns that are repeated throughout the map may be adhering to a conscious, or subconscious, formula. There are a number of visual, spatial and psychological factors that alone or collectively may influence map construction. Map layout which led by the physical structure of the map or a consistent size of internal chunks.

A map where nodes consistently offer six or more options would be expected to exceed the mental Working Memory Space (see chapter 3, section 3.12) of the students. Concept Maps are intended as a short-hand reminder of the mental steps taken in evaluating a key concept. Concept maps allow a person to see a larger picture.

8.2.2 Word Association Test (WAT)

In this stage, a Word Association Test was used to test the links between nodes in long term memory, related to *Evolution*. The number of students was 162. The instructions used were identical to those used before. The stimulus words selected were the most important key ideas relating to the *Evolution* topic. The stimulus words were *Natural Selection*, *Fossil Record*, *Variation*, *Mutation*, *Speciation*, *Selective Advantage*, *Micro-Evolution*, *Fitness*, *Morphospecies*, and *Geographical Barriers*. The full Word Association Test is given in Appendix E. The time provided for this test was 10 minutes. Five laboratory groups were involved in this test.

The responses were analysed as in the first stage, counting all relevant and valid words. The words used in the count were taken to be "valid" if they are meaningful and acceptable in terms of *Evolution* as a topic. Table 8.8 shows the result of descriptive statistics.

Table 8.8 Descriptive statistics for Word Association Test

	N	Minimum	Maximum	Mean	Std. Deviation
Word Association Test	162	5	59	23.7	9.9

Pearson correlation between this test and unit 3 shows a correlation at 0.24 ($p = 0.003$) – see Table 8.9.

Table 8.9 Correlation results for Word Association Test with unit 3 and other tests

Word Association Test Correlations	Unit 3	Concept Map (Nodes)	Concept Map (Links)
Pearson correlation (r)	0.24	0.39	0.40
Significance (2-tailed)	$p = 0.003$	$p < 0.001$	$p < 0.001$
Sample (N)	162	162	162

It might be expected that the Word Association Test and the two ways of making the Concept Maps would be highly correlated in that they all seek to measure the nodes and links related to the same topic: *Evolution*.

Word Association Tests offer insights into the way subject matter is organised in long term memory in terms of the connections between ideas. The results show that the way the students have organised ideas in the topic of *Evolution* is somehow related to their success in a problem based on germination. This correlation might be caused by the test on unit 3 and the Word Association Test both measuring some kind of generic biological ability. Perhaps both tests related to mental architecture (numbers of links and their accessibility).

8.2.3 Structural Communication Grid 1 (SCG1) on '*Forests that Need Fires*'

In this study, the Structural Communication Grid 1 was used as a technique to measure students' understanding and to show the interconnection of knowledge in their minds. Structural Communication Grid 1 was based on the topic of unit 3 (*Forests that Need Fires*). Six groups were involved: three groups took this test with the Ranking test, another three groups did it with Structural Communication Grid 2 (which was focussed on *Evolution*). The total number of students was 200. The time provided for this test was 10 minutes. The grid questions (Figure 8.3) were scored slightly different from the first stage although following the same principles. Table 8.10 shows the correct answers for this test. Tables 8.11-8.13 show the codes of marking for each question.

Figure 8.3 Structural Communication Grid 1 (on *Forests that Need Fires*)

The grid below contains adaptation of forests when exposed to fire. Look at the boxes below and answer the questions that follow by using the letters provided.

(Boxes may be used as many times as you wish).

causes organic matter to break down releasing minerals into the soil **A**	hard coated nuts **B**	conserves biodiversity of adapted species **C**
allows more light to penetrate to ground level **D**	may eliminate some marginal plant species **E**	sharp thorns or spines **F**
soft fruits containing small seeds **G**	roots buried deep in the soil **H**	thick bark, which is hard or spongy **I**

Select all the boxes which contain:

Q1 Fire in seasonally dry habitats ....

Q2 In damp habitats, microbial decay ....

Q3 Plants adapted to habitats where fires occur naturally, may show adaptations such as

....

Q4 Allowing natural fires to burn themselves out ....

Q5 Fire may be necessary to bring about germination in species that have ....

Q6 After flowering and fertilisation of ovules, a plant may produce ....

Table 8.10 Table of correct answers for Structural Communication Grid 1

Questions	Answers
Q1	A + C + D
Q2	A
Q3	B + H + I
Q4	A + C + E
Q5	B
Q6	B + G

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8.2.4 Structural Communication Grid 2 on *'Evolution'* (SCG2)

Three laboratory groups undertook this test with the Ranking test while another three groups did it with Structural Communication Grid 1 on *Forests that Need Fires* (unit 3) in Figure 8.4. The total number of students was 205. Scoring following the same pattern as before. Table 8.16 shows the correct answers for this test. Tables 8.17-19 show the codes of marking for each question. Here is the grid question on *Evolution*.

Figure 8. 4 Structural Communication Grid 2 (on *Evolution*)

The grid below contains examples of reproductive barriers which isolate gene pools of biological species. Look at the statements in the boxes below and indicate, using the letters A to I, which of them makes a complete, correct sentence with each of the phrases listed Q1 to Q6.

(Boxes may be used as many times as you wish).

Species occupy the same geographic area, but live in separate habitats and do not meet. **A**	Species have incompatible sex cells **B**	Species possess unique, exclusive mating signals and courtship behaviours. **C**
Species have anatomically incompatible reproductive organs **D**	Hybrids fail to produce functional gametes. **E**	Mating or flowering occurs at different seasons or times of day. **F**
Impede mating between species or hinder fertilization of ova. **G**	Hybrid zygotes fail to develop or fail to reach sexual maturity. **H**	Offspring of hybrids have reduced viability or fertility. **I**

Q1 Habitat isolation ....

Q2 Gametic isolation ....

Q3 Temporal isolation ....

Q4 Mechanical isolation ....

Q5 Prezygotic barriers ....

Q6 Postzygotic barriers ....

Table 8.16 Table of answers for Structural Communication Grid 2

Questions	Answers
Q1	A
Q2	B
Q3	F
Q4 .	D
Q5	A + B + C + D + F + G
Q6	E + H + I

Table 8.17 Codes for questions 1, 2, 3 and 4 (one correct answer)

Codes	Number of correct and wrong answers	Deduction
1	Correct answer	Any extra added deduct 0.2
0	Wrong answer	

Table 8.18 **Codes for question 5 (six correct answers)**

Codes	Number of correct and wrong answers	Deduction
1	All are correct	Any extra added deduct 0.2
0.8	Five are correct & one is missing	
0.6	Four are correct & two are missing	
0.4	Three are correct & three are missing	
0	All are wrong	

Table 8.19 **Codes for questions 6 (three correct answers)**

Codes	Number of correct and wrong answers	Deduction
1	All are correct	Any extra added deduct 0.2
0.6	Two are correct & one is missing	
0.3	One is correct & two are missing	
0	All are wrong	

Table 8.20 shows the result of descriptive statistics for Structural Communication Grid 2 (on *Evolution*).

Table 8.20 **Descriptive statistics for Structural Communication Grid 2 (*Evolution*)**

Structural Communication Grid 2 (*Evolution*)	N	Minimum	Maximum	Mean	Std. Deviation
	205	0	6.0	3.4	1.1

Pearson correlation showed a low correlation with success in unit 3: $r = 0.15$, with $p < 0.05$ for 205 students (see Table 8.21). Of course, SCG 2 was based on *Evolution* while unit 3 was based on germination. First and second stages are used different topics on biology, however, correlation results are vary between tests. This suggests that there is more than some kind of generic biological ability involved.

Table 8.21 **Correlation results for Structural Communication Grid 2 with unit 3 and other tests**

Structural Communication Grid 2 (E) Correlations	Unit 3	Structural Communication Grid 1	Ranking test
Pearson correlation (r)	0.15	0.29	0.17
Significance (2-tailed)	p = 0.003	p = 0.004	n.s.
Sample (N)	205	95	109

There is a very low, although significant, correlation between the Structural Communication Grid 2 on *Evolution* and the problem which was centred on germination and *Forests that Need Fires*.

8.2.5 Ranking Test (RA)

The Ranking test (Figure 8.5) was developed for this study. It attempted to measure students' understanding of information being taught in biology modules about *Evolution.* In addition, it was used to test the links between nodes to see if they exist in long term memory.

This test was completed by 214 students in 5 minutes. There were six laboratory groups: three groups did it with the Structural Communication Grid 1 on *Forests that Need Fires* and another three groups did it with Structural Communication Grid 2 on *Evolution.*

Students had to make the order from the most significant to the least significant answers. Students who obtained the right sequence clearly have a good understanding of a logical order of ideas. However, the test was aimed to measure if the students had established the appropriate links in long term memory so that they could see, overall, the correct sequence. The questions and their answers are as follows in Figure 8.5 and Table 8.22:

Figure 8. 5 Ranking test on 'Dogs and Evolution'

Alice has been studying the breeding of wolf-like common ancestors which have given rise to varieties of dogs. She wants to know which are the most significant observations from the view point of an evolutionary biologist.

A Newspaper reports demonstrate that bull terriers are dangerous as pets. This is because they have been selected over generations for aggressiveness.

B The dingo was probably introduced to Australia as a domesticated dog which, on returning to the wild, became a hunter again, under the influence of natural selection.

C The occurrence of breeds of dogs as large as a St Bernard, and as small as a chihuahua demonstrates that size in dogs is determined by many gene loci.

D The existence of many breeds of dogs demonstrates the power of selection over generations to alter phenotypes.

E Darwin studied domesticated species such as dogs and pigeons, because he thought that artificial selection acted in a similar way to natural selection.

F The skill sheepdogs exhibit in sheepdog trials demonstrates how selection over generations has made it easier for humans to train them to round up sheep.

Rank these statements concerning domesticated dogs in order of their significance to the evolutionary biologists by placing the letters A, B, C...etc. in the boxes below. The letter which comes first is the most significant and the letter which comes last is the least significant from your point of view.

Most significant Least significant

Table :rs of Ranking test – 'Dogs & Evolution'

B		E		C		D		A		F

Most significant Least significant

This test was scored in the following way, the aim being to obtain the best discrimination. First of all, the student starts with 10 marks and marks are *deducted* if the order deviates from the correct order in the following way: if the student changes the order of any letter by ***one*** position, no mark is deducted; if it is moved by two positions, one mark is deducted, for three positions movement, two marks are deducted, and so on. Here is an example:

B		D		C		E		A		F
		-1				-1				

Most significant Least significant

The student choices of position of D and E are each two positions out. The overall score for this student is 8

The full scoring system is presented as Appendix E. Table 8.23 shows the result of descriptive statistics.

Table 8.23 Descriptive statistics for Ranking test

	N	Minimum	Maximum	Mean	Std. Deviation
Ranking Test	214	0	10	5.5	2.5

The Ranking test showed no significant correlation with unit 3 and it is not correlated with any other test. The Ranking test is certainly based on biology and was considered by 'experts' on the course as being appropriate for the class. The performance was reasonable and yet it failed to correlate significantly with the other tests and, specifically, with the test on unit 3. This does undermine the idea of some kind of generic biological ability as the basis of observed correlations although it is possible that the Ranking test was simply testing a skill not being assessed in any way by any of the other tests. However, it did seek to test specifically within the area of *Evolution*. Perhaps it was focussing on the order of ideas rather than simply linking of ideas. Indeed, the question, with hindsight, was more akin to thinking typical in system biology.

8.3 Correlation with *Evolution*

The students sat an examination in January 2004 and this included two questions related to *Evolution*. The examinations marks were considered and students' performance in the two questions related to the tests used here. The questions are presented in the following paragraph. The correlation results are shown in Table 8.24 and 25. Table 8.26 shows the descriptive statistics for questions one and two.

In the box provided below, write an informative paragraph on ONE of the following topics:

1 (a) Using the eye as an example, discus how natural selection can explain the evolution of a complex, highly adapted structure.

1 (b) Comment on the consequences of the release of oxygen into the earth's atmosphere for the evolution of living organisms on the planet.

Table 8. 24 Correlation results for all tests with question 1a

Question 1a Correlations	Unit 3	Structural Communication Grid 1	Structural Communication Grid 2	Word Association Test	Concept Map (Links)	Concept Map (Nodes)	Ranking
Pearson correlation (r)	0.11	0.22	0.21	0.29	0.06	0.09	0.01
Significance (2-tailed)	n.s.	p = 0.026	p = 0.032	p = 0.016	n.s.	n.s.	n.s.
Sample (N)	274	102	101	68	68	68	109

Table 8. 25 Correlation results for all tests with question 1b

Question 1b Correlations	Unit 3	Structural Communication Grid 1	Structural Communication Grid 2	Word Association Test)	Concept Map (Links)	Concept Map (Nodes)	Ranking
Pearson correlation (r)	0.22	0.35	0.14	0.09	0.22	0.22	- 0.10
Significance (2-tailed)	p < 0.001	p = 0.001	n.s.	n.s.	p = 0.041	p = 0.044	n.s.
Sample (N)	282	87	93	87	87	87	95

Table 8.26 Descriptive statistics for questions 1 and 2

	N	Minimum	Maximum	Mean	Std. Deviation
Question 1a	274	0	10	4.3	2.2
Question 1b	282	0	10	5.1	2.0

8.4 Conclusions

The first experiment has shown that factual knowledge, links between ideas and understanding of these ideas seems to relate to performance in the open-ended problem, unit 3. This is consistent with previous work of Reid and Yang (2002b). However, there are other explanations for the observed correlations.

The second experiment was designed to gain more evidence to see if the understanding of conceptual knowledge and the linking of knowledge in student's minds are the vital factors to solve problems. Many of the tests used in the second experiment did *not* relate to the topic of germination or *Forests that Need Fires*. The overall patterns of results are now discussed.

Five tests were used: Structural Communication Grids 1 and 2 to measure students understanding, Word Association Test and Concept Map to test links between the ideas of knowledge, and Ranking test to measure understanding and the ability to link ideas in students' minds. Some of the measurements are statistically significant with correlated problem (unit 3).

For clarity, Table 8.27 shows descriptive statistics for all the tests together.

Table 8.27 Descriptive statistics for all tests

	Topic	N	Minimum	Maximum	Mean	Std. Deviation
Unit 3	*Germination*	644	3	24	12.7	2.9
Structural Communication Grid 1	*Forest Fires*	200	0	4.9	2.9	0.9
Structural Communication Grid 2	*Evolution*	205	0	6.0	3.4	1.1
Concept Map (Nodes)	*Evolution*	214	0	49	17.8	8.9
Concept Map (Links)	*Evolution*	162	0	50	18.2	9.2
Word Association Test	*Evolution*	162	5	59	23.7	9.9
Ranking Test	*Evolution*	162	5	59	5.5	2.5

Again, in the measurements, the means and standard deviations suggest that discrimination has taken place and that the tests are at an appropriate level. However, in the Structural Communication Grid 2, the spread is not very good, raising some doubts about how much confidence can be placed on the results from this test. Histograms for the various tests are shown in Appendix H.

Table 8.28 Correlations for all tests

Correlations Pearson r Significance Sample (N)	SCG1 (*Forest Fires*)	SCG2 (*Evolution*)	RA (*Evolution*)	WAT (*Evolution*)	CM (N) (*Evolution*)	CM (L) (*Evolution*)
Unit 3 (*Forest Fires*)	**0.36** p < 0.001 200	**0.15** p = 0.003 205	-0.04 n.s. 214	**0.24** p = 0.003 162	0.12 n.s. 162	0.13 n.s. 162
SCG1 (*Forest Fires*)		0.30 p = 0.004 95	0.14 n.s. 105	---	---	---
SCG2 (*Evolution*)			0.17 n.s. 109	---	---	---
RA (*Evolution*)				---	---	---
WAT (*Evolution*)					**0.39** p < 0.001 162	**0.40** p < 0.001 162
CM (N) (*Evolution*)						**0.99** p < 0.001 162

Firstly, looking at the top line of Table 8.28, the highest correlation (0.36) is when the *same topic* is the basis of the assessments. However, the 'average' of the correlations between the test on unit 3 (*Forests that Need Fires*) and Structural Communication Grid 2, Word Association Test and Concept Map is 0.16. These three tests all relate to *Evolution*, a different topic.

The second observation is that the Ranking test seems to be measuring something completely different. Thirdly, the intercorrelation between Word Association Test (on *Evolution*) with the Concept Map (on *Evolution*) is high (0.39 or 0.40).

It is possible that three factors might be involved in interpreting the correlation results. A positive correlation might arise if:

Two measurements are testing the same area of biology.
Two measurements are using the same test format.
Two measurements are reflecting the kind of 'brain architecture' of the student.

These three factors are likely to be interrelated and it is not easy to separate the factors. It would have been helpful to be able to apply a factor analysis on the data to explore any underlying structure behind the pattern of results but, unfortunately, students did not undertake all the tests. This was because of lack of time of access and the need to pair tests to match the time available.

It is possible that, if the same theme in biology is being tested, this accounts for a correlation of about 0.35-0.40 while, testing in different areas reduces this to about 0.15-0.18. Thus, the effect of the topic might be around 0.20-0.25. This might suggest that the effect of the 'brain architecture' (access to links and nodes, following the ideas of Otis, 2001) might contribute about 0.15. However, it has to be recognised that these contributions to correlations are very speculative in that possible inter-correlations might modify them considerably.

Chapter Nine

Experimental Work: Stage Three

9.1 The Third Stage

The third or final stage was conducted with 525 first year Level-1 biology students in October 2004. This stage involved the same four teaching units. Units 1, 2A, and 2B are group problems to give the students experience with open-ended problem. Unit 3 was for individual use. It would have been advantageous to use new units (and these were in preparation) but the Faculty of Biomedical and Life Sciences wished to repeat the same units without modification. In addition, because of increased pressures on time within the Faculty, there was very limited time for any assessment to be applied.

Five short tests were devised. For time reasons, any individual student only took two tests. In the previous two experiments, an attempt was made to see if a key factor in determining success in problem solving was the availability of links between ideas held in long term memory. It proved difficult to measure this as generic biological ability and general knowledge of biological themes were both important factors and tended to obscure insights into links between nodes of knowledge in long term memory.

In this experiment, the aim was to approach the issues of links between ideas in long term memory from a different perspective. Four of the five tests aimed to measure some kind of overall cognitive ability which might depend on the presence and accessibility of such links while the fifth test aimed to see how the students saw themselves with regard to these kind of general skills. The tests are described in detail later. Tables 9.1 and 9.2 show the numbers involved.

Table 9. 1 **The third stage**

Level-1 Biology (Glasgow University)	
Date	First term (Oct 2004)
No. of teaching units	4
No. of tests	5
Total number of students (N)	525

Table 9. 2 The units and number of groups and students involved in third stage

Units	Name of units	Type of work	Number of involved groups or students
1	*A Model Organism*	Group	135
2A	*The Chicken Run*	Group	85
2B	*MMR Vaccine*	Group	60
3	*Forests that Need Fires*	Individual	525

Table 9.3 lists the five tests and what they were seeking to explore.

Table 9. 3 Tests and their aims of measurement

No.	Tests	Measurement
1	Convergent/Divergent test (C/D)	To assess extent of divergency
2	Lateral Thinking test 1 (LT)	To assess ability to step outside a frame of reference
3	Lateral Thinking test 2 (LT)	
4	Ranking test (RA)	To assess ability to link ideas together
5	Self-Report Questionnaire (SRQ)	To test the attitudes of students towards creative and lateral thinking.

The organisation of the experiment is shown in Tables 9.4 and 9.5.

Table 9. 4 Schedule of the third stage in October (12-15/10/2004)

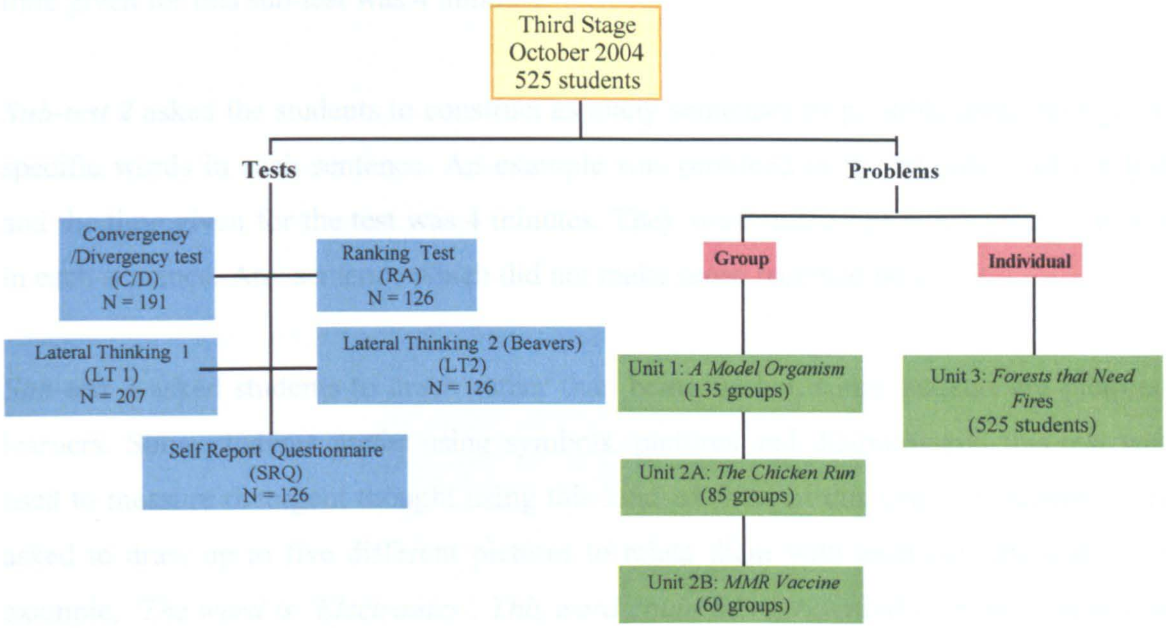
Day	Time	Tests for lab 1	Tests for lab 2
Tuesday	a.m.	RA & Q & LT 2	RA & Q & LT 2
	p.m.	LT 1	LT 1
Wednesday	a.m.	C/D	C/D
	p.m.	RA & Q & LT 2	RA & Q & LT 2
Thursday	a.m.	C/D	C/D
	p.m.	LT 1	LT 1
Friday	a.m.	RA & Q & LT (B)	No lab classes
	p.m.	LT 1	

C/D : Convergent/Divergent test; LT 1: Lateral Thinking test;
RA: Ranking test; SRQ: Self-Report Questionnaire;
LT 2: Lateral Thinking test (Beaver).

Table 9. 5 Number of tests applied in the third stage

Tests	Number of labs for each test	Number of students	Time (minutes)
C/D	4	191	20
LT 1	5	207	20
LT 2	5	126	10
RA	5	126	8
SRQ	5	126	7

Figure 9. 1 Summary of the third stage



9.2 Assessment Tools

Each of the tests is now outlined in detail. The results obtained are summarised and the results of correlation with the performance in unit 3 and the other tests are discussed in turn.

9.2.1 Convergent / Divergent Test (C/D)

A suitable test for convergency/divergency had been developed and used by Bahar (1999) and Danili (2004). Its structure, application and validity were well established. Essentially, high performance in the test indicates divergent behaviour. It is *assumed* that a low mark indicates convergency. This test was used without modification.

The test consisted of six sub-tests, described below. Four laboratory groups took the test which took exactly 20 minutes. Each sub-test was timed precisely. This test was applied after unit 3 was completed. The number of students who took this test was 191. The test is shown in full in Appendix F.

Sub-test 1 was designed to find out the students' ability to generate words of similar meaning to those given. At the beginning of the test an example was provided to clarify what the student was required to do. For example, the word '*short*' was given, a set of words such as '*brief, abbreviated, concise, momentary, little, limited, deficient, abrupt,* *petite, small, compact, tiny'* might be expected. This test included three questions and the time given for this sub-test was 4 minutes.

Sub-test 2 asked the students to construct as many sentences as possible using four given specific words in each sentence. An example was provided at the beginning of the test and the time given for the test was 4 minutes. They were instructed to use all four words in each sentence. Any sentence which did not make sense received no credit.

Sub-test 3 asked students to draw: rather than being verbal, some students are pictorial learners. Some students prefer using symbols, pictures and diagrams and this test was used to measure divergent thought using this kind of skill. In this test, the students were asked to draw up to five different pictures to relate them with each concept word. For example, *'The word is 'Electronics'. This word could be represented by many symbols or drawings as shown below'.* The sub-test was allowed 5 minutes.

Sub-test 4 aimed to see how many things the students could think of that are alike in some way. For example, they asked to write all things that are '*red*' more than any other colour. The time given to do this sub-test was 2 minutes.

Sub-test 5 attempted to measure students' ability to think of as many words as they could that begin with one letter. An example was given such as any word begins with letter 'G' and ends up with letter 'N'. Names of people or places were not allowed and the time was 2 minutes.

Sub-test 6 aimed to find out how many ideas the students could think of a given topic. They had to list all the ideas they knew about a topic. An example was given at the beginning of the test: about '*a train journey*'. Students were instructed to list all the ideas they can think about this topic. They were expected to provide answers like '*number of miles, suitcases, the rail way, people in the train*'. 3 minutes was allowed to complete this sub-test.

Each correct answer for each sub-test was awarded one mark and a total mark was then derived. Table 9.6 shows the descriptive statistics for this test.

Table 9. 6 Descriptive statistics for Convergent/Divergent test

Convergent/Divergent test	N	Minimum	Maximum	Mean	Std. Deviation
	191	17	74	47.5	10.4

The Convergent/Divergent test scores correlated significantly although not highly with the performance in problem unit 3 ($r = 0.18$, $p = 0.012$) as shown in Table 9.7.

Table 9. 7 Correlation results for Convergent/Divergent test with unit 3

Convergent/Divergent test Correlations	Unit 3
Pearson correlation (r)	0.18
Significance (2-tailed)	p = 0.012
Sample (N)	191

This shows that the students who were more divergent tend to do better at the open-ended problem (unit 3). This is consistent with other work (e.g. Danili and Reid, 2005; Hindal, 2005) where divergent students frequently do better at assessments. Convergent students are never found to do better at academic assessments although, sometimes, they do just as well as divergent students (Danili, 2004). Indeed, she found that the strength of correlation between divergency and performance depended on the *type* of test being used. Assessment tests which demanded a greater extent of linking ideas correlated more highly.

If the findings of Danili (2004) are generally true, then this suggests that success in solving problem (unit 3) did indeed require a skill at linking ideas. A possible hypothesis is that divergent students (either by generic disposition or by preference or by training, or some combination of all three) create (or are capable of creating) more links between nodes in long term memory. In traditional assessments, the higher number of linkages enables easier access to information and performance is enhanced. In open-ended problem solving, there is a need to move easily and rapidly between nodes in long term memory. The divergent person therefore has a clear advantage.

The sub-tests in the divergency test were also correlated with performance in unit 3 (Table 9.8). While sub-test 1 gave a correlation value of 0.15 but there is a much higher correlation between sub-test 6 and unit 3 at 0.26. Sub-test 6 explores the linking of ideas rather than words, sentences or images. This does suggest that it is the ability to *link ideas* which is important in problem-solving success.

Table 9. 8 Correlation results for sub-tests in Convergent/Divergent test

Unit 3 Correlations	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Pearson correlation (r)	0.15	0.10	- 0.02	0.10	0.05	0.26
Significance (2-tailed)	p = 0.034	n.s.	n.s.	n.s.	n.s.	p < 0.001

Sub-test 6 tested ideas while sub-test 1 tested word meanings. Sub-test 2 looked at sentence generation while sub-test 4 required the production of objects of similar characteristics. Sub-test 5 asked for words starting with the same letter while sub-test 3 depended on visual skills. Ideas and meanings are significantly correlated with success in unit 3. By contrast, generation of words and pictures are not. Sub-tests 2 and 4 are positively correlated but not significantly. Looking at unit 3, the skills represented by sub-tests 3 and 5 are irrelevant while those of sub-tests 2 and 4 are largely irrelevant. It is easy to see that meanings and ideas (sub-tests 1 and 6) are skills related to success in unit 3.

9.2.2 Lateral Thinking Test 1

Lateral thinking can be defined as the ability (and/or willingness) to step outside the frame of reference. It was thought that students who were capable of doing this would have an advantage at open-ended problem solving where success often dependent on being able to link ideas in a fresh way.

This test was developed on the basis of De Bono's ideas of lateral thinking (1970) Ideas were gathered from many sources and tried out on postgraduate students. Slowly, these ideas were refined to produce a test of five items. In actual practice, a reduction in the time available with the level 1 biology students meant that one item was omitted (item 4). The complete test is shown in Appendix F.

The purpose of the Lateral Thinking test 1 was to explore the extent to which students were able to move outside their normal frame of reference and to develop new ideas and approaches to problems. It was thought that this skill might reflect an ability to employ links or create links in long term memory. Five laboratory groups took part, the number of students taking this test being 207, and the time allocated was 20 minutes. Again because of time constraints, it was unfortunately not possible for these students to take other tests.

This test was marked in a very simple way. Each valid answer was given a score of one, giving a final total score. Table 9.9 shows the result of descriptive statistics.

Table 9.9 Descriptive statistics for Lateral Thinking test 1

	N	Minimum	Maximum	Mean	Std. Deviation
Lateral Thinking 1	207	0	9	3.3	1.3

The Pearson correlation of the results with the performance in unit 3 gave a high value of 0.35 ($p < 0.001$) (see Table 9.10).

Table 9. 10 Correlation results for Lateral Thinking test 1 with unit 3

Lateral Thinking 1 Correlations	Unit 3
Pearson correlation (r)	0.35
Significance (2-tailed)	$p < 0.001$
Sample (N)	207

Lateral thinking is difficult to measure and test validity is not easy to gauge. The test items sought to cover a wide range of skills which fitted the definition of lateral thinking and were consistent with the kinds of test items developed by De Bono. Nonetheless, the test results must be treated with some caution. If the Lateral Thinking test 1 results reflect ability to move outside a frame of reference, then this skill is clearly highly correlated with problem-solving success, as measured by success in unit 3.

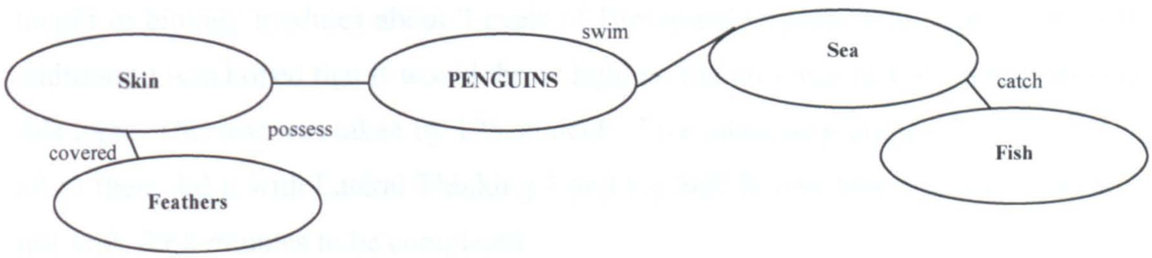
The result of this test gave evidence that the lateral thinkers are using this style critically to solve unit 3.

9.2.3 Lateral Thinking Test 2

The purpose of Lateral Thinking test 2 again was designed to explore the ability to move outside a frame of reference. The test was conducted with five laboratory groups and was not accompanied by any other tests because of time themes taught to the students previously. The major differences between Lateral Thinking test 1 and 2 lay in the length of each test and the subject matter. Test 2 had only one question about a beaver's life while 1 had five questions on more general knowledge. Lateral Thinking test 2 is shown in full in the Appendix F.

This test asked students to make links between twelve ideas or concepts given on the question sheet. The answer sheet was attached to the question sheet. In some ways, this test is similar to a Concept Map but differed in its purpose. Lateral Thinking test 2 gave the concept words but the students have to put the links between them while, in a Concept Map, only the name of the topic was given. The students were instructed by this sentence: *Here is a way to show some information about penguins* (the example is shown in Figure 9.2). They supplied by some linking words as *covered, swim, possess*. Then the students asked to use the same method and they can use as much information as they can about *'Beavers'*. It gave them opportunity to generate ideas and to create new ways of looking at things.

Figure 9. 2 *Example*: **Penguin**



Students taking this test, also, took the Ranking test (8 minutes) and the Self-Report Questionnaire (7 minutes). There were five laboratory groups with 126 students. The total time for the three tests was 25 minutes total, with only 10 minutes for Lateral Thinking test 2.

This test was marked in a very simple way. Two counts were taken: one was to count the valid position of each word (node) given and another by counting valid links between concepts. Each valid answer was given one score and then added them up at the end. There is no fixed total mark for this test. Table 9.11 shows the descriptive statistics for the test.

Table 9. 11 Descriptive statistics for Lateral Thinking Test 2

	N	Minimum	Maximum	Mean	Std. Deviation
Lateral Thinking 2	126	0	33	14.4	6.1

The Pearson correlation showed that the test was significantly correlated with unit 3 ($r = 0.19$ with $p < 0.05$ (see Table 9.12). It can also be seen that the Lateral Thinking test 2 also correlated with the Ranking test.

Table 9. 12 Correlation results for Lateral Thinking Test 2 with unit 3 and Ranking test

Lateral Thinking 2 Correlations	Unit 3	Ranking test
Pearson correlation (r)	0.19	0.19
Significance (2-tailed)	p = 0.037	p = 0.030
Sample (N)	126	126

As with Lateral Thinking test 1, the validity of the test is difficult to estimate. If the test is a genuine reflection of lateral thinking ability, then this seems advantageous when solving an open-ended problem.

9.2.4 Ranking Test (RA)

The Ranking test was developed to measure students' understanding of information being taught in biology modules about 'Levels of Biological Organisation' (see Figure 9.3). In addition, it was hoped that it would throw light on the presence of links between nodes in this topic. This test was taken by 126 students. Five laboratory groups were involved and all of them did it with Lateral Thinking 2 and the Self-Report Questionnaire (SRQ). This test took for 8 minutes to be completed.

The way of developing this test was based on the biology topic about 'animal physiology' which considered the diversity of cell structures that adapt them to different structures and the levels of structural organisation from cells to organs. The subject matter should have been familiar to the students but the test was whether the students had established enough clear links in long term memory so that they could place the various ideas in a logical order in a matter of levels of structural organisation from functional unit of the organisms (biochemical level) to the ecological level and whole body relating to the environment.

This test was marked in a similar way to the previous Ranking test but the maximum mark was set at 15. The correct answers are shown in Table 9.13.

Figure 9.3 Ranking test on 'Levels of Biological Organisation'

Biologists distinguish different levels of organisation from biochemical to ecological.

A The photosynthetic pigment chlorophyll is contained in chloroplasts.

B Oak woodlands in Britain have greater diversity of insect species than spruce plantations.

C Adenine is one of four nucleotides in DNA.

D In the human population of Europe, about 15% are of the blood type Rhesus(Rh)-negative.

E The pancreas contains cells that secrete insulin in humans.

F Mitosis is the normal process of cell division.

G In robins, both parents feed the young.

Rank these statements concerning levels of organisation in order of their level from biochemical to ecological starting at the lowest level by placing the letters A, B, C...etc. in the boxes below. The letter which comes first is the lowest level and the letter which comes last is the highest level from your point of view.

Biological level (Lowest level) — Ecological level (Highest level)

Table 9.13 Answers for Ranking test – *'Levels of Biological Organisation'*

C	A	F	E	D	G	B

Biochemical level (Lowest level) — Ecological level (Highest level)

As before, if the student marked the order of any answer by one position away from its correct position, there was no penalty. Marks were deducted increasingly as the student's answer deviated form the correct order. Table 9.14 shows the descriptive statistics for the test.

Table 9. 14 Descriptive statistics for Ranking test

	N	Minimum	Maximum	Mean	Std. Deviation
Ranking test (RA)	126	0	15	10.6	5.4

Pearson correlation analysis showed that there was no significant correlation between this Ranking test and unit 3 (see Table 9.15). It has to be noted that the subject matter for the test was very different from that of unit 3. If this Ranking test does indeed give some kind of measure of links in long term memory, then these links (which relate to cell organisation) are more or less irrelevant for the problem based on germination. This lends more support to the idea that the various tests are not simply measuring some kind of generic biological ability.

Table 9. 15 Correlation results for Ranking test with unit 3 and Lateral Thinking 2

Ranking test Correlations	Unit 3	Lateral Thinking 2
Pearson correlation (r)	0.05	0.19
Significance (2-tailed)	n.s.	p = 0.030
Sample (N)	126	126

9.2.5 Self-Report Questionnaire (SRQ)

A Self-Report Questionnaire was designed to reveal how students can describe themselves when they are solving any problem. It is also looked at attitudes towards creative and lateral thinking styles. This test was taken by 126 students, five groups. All students who took it also took the Lateral Thinking 2 test and the Ranking test. This test took 7 minutes to be complete (see the test in Figure 9. 3). Positions of responses for each student on each question were coded from 1 to 6. The data obtained are not necessarily normally distributed, and are categorical or ordinal in nature. To see if the responses of the students to each question related to their performance in unit 3, Kendall's tau_b correlation was applied.

Figure 9. 3 Self-Report Questionnaire

What Do You Think About Problems?

Your Matriculation Number

This survey is designed to reveal how you describe yourself when you are solving any problem.
Your participation will help us to improve learning.
Your responses will not affect your grades in Biology.

You can describe a racing car in this way:

quick	☑	☐	☐	☐	☐	☐	slow
important	☐	☐	☑	☐	☐	☐	unimportant
safe	☐	☐	☐	☐	☑	☐	dangerous

The positions of the ticks between the word pairs show that you consider it as <u>very</u> quick, slightly more important than unimportant and <u>quite</u> dangerous.

Think about the problems you have just attempted and the way you solve problems.

Please tick ***one*** box on each line to show your opinion.

I prefer to solve problems on my own							I prefer to work with a group when I solve problems
I prefer to try problems which follow clear procedures							I prefer to try open-ended problems
I feel uncertain when I solve open-ended problems							I feel confident when I solve open-ended problems
I'm happy to take a risk while I attempt problems							I'm not happy to take a risk while I attempt problems
I cannot be bothered with problems on unfamiliar topics							I like problems in new areas on knowledge
Pictures and diagrams help me solve problems							Pictures and diagrams do not help me solve problems
I find the problems more difficult without clear instructions							I find the problems easier without any instructions
Discussions during problem solving work enhance my understanding							Discussions during problem solving work do not help me in understanding
I usually make notes while solve problems							I rarely make notes while solve problems
I cope well with uncertainty in problems							I do not cope well with uncertainty in problems
I prefer step-by-step instructioned problems							I do not like step-by-step instructioned problems
I believe that the instructions are good starting point in solving problems							I do not want to be tied done when solving problems
I don't enjoy doing problem solving							I enjoy doing problem solving

Each question, in turn, was correlated with the performance in the unit 3 problem, using Kendall's tau-b correlation. Tables 9.16 and 9.17 only show the values which are statistically significant (other values are presented in Appendix G).

Table 9. 16 **Correlation results for Self-Report Questionnaire**

Unit 3 Correlations	Question 2
Pearson correlation r	- 0.15
Significance (2-tailed)	p= 0.031
Sample (N)	126

Table 9. 17 **Correlation results for Self-Report Questionnaire**

Lateral Thinking 2 Correlations	Question 5	Question 8
Pearson correlation r	0.14	- 0.15
Significance (2-tailed)	p = 0.035	p = 0.036
Sample (N)	126	126

Table 9.16 shows that there is a correlation between question 2 and performance in unit 3. This confirms that students who did best in unit 3 were the students who like to follow clear procedures in problem-solving work (question 2).

Questions 5 and 8 (Table 9.17) correlated with the Lateral Thinking test 2. This shows that students who like problems in new areas and who find discussions helpful during problem-solving work performed best in the Lateral Thinking test 2. This is to be expected.

9.3 Conclusions

The first experimental stage attempted to gain some kind of insight into the extent to which nodes and links in long term memory contribute to success in problem solving. The difficulty was that some kind of generic biological ability could explain the results, at least in part. In the second experiment, the use of tests on a completely different biological topic suggested that, indeed, there was a contribution from some kind of generic biological ability. In this final stage, the aim has been to approach the problem from a different perspective by looking at extent of divergency and ability to think laterally.

Four tests were used: Convergent/Divergent test to assess extent of divergency, Lateral Thinking tests 1 and 2 to assess ability to step outside a frame of reference, and Ranking test to assess ability to link ideas together. Some of the measurements show correlations with performance in unit 3 which are statistically significant.

The descriptive data for the various tests are presented in Table 9.9 and suggest that the tests are likely to be at the appropriate level and should be able to offer some discrimination.

Table 9. 9 Descriptive statistics of all tests

	N	Minimum	Maximum	Mean	Std. Deviation
Unit 3	525	1	23	12.1	4.5
Convergent/Divergent	191	17	74	47.5	10.4
Lateral Thinking 1	208	0	9	3.3	1.3
Lateral Thinking 2	126	0	33	14.4	6.1
Ranking test	126	0	15	10.6	5.4

For clarity, all the correlation results are summarised in table 9.18.

Table 9.18 Correlation results for all tests

Correlations Pearson r Significance Sample (N)	LT 1	C/D	RA	LT 2
Unit 3	**0.35** p<0.001 207	**0.18** p=0.012 191	0.05 n.s. 126	**0.19** p=0.037 126
LT 1		--	--	--
C/D			--	--
RA				**0.19** p=0.030 126

As before, the Ranking test seems to be measuring something different. Experiment two suggested that 'brain architecture' (see chapter 5) might contribute about 0.15 to the correlations, although this is quite speculative. This is consistent with the correlations obtained for divergency and Lateral Thinking test 2. However, it leaves the result for Lateral Thinking test 1 as very puzzling.

This test was longer and tested the skills of lateral thinking in several ways. Perhaps it is more sensitive than Lateral Thinking test 2.

The overall conclusion is that the results from experiment three seem to support the idea that the numbers of accessible nodes and links in long term memory (reflecting 'brain architecture' and, perhaps, aspects of cognitive styles) do seem to be related to success in a problem-solving exercise.

Given the correlation values obtained, there must be other factors influencing success in unit 3. Of course, it is known that working memory is a major factor in all problem solving and there will be no doubt other factors involved. For example, field-dependency is well established as factor in most assessment tasks.

Chapter Ten

Conclusions, Limitations and Recommendations

10.1 Introduction

In this chapter, the results of this study will be reviewed, with comments on the strengths and weaknesses of the work. Conclusions will be offered with suggestions for further research.

It has been noted that daily life problems tend to be open-ended problems. If problems can be described in terms of what is given, what is the goal and the method of reaching the goal, then open-ended problems have one or two of these three aspects not totally specified. In this study, the aim was to consider problems which are open-ended in this sense.

Of course, problem solving is complex and influenced by many factors. Yang had identified many of the factors which might be critical in problem-solving success (Reid and Yang, 2002a). This study was designed to explore many of these factors. Specifically, the suggestion that it was the presence of nodes of knowledge and accessible links between the nodes of knowledge (all held in long term memory) which have been a major focus of this study. Gaining evidence is very difficult in that conclusions have to be inferred from experimental data and there is never any certainty that the experimental data are completely valid or that they cannot be interpreted in other ways.

10.2 The Experimental Work

This experimental work was conducted in three stages, from October 2003 to October 2004. A set of open-ended problems was developed and scrutinised by many staff members in the Faculty of Biomedical and Lifesciences. They were then used with large numbers of first year university students studying biology. One of the open-ended problems was individually based and this was the key to the data analysis. Student samples were very large: 642 and 525, respectively for the three stages. A large number of tests were developed to explore aspects of the skills of problem solving. The aim was to probe the underlying skills of problem solving from many perspectives in order to gain insights into what was happening. Each of the outcomes from each stage are now summarised briefly.

10.3 The Experimental Outcomes

In the study, four problem-solving units were developed and used (see Table 10.1):

Table 10.1 First stage: Units Used

Group units	Unit 1	A Model Organism
	Unit 2A	The Chicken Run
	Unit 2B	MMR Vaccine
Individual unit	Unit 3	Forests that Need Fires

The first stage of the experiment was designed to focus on factors relating to long term memory in particular. What the learner held and how the knowledge was linked were particularly important. The perceived role of students and lecturers was also thought to be an important aspects and this was explored. Numerous measurements were made to explore links in long term memory related to how students handled problem solving. The tests were correlated with unit 3. Five tests were used in the first stage, as shown in Table 10.2

Table 10.2 First stage: Tests Used

Tests Used	Purpose
True-False test 1	What students know (nodes of knowledge)
True-False test 2	What students know (nodes of knowledge)
Word Association Test	How knowledge is linked
Structural Communication Grid	What students understand
Perry Position Questionnaire	How students view learning

All the test measurements were correlated with success in unit 3 and all correlations were found to be statistically significant at level 0.01 (see Table 10.3). However, the student's responses to the Perry questionnaire only one significant correlation with any aspect of problem solving, suggesting that attitudes related to learning are not related to problem-solving success.

Table 10.3 **First Stage: Correlations**

Test Used	Sample	Pearson Correlation	Significance
True-False Test 1	273	0.26	$p < 0.001$
True-False Test 2	178	0.20	$p = 0.007$
Word Association Test	282	0.20	$p < 0.001$
Structural Communication Grid	280	0.25	$p < 0.001$

The results indicate that performance in unit 3 is related to the performance in each of these four tests. This *suggests* that success in unit 3 may be related to:

(1) Factual knowledge;
(2) Links between nodes or ideas;
(3) Understanding of ideas.

However, it is possible to interpret the data in terms of some kind of generic biological ability. To test this, the second stage used assessments based on a completely separate section of the curriculum. Thus, many of the tests used in the second experiment did *not* relate to the topic of unit 3: *Forests that Need Fires*. Five tests were used (Table 10.4).

Table 10.4 **Second stage: Tests Used**

Tests Used	Purpose
Structural Communication Grid 1	What students understand (germination)
Structural Communication Grid 2	What students understand (evolution)
Word Association Test	How knowledge is linked (evolution)
Concept Map	How knowledge is linked (evolution)
Ranking test	How knowledge is linked (evolution)

Some of the measurements are significantly correlated with success in unit 3 (see Table 10.5). It is clear that the correlation values are much less when the test is measuring in a different content area. Unit 3 was based on germination while all the tests except the first Structural Communication Grid related to *Evolution*. This suggests that, while generic biological ability has some effect, there are other reasons for the correlations observed in the first stage.

Table 10.5 Second Stage: Correlations

Test Used	Topic	Sample	Pearson Correlation	Significance
Structural Communication Grid 1	Germination	200	0.36	$p < 0.001$
Structural Communication Grid 2	Evolution	205	0.15	$p < 0.005$
Ranking Test	Evolution	214	-0.04	n.s.
Word Association Test	Evolution	162	0.24	$p < 0.005$
Concept Map (nodes)	Evolution	162	0.12	n.s.
Concept Map (links)	Evolution	162	0.13	n.s.

This seems to be confirmed by the observation that the tests relating to *Evolution* tended to correlate with each other at around 0.3 - 0.4.

The third stage approached the possible relationships between problem-solving success and the accessibility of links in long term memory in a different way. It is hypothesised that if a person is divergent and is good a lateral thinking then this might suggest that there are more accessible links in long term memory. Four tests and one questionnaire were related to performance in the open-ended problem, unit 3 (see Table 10.6).

Table 10.6 Third stage: Tests used

Tests Used	Purpose
Test of divergency	High score indicates divergent behaviour
Lateral Thinking Test 1	Ability to step outside frame of reference
Lateral Thinking Test 2	Ability to step outside frame of reference
Ranking test	How knowledge is linked
Self report questionnaire	How they see their learning

For practical reasons of timing, two Lateral Thinking tests were used. Most of the measurements show statistically significant correlations with the open-ended problem (unit 3) – see Table 10.7.

Table 10.7 Third Stage: Correlations

Test Used	Sample	Pearson Correlation	Significance
Divergency Test	191	0.18	$p < 0.05$
Lateral Thinking Test 1	207	0.35	$p < 0.001$
Lateral Thinking Test 2	126	0.19	$p < 0.05$
Ranking test	126	0.05	n.s.

These tests did not relate specifically to biology. The significant correlations are consistent with the suggestion that problem-solving success depends, in part, on the accessibility of links between nodes of knowledge in long term memory. It has to be noted that the test for divergency is well established. However, the Lateral Thinking tests were devised for this work and their validity is not so well established. Perhaps they were measuring the ability to link ideas at different levels of thought.

In all this work statistical analysis has used pearson correlation. Of course, correlation does not imply causality. Thus for example, the fact that a Word Association Test (which measures links in long term memory) correlates with performance in unit 3 does not demonstrate with certainty that the presence of such links influences problem-solving success. All can be said is that such a correlation is consistence with this hypothesis. Therefore, in this entire study, conclusions must be drawn with caution.

10.4 General Conclusions

It is clear that the tests worked well in comparing with performance with unit 3. Observation indicated that most students enjoyed working with the tests as well as with the four problem units used. They found them challenging in terms of novelty and complexity. The unit and tests were at right level of difficulty and students were positively attracted to the way the units and tests were presented.

The students liked the group work as they could share their views and ideas towards new issues. This was consistent with Yang's (2000) finding that students like working in groups. As with Yang's work, confidence was observed to grow after they had tackled the first unit. Units 1, 2A and 2B are demanding but not impossible to solve. Unit 3 seemed more demanding but this have simply reflected that it was individual.

Units 1, 2A and 2B were used partly to enable the students to gain confidence in approaching this style of open-ended problem so that they would come to unit 3 familiar with the style and approach and what was expected of them. However, the needs of the Faculty of Biomedical and Lifesciences were a major determining factor in what was possible. Group problem solving was important to the teaching programme and they were not able to use more than one individual problem-solving exercise.

The study was seeking to probe the importance of accessible links in long term memory as a factor in open-ended problem-solving success. While all the results are consistent with this, it is, of course, impossible to be certain. Some kind of generic biological ability, or even a more general ability, is certainly a factor. Is this to be seen in terms of biological knowledge, biological confidence, interest or commitment to the subject? It is known that working memory and field dependency are factors and these may be part of the generic ability as well (Reid and Yang, 2002b). These were not explored simply because previous work had established their importance so clearly.

Nonetheless, this study had the aim of looking at links in long term memory and the data do seem to support the idea that the accessibility of such links (as reflected in a battery of tests with large samples) is related to open-ended problem-solving success.

10.5 Strengths and Limitations

A number of features offer a measure of confidence in drawing conclusions:

(a) Sample sizes were large, making it likely that there is high reliability in the measurements;

(b) The range of tests was considerable and probed the linking of ideas from many standpoints, with a fair measure of consistency of results;

(c) There were four problems used (many more were devised but were not able to be used) and these all went very successfully.

One real area of weakness in a study such as this is being to establish the validity of the tests used. Some clearly test the knowledge base while Structural Communication Grids are known to test understanding. The divergency test is well established and does offer a measure of divergent skill (although it assumes that convergency is the *lack* of divergent skill). Many of the other tests were new, both in terms of their nature and their content. There is no easy way to assess their validity with total objectivity.

It would have been much better if there had been more individual problems used but, although written, it was not possible to use them. This is an unfortunate and major weakness but was beyond the control of the researcher. Students did not undertake all the tests. This was because of lack of time of access and the need to pair tests to match the time available. In all of this, the problem of a crowded curriculum was very obvious and the opportunities to gain access to the students was very much appreciated, given the pressures on teaching staff.

10.6 Specific Conclusions

The following specific conclusions are offered:

(a) Factual knowledge and the links between ideas and understanding of these ideas seems to relate to performance in an open-ended problem, unit 3. This is consistent with previous exploratory work of Reid and Yang (2002b).

(b) The correlations between performance in unit 3 and performance in a large range of tests do not seem to be explained completely by some kind of general ability in biology. While the results show that if students are good at one kind of skill in biological context, then they are likely to be good at other skills but this does not account for all the relationships observed.

(c) Nonetheless, generic biological ability seems to be a factor influencing problem-solving success.

(d) The Ranking tests seem to be measuring something completely different from the proposed purpose. This needs further exploration.

(e) The intercorrelation between a Word Association Test with the Concept Map is high. This suggests that it is indeed the links between nodes of knowledge which is important.

(f) It is recognised that biological ability, ability to respond in a specific test format and the actual 'brain architecture' (nature and accessibility of nodes and links) of students may all be reflected in the observed correlations. These three aspects are likely themselves to be interrelated and it is not easy to separate them.

(g) The Perry Position Questionnaire suggests that students' views related to aspects of learning are not a major correlate of problem-solving success. However, confidence seems to be important to enable students to take what Reid and Yang (2002b) called '*cognitive risks*', a potentially important feature of open-ended problem-solving success.

(h) The Self-Report Questionnaire confirms that students who did best in unit 3 were the students who like to follow clear procedures in problem-solving work. Also, as might be expected, they like problems in new areas. Working in groups is another important feature of success in problem solving.

The overall conclusion is that the results from experiment three seem to support the idea that the number of accessible nodes and links in long term memory (reflecting 'brain architecture' and, perhaps, aspects of cognitive styles) do seem to be related to success in a problem-solving exercise.

10.7 Suggestions for Further Work

Some suggestions for further research are offered below:

(1) The work needs repeated using more individually based problems.

(2) Parallel tests need to be developed to check if some of the correlations obtained are repeated.

(3) The real issue lies in the way humans develop links between ideas. Is this largely dependent on some kind of 'brain architecture' which is determined in the main genetically (as the work of Otis, 2001, might suggest) or is it possible to employ teaching strategies which enable students to develop increasing skills in linking ideas meaningfully and in such a way that the linkages are accessible? This would require the development of new teaching materials or strategies and testing the growth (or otherwise) of links in long term memory using, perhaps, a similar battery of tests as used here.

(4) From the perspective of teaching and learning practicalities, the units were very well received by both students and their teachers. The scope for the increasing use of this teaching approach is considerable. However, it needs to be established whether this approach is efficient and effective for learning and, indeed, what different outcomes can also be gained. Previous work (e.g. Johnstone *et al.*, 1981; Reid, 1978) in this field needs to be considered and, perhaps, expanded.

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Appendices List

APPENDIX A

The Preliminary Study

I. Questionnaire 1X

II. Questionnaire 1Y

Biology 1X - Difficulties Survey - Centre for Science Education

This survey is designed to reveal the difficulties in this course.
Your participation will help us to improve learning.

Easy	*I understand the topic first time*
Moderate	*I found it difficult but I understand it now*
Difficult	*I still do not understand it*

If you wish, you may write comments about difficulties in the space provided.

Please tick a box to show how you found the following topics in biology.

	Easy	Moderate	Difficult	*If difficult, please say why*
From molecules to organism	☐	☐	☐	
Atoms, chemical bonds, molecules and pH	☐	☐	☐	
Protein structure I & II	☐	☐	☐	
Protein function	☐	☐	☐	
DNA as a store of biological information	☐	☐	☐	
DNA replication	☐	☐	☐	
How genes are expressed as RNA	☐	☐	☐	
How cells make proteins	☐	☐	☐	
Cell membrane: structure and function	☐	☐	☐	
Introduction to metabolism	☐	☐	☐	
Mitochondria and chloroplasts	☐	☐	☐	
Photosynthesis	☐	☐	☐	
The light-reactions of photosynthesis	☐	☐	☐	
The dark-reactions of photosynthesis	☐	☐	☐	
Genes, chromosomes and mitosis	☐	☐	☐	
Mieosis	☐	☐	☐	
One factor crosses	☐	☐	☐	
Two factor crosses; independent segregation.	☐	☐	☐	
Two factor crosses; 2 genes on a chromosome	☐	☐	☐	
Sex determination and sex linkage	☐	☐	☐	
Genetic disease: sickle cell anaemia	☐	☐	☐	
Chromosome disease: prenatal diagnosis	☐	☐	☐	
Microbes: How big are they& how they work?	☐	☐	☐	
How microbes make us sick?	☐	☐	☐	
Beer, drugs and dairylea slices	☐	☐	☐	
Evidence of evolution I & II	☐	☐	☐	
The selection process I & II	☐	☐	☐	
The story of evolution I & II	☐	☐	☐	
Seed structure	☐	☐	☐	
Phyotochrome and germination	☐	☐	☐	
How plants fix nitrogen	☐	☐	☐	
Plant tissues and cell types I & II	☐	☐	☐	
Water uptake and transport	☐	☐	☐	
Regulation of water loss	☐	☐	☐	
Flowering and photoperiodism	☐	☐	☐	
Hormonal regulation and growth I & II	☐	☐	☐	

Are there any of the laboratories in Biology-1X you found difficult? If so please say why.

Biology 1Y - Difficulties Survey - Centre for Science Education

This survey is designed to reveal the difficulties in this course.
Your participation will help us to improve learning.

Easy	*I understood just first time*
Moderate	*I found it difficult but I understand it now*
Difficult	*I still do not understand it*
If you wish you may write comments about difficulties in the space provided.	

Please tick a box to show how you found the following topics in biology.

	Easy	*Moderate*	*Difficult*	*If difficult, please say why*
Gene expression in plant growth	☐	☐	☐	
Arabidopsis, gene function	☐	☐	☐	
How plants perceive their environment	☐	☐	☐	
Introduction of new genes into plants	☐	☐	☐	
The potential of plant biotechnology	☐	☐	☐	
Introduction to animal physiology	☐	☐	☐	
Cells, tissues and organs	☐	☐	☐	
Food and nutrition	☐	☐	☐	
Digestion and absorption	☐	☐	☐	
Diet and health	☐	☐	☐	
The circulation	☐	☐	☐	
The heart	☐	☐	☐	
Arteries, veins and capillaries	☐	☐	☐	
The supply of oxygen to the tissues	☐	☐	☐	
The immunological armoury	☐	☐	☐	
Antibodies	☐	☐	☐	
Cell mediated immunity	☐	☐	☐	
Lice, fleas & mites and their life cycles	☐	☐	☐	
People, parasites and pets	☐	☐	☐	
Toxoplasma, cryptosporidium and hydatid	☐	☐	☐	
Hazards of the tropics	☐	☐	☐	
Malaria, ascaris and hookworms	☐	☐	☐	
Homeostasis and the internal environment	☐	☐	☐	
The kidney: structure and function I & II	☐	☐	☐	
Control of water balance by the kidney	☐	☐	☐	
Chemical signalling	☐	☐	☐	
Actions of hormones	☐	☐	☐	
Why sex? human reproduction in the male	☐	☐	☐	
Human reproduction in the female	☐	☐	☐	
Infertility, natural and induced	☐	☐	☐	
Sex, drugs and alcohol	☐	☐	☐	
Patterns of reproduction	☐	☐	☐	
Courtship and mating- evolutionary context	☐	☐	☐	
Niches, guilds and keystone predators	☐	☐	☐	
The trophic structure of ecosystems	☐	☐	☐	
Biotic interactions in ecosystems	☐	☐	☐	
The ecology of populations I & II	☐	☐	☐	
Conservation biology	☐	☐	☐	

Are there any of the laboratories in Biology-1Y you found difficult? If so please say why.

APPENDIX B

The results of the Preliminary Study

I. Difficulty survey in Biology-1X (results of the questionnaire)

II. Difficulty survey in Biology-1Y (results of the questionnaire)

III. Students comments on Module-1X

IV. Students comments on Module-1Y

Students comments in Module-1X

1) from molecules to organism

no comments

2) Atoms. chemical bonds, molecules and pH

Like chemistry
Difficult to understand
No chemistry background
Notes not explained in depth

3) Protein structure I & II

Difficult topic and need more time to grasp it
Difficult to understand

4) Protein function

Difficult topic needs more time to grasp it
Difficult to understand
Remembering X-acids

5) DNA as store of biological information

Difficult idea and needs more time taken on
There was a lot to take in
Hard to remember the steps
Difficult to understand
Lots of handouts and very difficult to see and make notes from
Notes pamphlet was too complex, not helpful and lecture information difficult a lot from textbook

6) DNA replication

Following the process, start ---------- finish
Very detailed
Several processes
Hard to practice
Difficult to understand
Complex
Hard to remember the steps
Quite hard to understand
Quite lots to follow
Lots of handouts, very difficult to see and make notes from
**** Topic from 2-6**: Difficult to learn material that has a weak context, is numerically oriented or is non graphical
in nature. material is highly graphical or leads. It is well represented by analogy and is very easy to learn and remember.

7) How genes are expressed as RNA

Following the process, start ---------- finish
Complex
Confining
Not specific and too vague
Quite hard to understand
Quite lots to follow
A lot of information to be taken
Difficult to understand
Lots of handouts, very difficult to see and make notes from

8) How cells make proteins

Following the process, start ---------- finish
Difficult topic needs more time to grasp it
Not specific and too vague
Difficult to understand
Complex
Quite lots to follow
Lots of handouts and very difficult to see and make notes from
Not explained enough

9) Cell membrane: structure and function

Lots of handouts and very difficult to see and make notes from
Confused
**** Positive comment on topic from 1-9:** very well lectured and the handout on DNA was very helpful

10) Introduction to metabolism

Lots of information
Different terms to understand
Lots to follow
Not done in much detail – very easy
Expanded notes could be given
Notes were more detailed, It would better if not
Doesn't really interest me, so I didn't enjoy it
Found it difficult but not impossible

11) Mitochondria and chloroplasts

Complicated diagrams, not enough time taken
Complicated (3)
A lot of information
Difficult to know which is important
Notes were more detailed, It would better if not
Doesn't really interest me, so I didn't enjoy it
Found it difficult but not impossible

12) Photosynthesis (11.1 %)

Difficult to understand whole view
Link to chemistry
Complex
Complicated (3)
Lots of learning
A bit confusing
Two photosynthesis and Far Red Light
Difficult/hard
A lot of mechanisms and name to remember in one go
Done very quickly
New and many information which wet so quickly
Notes were more detailed, It would better if not
Doesn't really interest me, so I didn't enjoy it
Found it difficult but not impossible

13) The light-reaction of photosynthesis (17.5 %)

Hard to see how they are linked
Too many details to learn
Not enough information

Taught previously, but now taught in different way using different terms
Confusing
The mechanisms of these reactions where complex and processes to understand
Not very well taught
Difficult to understand
Complex
Lots to learning
Difficult to grasp concepts
A lot information given
New topic-briefly covered
Textbook support poor
Not well explained
Don't much like photosynthesis on Near Red Light
Confusing with terminology
Too complicated
Very vague
Doesn't really interest me, so I didn't enjoy it
Found it difficult but not impossible
First time I have studied plants at a great depth

14) The dark-reactions of photosynthesis (21.1 %)

Hard to see how they are linked
Too many details to learn
Not enough information
Confusing
The mechanisms of these reactions where complex and processes to understand
Not very well taught
Difficult to understand
Complex
Lots to learning
Difficult to grasp concepts
A lot information given
New topic-briefly covered
Textbook support poor
Not much in lecture notes
Complicated for Red Light
Lots of details
Taught previously, but now taught in different way using different terms (neutral)
Doesn't really interest me, so I didn't enjoy it
Found it difficult but not impossible

15) Genes, chromosomes and mitosis (13.1 %)

A lot to learn
Difficult to understand
Not enough information in text only really diagrams
Complicated
Process of mitosis
Lots of steps to remember and large amount of data
Only mitosis-mixed up with meiosis
Confusing to start, eventually OK
Full of diagrams but not enough information (writing)
So much to remember
Confusing
Lectures were not well structured
Not interesting
Many different names
A lot to take in a short space of time

16) Mitosis (11.7 %)

A lot to learn
Difficult to understand
Process of mitosis
Complicated and a lot of information to take
Easily confused with mitosis
Not interesting
Took some time to understand and doing some examples may help
Lectures were not well structured
A lot to take in a short space of time

17) One factor crosses (9.4 %)

Genetic section generally quite confused with pedigree and sex linked inheritance
Hard
Difficult to understand
Didn't like this section
Quite confusion
Too much information in a short time
Relatively difficult
Confusion surrounding crosses
Not good
Took some time to understand and doing some examples may help
Lectures were not well structured

18) Two factor crosses; independent segregation (12.9 %)

Genetic section generally quite confused with pedigree and sex linked inheritance
Needs practice questions and more worked examples
Hard
Difficult to understand
Getting read round the way they worked out
Felt material was rushed through before I could work wrong (in my head), the problems presented on the Power point slide
Quite confusion
Too much information per a time
Relatively difficult
Confusion surrounding crosses
Not good
Very fast
Lectures were not well structured
Took some time to understand and doing some examples may help
There are a lot of complication alleles

19) Two factor crosses; 2 genes on a chromosome (14.6 %)

Genetic section generally quite confused with pedigree and sex linked inheritance
Needs practice questions and more worked examples
Hard
Difficult to understand
Getting read round the way they worked out
Felt material was rushed through before I could work wrong (in my head), the problems presented on the Power point slide

Quite confusion
Too much information per a time
Relatively difficult
Confusion surrounding crosses
Not good
Lectures were not well structured
Took some time to understand and doing some examples may help
There are a lot of complication alleles

20) Sex determination and sex linkage (14.6 %)

Genetic section generally quite confused with pedigree and sex linked inheritance
Quite complicated
Need to go over it more slowly to understand it and to make clearer
Confusion surrounding crosses
Difficult to understand (4)
Not good
Hard
Not interesting
Confused (2)
Took some time to understand and doing some examples may help
Lectures were not well structured
Chapter questions were helpful
There are a lot of complication alleles
Found it tricky

21) Genetic disease: sickle cell anemia

Not good
Not enough information
Confused
Questions hard to understand
Took some time to understand and doing some examples may help

22) Chromosome disease: prenatal diagnosis

Not understand
Too fast
Confused
**** Suggestion on topic 15-22:** Computer programmes, which had been done on the lecture 9, were helpful, and (suggest) more programmes should be constructed to ensure a full understanding in more areas.

23) Homeostasis and the internal environment

Not enough time for information
Lectures were given fast
Lectures were difficult to grasp
A lot of common sense and little information

24) The kidney: structure and function I & II

Notes weren't good
Not enough time for the information
Lectures were difficult to understand
A lot of common sense
Little information
Not understand
Poorly lectured in that the material to learn for exam was ambiguous

25) Beer, drugs and dairylea slices

Not interesting, so no need to study it
Notes weren't good
Not enough time for information
Lectures were difficult to understand
A lot of common sense
Little information
Poorly lectured in that the material to learn for exam was ambiguous

26) Evidence of evolution I & II

Notes weren't good
Not interesting
Boring
No clear structure
Quite confusion
Not understand
Concepts were difficult
Wasn't interested in topic and lectures through the slides
Lectures were difficult to understand
I didn't like the way they presented
Notes weren't so helpful
Not adequate material for my lecture notes
Some aspects hard to grasp
Poorly lectured in that the material to learn for exam was ambiguous
Difficulty with concepts of computer programme

27) The selection process I & II

Notes weren't good
Wasn't interesting
Boring
No clear structure to the lectures
Difficult to remember details
A lot to read
Quite confusion
Lectures were difficult to understand
Not adequate material for my lecture notes
Some aspects were hard to grasp
Difficulty with concepts of computer programme

28) The story of evolution I & II

Notes weren't good
Wasn't interesting
Boring
No clear structure to the lectures
Difficult to remember details
A lot to read
Quite confusion
Lectures were difficult to understand
Not understand function of seed types
Not adequate material for my lecture notes
Some aspects were hard to grasp
Difficulty with concepts of computer programme

29) Seed structure

Difficult names of seed to learn
Very complicated

All plants really confusion
Hard to explain detail through a lecture presentation – then became clearer in labs
Poor notes
Confusing
Went too fast
A lot of information
Not enough time given
Difficult to understand and remember
New topic
Varied facts in lecture and labs
Difficult
Did not understand functions of seed types
Should have reinforced as seem to be very examinable
Complicated and a lot to take in
Plant material covered in lectures was very dry and difficult to get a grasp of

30) Phytochrome and germination (15.2 %)

Very complicated
Not well explained
Too much technical terms
A lot of information
Not enough time giving
Confusing
New topic
Difficult
Plants are tricky
Too much to remember terms and fast getting lost
Plant material covered in lectures was very dry and difficult to get a grasp of
Should have reinforced as seem to be examinable
Complicated and a lot to taken in
There had a monotonous lecture that made it difficult to listen

31) How plants fix nitrogen (12.9 %)

Very complicated
A lot of information
Difficult
Should have reinforced as seem to be examinable
Complicated and a lot to take in
There had a monotonous lecture that made it difficult to listen

32) Plant tissues and cell types I & II

Notes weren't good
Very complicated
No lecture slides
Hard to take notes
Bid words
Poorly explained
A lot of information
Difficult
There had a monotonous lecture that made it difficult to listen
Ineffective notes

33) Water uptake and transport (11.4 %)

Very complicated
Too many information
Hard to follow
Explained quite badly
Not enough time to cover it
Tricky
Confusing concepts
Difficult concepts to grasp
Difficult concepts and only covered briefly in lectures
Difficult
Too much to take
There had a monotonous lecture that made it difficult to listen
Ineffective notes

34) Regulation of water loss (10.8 %)

Very complicated
Confusing
Some calculations using I didn't understand them
Difficult to follow
Unfamiliar with symbols and theories
Too many information
Not enough time to cover it
So difficult to pay attention and understand
Poorly explained
Difficult
Too much information at one time to keep following
Too much to take
There had a monotonous lecture that made it difficult to listen
Ineffective notes

35) Flowering and photoperiodism (12.9 %)

Notes weren't good
Very complicated
Some parts were confusing
Poorly explained
A lot of information
Difficult
Diagrams not clear
Too much to take
There had a monotonous lecture that made it difficult to listen
Ineffective notes

36) Hormonal regulation and growth I & II (14.0 %)

Very complicated
Some parts were confusing
Very hard to follow
Not enough time to cover it
Poorly explained
Rushed
Not linked easily
Went too fast
Difficult
Glossed over at end and seemed to be rushed
Very complex
There was a lot more detail in textbook but the key points were unclear
Too much to take
Ineffective notes

Students comment on lab work

- Not Difficult
- Not Difficult, overall if all notes were on the web, we could spend more time listening and taking information rather than scribbling notes>
- Too over structured
- Not left enough by ourselves
- Too over structured
- I found them a bit difficult
- The labs weren't difficult but I found some of the drawing quite challenging and difficult to revise even with the help of text
- the meiosis lab as platsticine made it confusing and it wasn't helpful
- meiosis had many unclear questions such as making models and drawing of what you saw
- The genetics were difficult, the platsticine was supposed to be helpful to understand, but I found it not
- Genetics lab very boring
- Two factor crosses; independent segregation was difficult
- Drosophila lab because the acetone affecting my evaluation skills
- Drosophila lab was difficult
- Plant section not interesting and so no need to take it
- Seed structure poorly explained
- Seed structure was difficult

1) Gene expression in plant growth

Genes are difficult
Not fully explained
Was difficult to understand
Confusing
Lectures were not engaging and accessible
Topics are boring and hard to conceive
Plant work was hard
Very boring
Difficult because content was quite dry

2) Arabidopsis, gene function

Not fully explained
Was difficult to understand
Confusing
Lectures were not engaging and accessible
Topics are boring and hard to conceive
Plant work was hard
Very boring
Difficult because content was quite dry

3) How plants perceive their environment

Plant work was hard
Very boring
Difficult because content was quite dry
Complex process and tried to be made simple but not interested in this area

4) Introduction of new genes into plants

Genes are difficult
Plant work was hard
Very boring
Difficult because content was quite dry
Complex process and tried to be made simple but not interested in this area

5) The potential of plant biotechnology

Plant work was hard
Very boring
Difficult because content was quite dry
Complex process and tried to be made simple but not interested in this area

6) Introduction to animal physiology

Very boring

7) Cells, tissues and organs

8) Food and nutrition

Good lecturer

9) Digestion and absorption

Good lecturer

10) Diet and health

11) The circulation

Confusing
Complex
A lot of very complicated diagrams to take and a lot of complex terms used
A lot of new information and ideas

12) The heart

Confusing
Not clear on route to brain
A lot to remember
Complicated
Complex ideas and names
A lot of new information and ideas
A lot of very complicated diagrams to take and a lot of complex terms used

13) Arteries, veins and capillaries

Confusing
A lot to remember
Hard to distinguish the heart what is what

14) The supply of oxygen to the tissues

Complex

15) The immunological armoury

Not well explained and run too fast
The lecturer needs to update his methods and use Campbell and having a bit of irrelevant words on an overhead is no use at the last
Concepts were poorly explained
Random words were used
Notes provided weren't enough, just keywords which were hard to relate to the lectures
Complicated and some concepts were difficult to grasp
Confusing
Overheads were poor and explanation was brief
Very detailed and lecturer went very quickly
Too much information were given

16) Antibodies

Not well explained and run too fast
The lecturer needs to update his methods and use Campbell and having a bit of irrelevant words on an overhead is no use at the last
Concepts were poorly explained
Notes provided weren't enough, just keywords which were hard to relate to the lectures
Confusing
Chemistry was difficult
Overheads were poor and explanation was brief
Difficult to learn structures of antibodies
Very detailed and lecturer went very quickly
Too much information were given

17) Cell mediated immunity

Not well explained and run too fast
The lecturer needs to update his methods and use Campbell and having a bit of irrelevant words on an overhead is no use at the last
Complicated lectures
Concepts were poorly explained
Notes provided weren't enough, just keywords which were hard to relate to the lectures
Overheads were poor and explanation was brief
Very detailed and lecturer went very quickly
Too much information were given

18) Lice, fleas & mites and their life cycles

Lecturer very hard to follow and much information were given
Not well explained and run too fast
The lecturer could do with same improvements in his slides and presentation skills. In addition, information cannot be found in textbook and supplementary notes should be given
Overheads were poor and explanation was brief
Notes provided weren't enough and very difficult notes from them

19) People, parasites and pets

Lecturer very hard to follow and much information were given
Not well explained and run too fast
The lecturer could do with same improvements in his slides and presentation skills. In addition, information cannot be found in textbook and supplementary notes should be given
Overheads were poor and explanation was brief

20) Toxoplasma, cryptosporidium and hydatid

Lots of new words not defined well in lecture presentation
Very detailed and discussed a lot in short time
Lecturer very hard to follow and much information were given
Not well explained and run too fast
The lecturer could do with same improvements in his slides and presentation skills. In addition, information cannot be found in text book and supplementary notes should be given

21) Hazards of the tropics

Very detailed and discussed a lot in short time
The lecturer could do with same improvements in his slides and presentation skills. In addition, information cannot be found in text book and supplementary notes should be given

22) Malaria, ascaris and hookworms

Very detailed and discussed a lot in short time
The lecturer could do with same improvements in his slides and presentation skills. In addition, information cannot be found in text book and supplementary notes should be given

23) Homeostasis and the internal environment

Complex
Tough to see connections between systems
Difficult topics and done quickly

24) The kidney: structure and function I & II

Complex structures to learn
Difficult topics and done quickly
The approach to the kidney overheads weren't good
Lots of names, the topic itself is easy but when combined with other topics become more difficult
Confusing
Difficult to understand

25) Control of water balance by the kidney

Complex
Difficult topics and done quickly

26) Chemical signalling

Lots to learn
Difficult topics and done quickly

27) Actions of hormones

Lots to learn
Bad notes were given
Difficult topic

28) Why sex? human reproduction in the male

Lots to learn
Bad notes were given
Thought notes and had too much to learn
Lectured quickly with lots of information
Really enjoyable
Would have been difficult if not for web notes

29) Human reproduction in the female

Lots to learn
Bad notes were given

30) Infertility, natural and induced

31) Sex, drugs and alcohol

Complete wasn't at time
Irrelevant
Funny but didn't see the point

32) Patterns of reproduction

Not properly explained
Was not interested in subject

33) Courtship and mating- evolutionary context

34) Niches, guilds and keystone predators

35) The trophic structure of ecosystems

36) Biotic interactions in ecosystems

Didn't keep the slides up long enough
Notes were hard to understand

37) The ecology of populations I & II

Lots of new technology and not well explained
Notes were hard to understand

38) Conservation biology

Good
Boring
Lots of new technology and not well explained

Students comments on lab work

Malaria lab

- Hard to see things on specimens and demonstrators didn't seem to know either
- Too long, too many questions with too little information
- I didn't think there should be dissections where the animals are specifically killed for dissection
- Too much to cover in one lab with no previous knowledge
- The information needed to answer the questions was not given and demonstrators where not always available to ask

Heart and lungs lab

- Confusing diagrams
- Dissection of hearts and lungs
- Unfamiliar terminology used
- Not enough assistance

Mammalian structure and function

- Unfamiliar terminology used

Genetic crosses in flies

- Difficult

Gene modification

- The discussion weren't enjoyable and there are better ways of converging the knowledge gained.

General comments:

- Most of them were tedious
- Not really difficult and some were little tedious and boring
- All of them were difficult and it was hard to find the information needed to answer the questions and the information wasn't always available in the labs

Positive comments:

Easy
Were great

APPENDIX C

The Units and their Answers

I. Unit 1: A Model Organism

II. Unit 2A : The Chicken Run

III. Unit 2B : MMR Vaccine

IV. Unit 3 : The Forests that Need Fires

Unit 1

Please do not mark these sheets

A Model Organism

Introduction

Biological scientists often choose a particular species of plant or animal on which to conduct their research not because they have a particular interest in the species itself but because they think it will be a suitable one for investigating fundamental principles that can then be generalised to other species.

Such a species is referred to as a 'model system' or 'model organism'. This discussion unit is concerned with identifying a suitable model organism for the study of plant genetics.

You will be working in a small group.
Discuss the possible answers to the questions below.
One member of the group can write in your agreed answers on the 'Answer Sheet'.

This discussion exercise has four parts.

(1) Before you start, work as a group and look at the list of terms and definitions in the table below. Mark on the 'Answer Sheet' the letter to show which definition belongs to each term.

Term		Definition
Gene	A	The genetic makeup of an organism.
Genome	B	Deoxyribonucleic acid (DNA), A double stranded, helical nucleic acid molecule capable of replicating and determining the inherited structure of a cell's proteins.
DNA	C	A single pair of complementary nucleotides from opposite strands of the DNA double helix.
Chromosome	D	The complete complement of an organism's genes; an organism's genetic material.
Eukaryotic cell	E	The physical and physiological traits of an organism.
Genotype	F	A discrete unit of hereditary information consisting of a specific nucleotide sequence in DNA (or RNA, in some viruses).
Phenotype	G	The number of chromosomes in a somatic cell.
Mutation	H	A type of cell with a membrane-enclosed nucleus and membrane-enclosed organelles, present in protists, plants, fungi, and animals; also called eukaryote.
Base pairs	I	A threadlike, gene-carrying structure found in the nucleus. Each one consists of one very long DNA molecule and associated proteins.
	J	A rare change in the DNA of genes that ultimately creates genetic diversity.
	K	An alternative form of a gene.

Discuss the following and write your agreed answers on your group 'Answer Sheet'.

(2) What is the Human Genome Project (HGP)?

(3) What is the HGP for?

Please turn over

Part One

Identifying a suitable model plant species (first attempt)

(1) Suppose you wanted to sequence the genome of a plant and could choose any species to be a representative plant – suggest a plant which you would choose and explain why?

(2) Suppose you wanted to choose a species other than a plant as a research tool for molecular genetic studies essentially because it was a convenient research tool, what sort of species would you choose and why?

Part Two

Looking at some model organisms

A model organism is chosen because it is easy to study a particular biological phenomenon using it, rather than because it has economic or other importance. Different species will be suitable models for different biological problems. To study a physiological problem, for example, a relatively large animal might be desirable to make handling easier. For a molecular genetics, study of a micro-organism might be suitable.

Using model organisms works because fundamental biological principles are conserved across metabolic and developmental pathways. For example, many key biological principles identified in bacteria are also applicable to more complex organisms. The cell cycle in a simple yeast is very similar to the cell cycle in humans, and regulated by homologous proteins.

The bacterium *Escherichia coli*, which is common in the human digestive system and has served for decading basic studies of biochemistry, physiology, genetics and biotechnology. In eukaryotes, several yeasts, particularly *Saccharomyces cerevisiae* ("baker's" or "budding" yeast), have been widely studied, largely because they are quick and easy to grow. The fruit fly *Drosophila melanogaster* has been studied, again in part because it was relatively easy to grow for a multicellular organism. The roundworm *Caenorhabditis elegans* has been studied studied because it has very sterotyped development patterns and can be rapidly screened for abnormalities.

There are a lot more features to these organisms that make them suitable models for genetic and molecular research. You must now look in more detail at the fruit fly *Drosophila*.

(1) Give reasons why the fruit fly has been such a popular model species for genetic studies in terms of its:

1. Phenotypic variation
2. Genome size
3. Body size
4. Generation time

Please turn over

Part Three

Identifying a suitable model plant species (second attempt)

(Genome size is measured by the number of 'base pairs' in the nuclear genome.)

Organism (Scientific Name)	Organism (Common Name)	Genome size (Mb)
Fritillaria assyrica	Fritillary plant	120000
Zea mayis	Maize	5000
Locusta migratoria	Locust	5000
Homo sapiens	Human	3000
Oryzae sativa	Rice	565
Drosophila melanogaster	Fruit fly	140
Arabidopsis thalania	Small weed-like plant	100
Sacchromyces cerevisiae	Yeast	12

1Mb = one thousand million base pairs

(1) Having seen what the genome sizes are of the organisms, which three would you choose as model species for molecular genetic studies?

(Take a look at the specimens of *Arabidopsis* provided in the laboratory class.)

Please turn over

Part Four

Arabidopsis – data and interpretation

looking at the indication of gene expression in *Arabidopsis*.

Molecular biological techniques can be used to manipulate DNA sequences. We can take the control (promoter) sequence from one gene, and fuse it to the coding sequence of another gene. In the example given here, the promoter of the Chalcone Synthase (*CHS*) gene from *Arabidopsis thaliana* has been fused to the coding sequence of the luciferase (*Luc*) gene of the firefly (the gene that makes its abdomen glow!). This GENE FUSION can be introduced to plants, and allows researchers to investigate the expression of the *CHS* gene. The gene fusion should be expressed in exactly the same pattern as the native CHS gene. This allows us to observe when the *CHS* gene is being expressed from the light being produced by the plant from the simultaneous expression of the luciferase (*Luc*) gene. Chalcone synthase (*CHS*) is a gene in *Arabidopsis thaliana* produces chemical sunscreens, which help protect the plant from harmful radiation from the sun (light energy, such as UV-B).

The table shows the light being generated by *Arabidopsis* containing the inserted luciferase (*Luc*) gene (i.e. transgenic) before and after being expressed to ultra violet (UV-B) radiation.

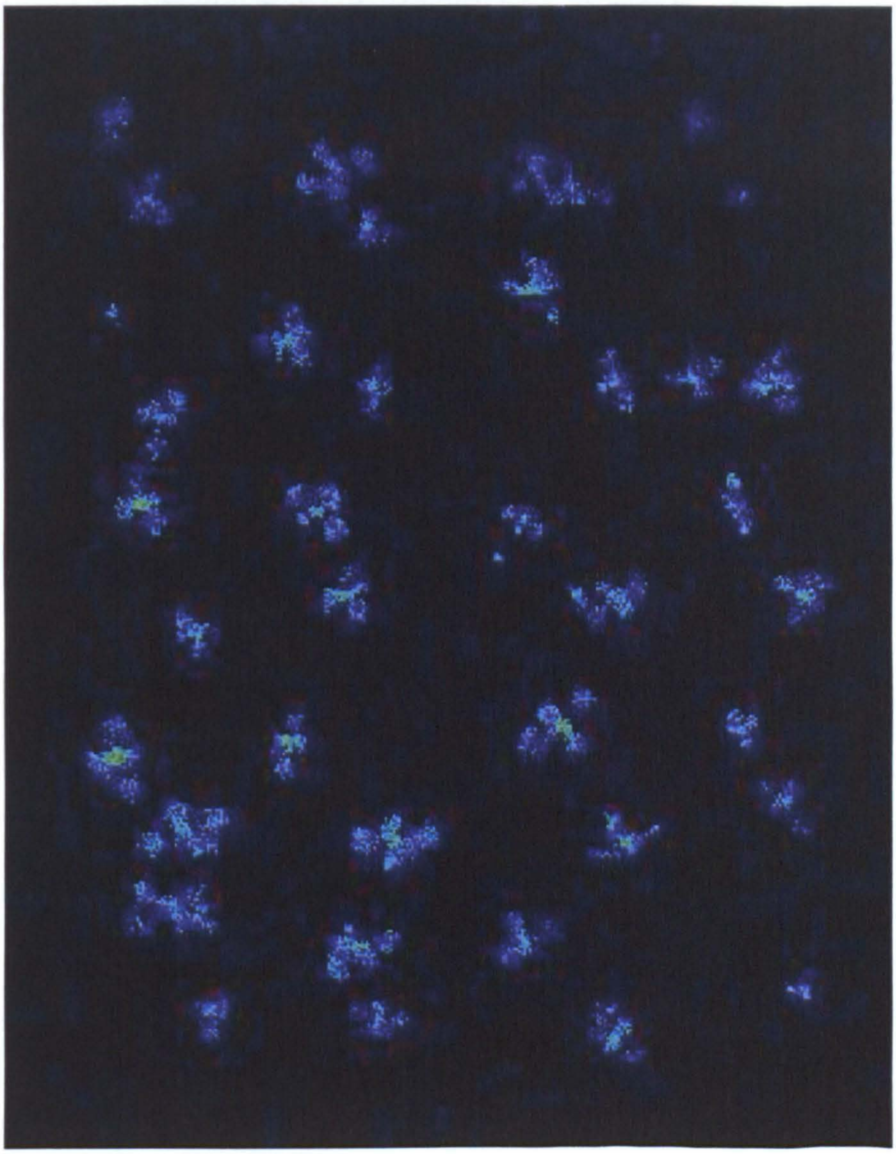
(1) What does it shows?

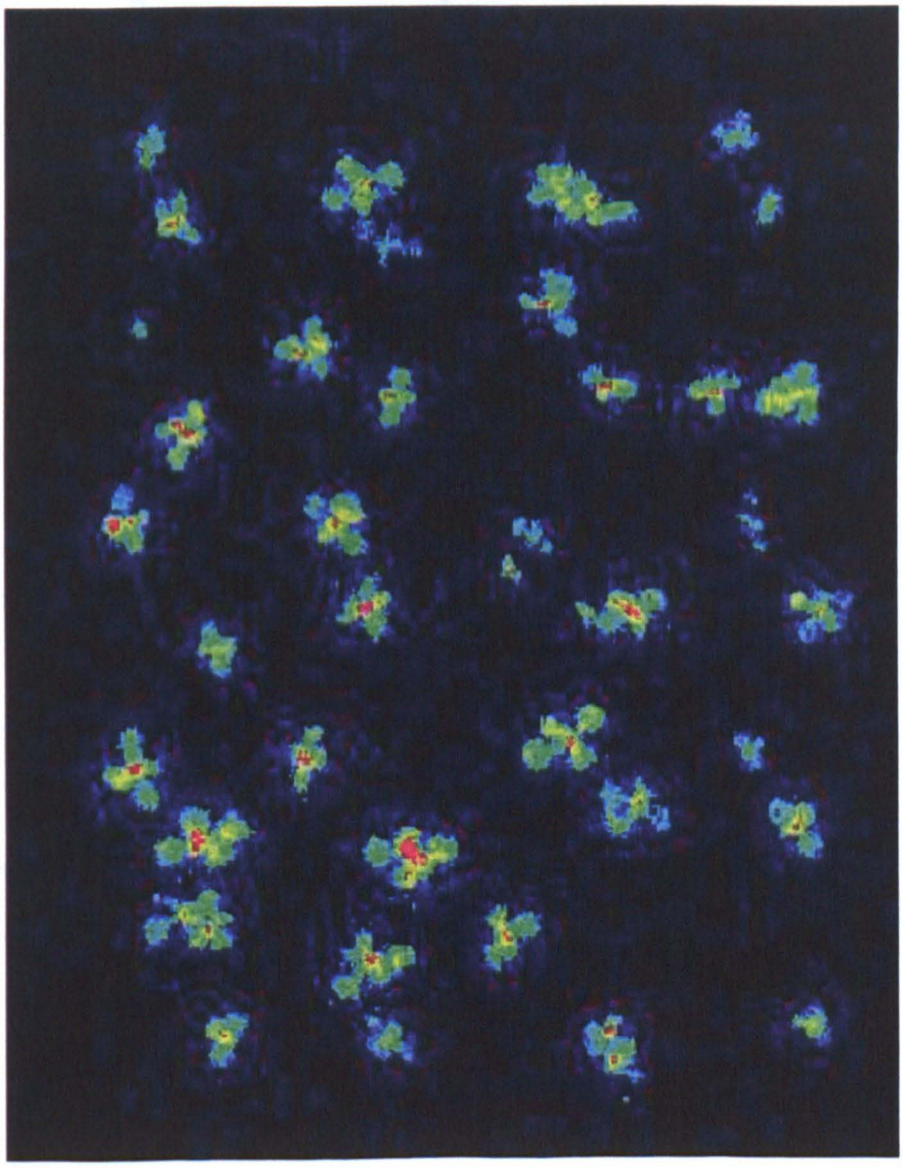
(2) How could this response protect the plant?

CHS gene expression visualised using the luciferase reporter gene

I. Transgenic Arabidopsis before UV-B treatment

II. Transgenic Arabidopsis after UV-B treatment





Unit 1

Answer Sheet

Write in your group's agreed answers

(1)

Term	Write correct letter in this column		Definition
Gene		A	The genetic makeup of an organism.
Genome		B	Deoxyribonucleic acid (DNA), A double stranded, helical nucleic acid molecule capable of replicating and determining the inherited structure of a cell's proteins.
DNA		C	A single pair of complementary nucleotides from opposite strands of the DNA double helix.
Chromosome		D	The complete complement of an organism's genes; an organism's genetic material.
Eukaryotic cell		E	The physical and physiological traits of an organism.
Genotype		F	A discrete unit of hereditary information consisting of a specific nucleotide sequence in DNA (or RNA, in some viruses).
Phenotype		G	The number of chromosomes in a somatic cell.
Mutation		H	A type of cell with a membrane-enclosed nucleus and membrane-enclosed organelles, present in protists, plants, fungi, and animals; also called eukaryote.
Base pairs		I	A threadlike, gene-carrying structure found in the nucleus. Each one consists of one very long DNA molecule and associated proteins.
		J	A rare change in the DNA of genes that ultimately creates genetic diversity.
		K	An alternative form of a gene.

(2) What is the Human Genome Project (HGP)?

....

....

....

(3) What is the HGP for?

....

....

....

Part One

(1) Suppose you wanted to sequence the genome of a plant and could choose any species to be a representative plant – suggest a plant which you would choose and explain why?

....

....

(2) Suppose you wanted to choose a species other than a plant as a research tool for molecular genetic studies essentially because it was a convenient research tool, what sort of species would you choose and why?

....

....

....

Part Two

(1) Give reasons why the fruit fly has been such a popular model species for genetic studies in terms of its:

1. Phenotypic variation ....
2. Genome size ....
3. Body size ....
4. Generation time ....

Part Three

(1) Having seen what the genome sizes are of the organisms, which three would you choose as model species for molecular genetic studies?

....

Part Four

(1) What does it shows?

....

....

(2) How could this response protect the plant?

....

....

Unit 1

A Model Organism

Introduction (14 Marks)

(1) Before you start, work as a group and look at the list of terms and definitions in the table below. (9 Marks)

Mark on the 'Answer Sheet' the letter to show which definition belongs to each term.

No.	Term	Letter	Definition
1	Gene	F	A discrete unit of hereditary information consisting of a specific nucleotide sequence of DNA (or RNA in some viruses).
2	Genome	D	The complete complement of an organism's genes; an organism's genetic material.
3	DNA	B	Deoxyribonucleic acid (DNA). A double stranded, helical nucleic acid molecule capable of replicating and determining the inherited structure of a cell's proteins.
4	Chromosome	I	A threadlike, gene-carrying structure found in the nucleus. Each one consists of one very long DNA molecule and associated proteins.
5	Eukaryotic cell	H	A type of cell with a membrane-enclosed nucleus and membrane-enclosed organelles present in protists, plants, fungi and animals; also called eukaryote.
6	Genotype	A	The genetic make-up of an organism.
7	Phenotype	E	The physical and physiological traits of an organism.
8	Mutation	J	A rare change in the DNA of genes that ultimately creates genetic diversity.
9	Base pairs	C	A single pair of complementary nucleotides from opposite strands of the DNA double helix.

(2) What is the Human Genome Project (HGP)? (3 Marks)

The Human Genome Project (HGP) is an international research programme to map the whole of the human genome. It officially began in 1990.

(3) What is the HGP for? (2 Marks)

The managing of the human genome opens up the possiblity of diagnosis and treatment of congenital human diseases.

Part One (6 Marks)

Identifying a suitable model plant species (first attempt)

(1) Suppose you wanted to sequence the genome of a plant and could choose any species to be a representative plant – suggest a plant which you would choose and explain why? (3 Marks)

The idea in this first attempt is to get an idea of what a model species is for and therefore what sort of plant would be suitable. It is possible that an economically important species might be suggested (e.g. rice or potato).

At the end of this stage you should at least have got to the stage of thinking about a small plant, with a small genome.

(2) Suppose you wanted to choose a species other than a plant as a research tool for molecular genetic studies essentially because it was a convenient research tool, what sort of species would you choose and why? (3 Marks)

Most students chose **Drosophila** ***as it was familiar to them as a model organism. Other choices included bacteria,*** **E. coli** ***in particular.***

Part Two (8 Marks)

Looking at some model organisms

(1) Give reasons why the fruit fly has been such a popular model species for genetic studies in terms of its:

1. Phenotypic variation (3 Marks)
2. Genome size (1 Mark)
3. Body size (2 Marks)
4. Generation time (2 Marks)

Drosophila has been convenient for genetic research, because:

(1) It has been easy to create a wide range of single gene mutants with easily recognisable phenotypes. Some of these are morphological (wingless, stumpy winged) and some of them behavioural (alterations of diurnal activity rhythms).

(2) The genome of Drosophila species is about 140 Mb.

(3) Drosophila species are mostly small, with a body length of 2-3mm. This means that thousands of them can be housed in a controlled environment no larger than a domestic refrigerator.

(4) From egg to egg the generation time of Drosophila can be as little as two weeks, at a suitable temperature.

Part Three (3 Marks)

Identifying a suitable model plant species (second attempt)

(Genome size is measured by the number of 'base pairs' in the nuclear genome.)

Organism (Scientific name)	Organism (Common name)	Genome size (Mb)
Fritillaria assyrica	Fritillary plant	120000
Zea mays	Maize	5000
Locusta migratoria	Locust	5000
Homo sapiens	Human	3000
Oryzae sativa	Rice	565
Drosophila melanogaster	Fruit fly	140
Arabidopsis thaliana	Small weed-like plant	100
Saccharomyces cerevisiae	Yeast	12

1Mb = one million base pairs

(1) Having seen what the genome sizes are of the organisms, which three would you choose as model species for molecular genetic studies? (3 Marks)

Yeast, Drosophila and Arabidopsis have the three smallest genome sizes and are small and rapidly reproducing species.

Part four (5 Marks)

Arabidopsis – data and interpretation

(1) What does it show? (3 Marks)

The experiment shows that luminescence is induced by the UV-B light, therefore UV-B light causes the expression of the fused CHS and luciferase genes.

(2) How could this response protect the plant? (2 Marks)

This indicates that when exposed to UV-B light, the plant protects itself with the production of chemical sunscreen, the product of the CHS gene.

The Chicken Run

Introduction

The frozen chicken industry in Holland, which ships over a thousand tonnes of chicken into UK each week routinely, adds water to it to make it weigh more. But to keep the water in, there is an additional ingredient - protein additives. The practice of injecting chicken with water and proteins together, allows the meat to retain more water.

The chicken you are eating could have been injected with beef or pork protein. Tests carried out for a TV programme reveal that beef or pork **DNA** has been found in chicken indicating the addition of beef and pork protein to the chicken samples.

There are actually two methods that some chicken processors in Holland use to bulk up their products. Both of the methods involve adding water and additives to the product. The first process is called *tumbling*; in this process the chicken fillets are spun in washing machine-like drums for between an hour and an hour and a half, together with the water and additives. The other method simply involves *injecting* water and additives into the chicken.

Results of tests on chicken samples

Identigen

Identigen is a company specialising in **DNA** testing. It is a leading provider of DNA-based testing to the food industry. It is one of the companies which *BBC Panorama* used to test the samples of chicken for one of their programmes. Based in Dublin, the company's area of expertise is in genetic identification, giving retailers, meat processors, producers and local governments the ability to trace meat back to source. Its core business is in helping food firms to ensure that foods are either GM free or comply with food labelling legislation.

The company was founded in 1996 in the wake of BSE crisis by a team of specialist scientists. Since then Identigen has worked together on a wide range of projects in animal genetics, food science and agriculture. It is responsible for developing the *TraceBack* system, the worlds first DNA based traceability system. This system is now operating in a number of countries across Europe. Their service is one of the few which has been formally recognised by the European Union.

The samples tested in this study included 17 samples of chicken meat and 15 of processed chicken products, such as chicken nuggets. These include some of the best known brands on sale in fast food restaurants and supermarkets across the United Kingdom. Tables 1&2 show the results.

Please turn over

Table 1 Test results for chickens (Example of chicken : legs, breast, ... Etc)

	Manufacturer / brand	Meat content (declared)	Meat content (actual)	Cow protein?	Pig protein?
1	T Lelie	70% min	73.0%	Yes	No
2	T lelie	N/A	N/A	Yes	No
3	Den Hertog	80%	76.6%	N/A	N/A
4	De kippenhof (brand 1)	70% min	62.7%	N/A	N/A
5	De kippenhof (brand 2)	65%	60.1%	No	No
6	Capri chicken	80%	76.6%	N/A	N/A
7	Slegtenhorst (MR brand 1)	70%	64.7%	No	No
8	Slegtenhorst (MR brand 2)	80%	71.0%	No	No
9	Lamex Sun Brand 1 *	68%	72.5%	Yes	No
10	Lamex Sun Brand 2 *	68%	66.7%	Yes	No
11	Jozef Hassan	N/A	53.5%	Trace	Trace
12	Seamark "Nice" (brand 1)	70%	66.2%	No	No
13	Seamark "Nice" (brand 2)	70%	68.5%	No	No
14	Vriesekoop "Duke" (brand 1)	80%	80.6%	Yes	No
15	Vriesekoop "Duke" (brand 2)	80%	60.4%	No	No
16	Vriesekoop "Theco"	N/A	N/A	No	No
17	Slegtenhorst	70%	51.0%	Yes	No

* Product contains casein, a milk protein

N/A : No available information

Table 2 Test results for chicken products: e.g. chicken nuggets

	Brand	Cow protein	Pork protein
1	Sainsbury's Blue Parrot Café Chicken Nuggets (brand 1)	Yes	Yes
2	Sainsbury's Blue Parrot Café Chicken Nuggets (brand 2)	No	No
3	Sainsbury's Blue Parrot Café Chicken Nuggets (brand 3)	Trace	No
4	Sainsbury's Blue Parrot Café Chicken Nuggets (brand 4)	Yes	No
5	McDonald's chicken nuggets	No	No
6	KFC Popcorn chicken	No	No
7	Asda chicken nuggets	No	No
8	Tesco breaded chicken nuggets	Yes	No
9	Somerfield breaded chicken nuggets	No	No
10	Safeway breaded chicken nuggets	No	No
11	Iceland breaded chicken fingers	No	No
12	M&S chicken nuggets	No	No
13	Dairylea Lunchables tasty chicken (brand 1)	Yes	Yes
14	Dairylea Lunchables tasty chicken (brand 2)	Yes	Yes
15	Bernard Mattew's coronation sauce chicken escalope	Yes	No

Please turn over

You will be working in a small group.
Discuss the possible answers to the questions below.
One member of the group can write in your agreed answers on the 'Answer Sheet'.

Part One

Biological Component

What do you know about the biology of the test material

(1) Where does the DNA come from?
(2) How can it be recognised as from cow, pig or chicken?
(3) Why use a DNA test?
(4) How might the food companies try to defeat this analytical technology?

Part Two

Numerical Component

Examine the data in the tables and calculate some relationships

(1) What percentage of tested samples of chicken meat use pig protein (As identified by the DNA content)? (Table 1)
(2) What percentage of tested samples of chicken meat use cow proteins? (Table 1)
(3) What percentage of chicken products use pig protein? (Table 2)
(4) What percentage of chicken products use cow protein? (Table 2)
(5) What percentage of the chicken meat samples do you think show that the meat processors ot behaving in an immoral and unethical way? And why? (What boundries did you set to acceptable practice)? (Table 1)

Part Three

Ethical Component

Discuss the ethics of the food industry based on the evidence presented here

(1) What reasons, if any, does your group give in support of the activities of these meat processing companies?
(2) What reasons, if any, does your group give in support of the view that these meat processing companies are behaving wrongly?

Unit 2A

The Chicken Run

Part One (10 Marks)

Biological Component

What do you know about the biology of the test material?

(1) Where does the DNA come from? (2 Marks)

The DNA is from the nuclei of the animal cells. DNA will be present in chicken meat as well as the cow and pig meat.

(2) How can it be recognised as coming from cow, pig or chicken? (2 Marks)

Parts of the DNA will have sequences that are unique to particular species.

(3) Why use a DNA test? (3 Marks)

The DNA contained in a single somatic cell carries a complete genome for that species. The base pair sequences on the chromosomes therefore provide a fingerprint for the identification of the species from which that cell originated.

(4) How might the food companies try to defeat this analytical technology? (3 Marks)

The shorter the sequence of base pairs in a fragment of DNA the less easy it is to be certain of the species from which it originated. In practice sequences of less than 7-10 base pairs cannot reliably be assigned to a species. However, to break down the DNA further would probably cost the food companies more and possibly damage the quality of the cow and pig protein in the process.

Part Two (6 Marks)

Numerical Component

Examine the data in the tables and calculate some relationships

(1) What percentage of tested samples of chicken meat contain pig protein (As identified by the DNA content)? (Table 1) (1 Mark)

Chicken meat with pig protein ***1/14 = 7.1%***

(2) What percentage of tested samples of chicken meat contain cow proteins? (Table 1) (1 Mark)

Chicken meat with cow protein ***7/14 = 50%***

Note: Although there were seventeen samples of chicken meat, the information for three of them was unavailable. Therefore we cannot say for certain that they contained protein from another species and so have left them out of the calculation.

(3) What percentage of chicken products contain pig protein? (Table 2) (1 Mark)

Chicken products with pig protein ***3/15 = 20%***

(4) What percentage of chicken products contain cow protein? (Table 2) (1 Mark)

Chicken products with cow protein ***7/15 = 46.7%***

(5) What percentage of the chicken meat samples do you think show that the meat processors are behaving in an immoral and unethical way? And why? (What limits did you set for acceptable practice)? (Table 1) (2 Marks)

Using a 'morality' rule of no pig or cow protein and of not more than 5% exaggeration in meat content gives an immoral account of 11/17 = 64.7%.

Part Three (4 Marks)

Ethical Component

(1) What reasons, if any, does your group give in support of the activities of these meat processing companies? (1 Mark)

There is a possible argument that they are ensuring that all animal protein that can be used in feeding us is used in meat products and not wasted.

(2) What reasons, if any, does your group give in support of the view that these meat processing companies are behaving wrongly? (3 Marks)

Increasing the natural weight of meat by adding water clearly occurs. Adding alien protein is misleading the public that believes it is buying chicken protein alone. This may not seem so serious for 'chicken products', where the public may expect that ingredients other than chicken may have been used. But the public will expect 'chicken meat' to be just that. They may even have strongly felt religious objections to eating cow or pig protein.

Unit 2A

Answer Sheet

Write in your group's agreed answers

Part One

(1) Where does the DNA come from?

....

(2) How can it be recognised as from cow, pig or chicken?

....

(3) Why use a DNA test?

....

(4) How might the food companies try to defeat this analytical technology?

....

Part Two

(1) What percentage of tested samples of chicken meat use pig protein (As identified by the DNA content)? (Table 1) ....

(2) What percentage of tested samples of chicken meat use cow proteins?(Table 1) ....

(3) What percentage of chicken products use pig protein? (Table 2) ....

(4) What percentage of chicken products use cow protein? (Table 2) ....

(5) What percentage of the chicken meat samples do you think show that the meat processors are behaving in an immoral or unethical way? And why? (What boundries did you set to acceptable practice)? (Table 1)

....

....

Part Three

(1) What reasons, if any, does your group give in support of the activities of these meat processing companies?

....

(2) What reasons, if any, does your group give in support of the view that these meat processing companies are behaving wrongly?

....

The Measles, Mumps and Rubella vaccine: MMR

Background

Combined measles, mumps and rubella (MMR) vaccines were introduced into the UK routine childhood immunisation programme in 1988. Only one MMR dose was given, but a two-dose immunisation schedule with measles, mumps and rubella vaccine has existed in the UK since October 1996 (the first dose is given at 12-15 months and the second dose at 3-5 years). Since 1998, however, there have been speculation and controversy surrounding the MMR vaccination focusing on a possible connection to inflammatory bowel disease and autism.

If public concern causes a decline in MMR vaccination uptake, this could be detrimental to public health because high uptake levels must be maintained to prevent disease transmission.

The MMR Expert Group says that in spite of the recent speculation on the safety of MMR, the overall body of scientific evidence to date is that this vaccine has an excellent safety record. No credible evidence has been produced to support the hypothesis that there is a link between MMR and autism or inflammatory bowel disease. They claim that the data show that the high uptake of this vaccine, first introduced in 1988, has resulted in a substantial decrease in these three serious infections.

Autism and Autistic Spectrum Disorders (ASD)

Autism is one of a set of neurodevelopmental disorders which impair a person's capacity to communicate and interact with others. It is a term which has been in use for over 60 years, but is now, increasingly, being replaced by the concept of an autistic spectrum, covering a range of ability levels and manifestations of a set of common criteria: qualitative impairments in social, communicative and imaginative development. Autistic spectrum disorder (ASD) is a complex, debilitating and lifelong set of conditions which manifests itself in many different ways.

Risks Associated with contracting the diseases; Measles, Mumps and Rubella

The Expert Group claim that the success of immunisation against measles, mumps and rubella has led to a decline in the incidence of these diseases. As a result, the serious risks associated with measles, mumps and rubella infection may not be fully appreciated. These are presented in their information document as shown in Table 1:

Table 1

Complications of measles	Complications of mumps	Complications of rubella
▫ ear infection (1 in 20) ▫ pneumonia / bronchitis (1 in 25) ▫ convulsions (1 in 200) ▫ diarrhoea (1 in 6) ▫ meningitis / encephalitis (1 in 1000) ▫ conditions affecting blood clotting (1 in 6000) ▫ late onset subacute sclerosing panencephalitis (SSPE) (1 in 8000 children under 2 years) ▫ deaths (1-2 deaths in 1000 reported cases in recent years)	▫ viral meningitis (1 in 20) ▫ encephalitis (1 in 1000) ▫ permenant hearing loss (1 in 20,000) ▫ inflammation of testicles (4 in 10 adult males) ▫ inflammation of ovaries	▫ encephalitis (1 in 6000) ▫ birth defects (90% chance baby will have birth defects if mother catches rubella early in pregnancy). Birth defects include blindness, deafness, learning difficulties and heart disease ▫ conditions affecting blood clotting (1 in 3000)

Please turn over

You will be working in a small group.
Discuss the possible answers to the questions below.
One member of the group can write in your agreed answers on the 'Answer Sheet'.

Part One

Establishing a background knowledge of basic immunological terminology

(1) Match the following terms to the definitions provided on the answer sheet.

	Term		Definition
1	Immune response	A	A harmless variant or derivative of a pathogen that stimulates a host's immune system to amount defenses against the pathogen.
2	Immunity	B	A white blood cell. The lymphocytes that complete their development in the bone marrow are called B cells, and those that mature in the thymus are called T cells.
3	Primary immune response	C	One of the class of proteins comprising the antibodies.
4	Secondary immune response	D	The immune response elicited when an animal encounters the same antigen at some later time. This response is more rapid, of greater magnitude, and longer duration than the primary immune response.
5	Vaccine	E	The type of immunity that functions in defense against fungi, protests, bacteria, and viruses inside host cells and against tissue transplants, with highly specialized cells that circulate in the blood and lymphoid tissue.
6	Antibody	F	An antigen-binding immunoglobulin, produced by B cells, that functions as the effector in an immune response.
7	Antigen	G	A system of vessels and lymph nodes, separate from the circulatory system, that returns fluid and protein to the blood
8	Immunoglobulin	H	Resistance to the onset of disease after infection by harmful microorganisms or internal parasites.
9	Macrophage	I	An amoeboid cell that moves through tissue fibres, engulfing bacteria and dead cells by phagocytosis.
10	Cell mediated immunity	J	The initial immune response to an antigen, which appears after a lag of several days.
		K	A type of lymphocyte responsible for cell mediated immunity that differentiates under the influence of the thymus.
		L	A foreign macromolecule that does not belong to the host organism and that elicits an immune response.
		M	A selective response mounted by the immune system of vertebrates in which specific antibodies and/or cytotoxic cells are produced against invading foreign substances which are recognised by the body.

(2) As a scientist, what evidence would you require to demonstrate a link between MMR and ASD?

(3) How do you think a vaccine like MMR should be tested in order to demonstrate that it is safe?

(4) Do you think that MMR has been properly tested? If not, why?

More Information

The relationship between immunisation rates and the number of notified cases of measles, mumps and rubella given in this document are shown in Figures 1-3 below. The scales on the left in each graph refer to the number of notified cases of the disease, and those on the right to the percentage uptake of the vaccination.

Please turn over

Figure 1 **Measles notifications and measles vaccine and MMR vaccine uptake, Scotland, 1968-2000**

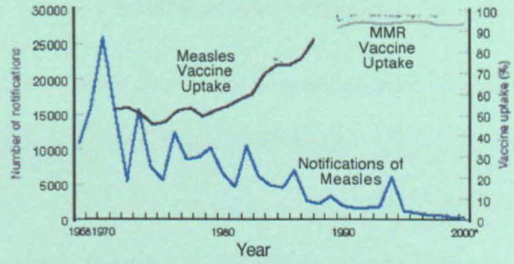


Figure 2 **Mumps notifications and MMR vaccine uptake, Scotland, 1989-2000**

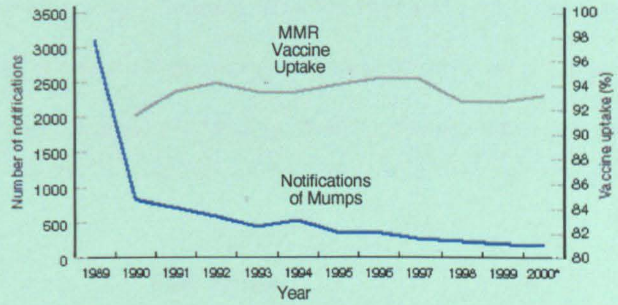
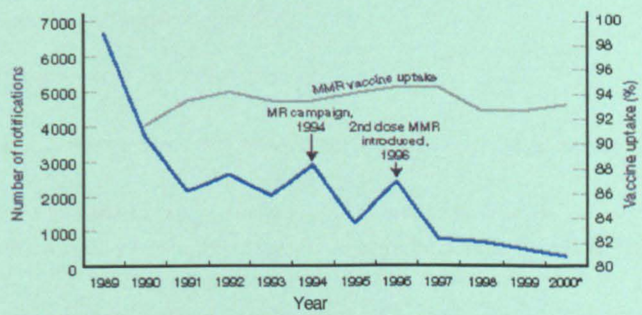


Figure 3 **Rubella notifications and MMR vaccine uptake, Scotland 1989-2000**



Please turn over

Part Two

Examination of the Data

In this part you are required to give quite scientific and factual answers based on the evidence provided in Figures 1- 3.

(1) In what year was vaccination for measles introduced in Scotland?

(2) What evidence is there that measles epidemics can occur in spite of high levels of vaccination?

(3) In 1989, which was the more common disease in Scotland, mumps or rubella and how many notified cases were there of each?

(4) How many notified cases of measles were there in Scotland in 1970?

(5) What trend did rubella notifications show between 1994 and 1997 and why do you think the trend took this form?

(6) What evidence, if any, is there that public concern over MMR since 1998 has led to a decline in vaccination rate?

(7) What evidence, if any, is there that decline in MMR vaccination rates has led to an increase in measles, mumps or rubella?

Part Three

Benefits and problems associated with public immunisation programmes such as MMR

(1) If you had a child that was due for MMR vaccination :

(a) What further information would you want to know?

(b) What argument would you use to persuade another parent to your point of view?

(2) Some parents may not, for whatever reason, wish their child to be vaccinated.
How much should individual freedom be constrained by a possible overall benefit to the community?

(3) What factors of your family medical history would you take into account before deciding whether to permit your child to receive the MMR vaccine, and why?

Please turn over

Unit 2B

Answer Sheet

Write in your group's agreed answers

Part One

(1)

Term	Write Correct Letter in this Column		Definition
Immune response		A	A harmless variant or derivative of a pathogen that stimulates a host's immune system to amount defenses against the pathogen.
Immunity		B	A white blood cell. The lymphocytes that complete their development in the bone marrow are called B cells, and those that mature in the thymus are called T cells.
Primary immune response		C	One of the class of proteins comprising the antibodies.
Secondary immune response		D	The immune response elicited when an animal encounters the same antigen at some later time. This response is more rapid, of greater magnitude, and longer duration than the primary immune response.
Vaccine		E	The type of immunity that functions in defense against fungi, protests, bacteria, and viruses inside host cells and against tissue transplants, with highly specialized cells that circulate in the blood and lymphoid tissue.
Antibody		F	An antigen-binding immunoglobulin, produced by B cells, that functions as the effector in an immune response.
Antigen		G	A system of vessels and lymph nodes, separate from the circulatory system, that returns fluid and protein to the blood
Immunoglobulin		H	Resistance to the onset of disease after infection by harmful microorganisms or internal parasites.
Macrophage		I	An amoeboid cell that moves through tissue fibres, engulfing bacteria and dead cells by phagocytosis.
Cell mediated immunity		J	The initial immune response to an antigen, which appears after a lag of several days.
		K	A type of lymphocyte responsible for cell mediated immunity that differentiates under the influence of the thymus.
		L	A foreign macromolecule that does not belong to the host organism and that elicits an immune response.
		M	A selective response mounted by the immune system of vertebrates in which specific antibodies and/or cytotoxic cells are produced against invading foreign substances which are recognised by the body.

(1) As a scientist, what evidence would you require to demonstrate a link between MMR and ASD?

....

....

....

(2) How do you think a vaccine like MMR should be tested in order to demonstrate that it is safe?

....

....

....

(3) Do you think that MMR has been properly tested? If not, why?

....

....

....

Part Two

(1) In what year was vaccination for measles introduced in Scotland? ....

(2) What evidence is there that measles epidemics can occur in spite of high levels of vaccination?

....

....

....

(3) In 1989, which was the more common disease in Scotland, mumps or rubella and how many notified cases were there of each? ....

(4) How many notified cases of measles were there in Scotland in 1970? ....

(5) What trend did rubella notifications show between 1994 and 1997 and why do you think the trend took this form?

....

....

(6) What evidence, if any, is there that public concern over MMR since 1998 has led to a decline in vaccination rate?

....

....

....

(7) What evidence, if any, is there that decline in MMR vaccination rates has led to an increase in measles, mumps or rubella?

....

....

....

Part Three

(1) If you had a child that was due for MMR vaccination,

(a) What further information would you want to know?

....

....

....

(b) What argument would you use to persuade another parent to your point of view?

....

....

....

(2) Some parents may not, for whatever reason, wish their child to be vaccinated.
How much should individual freedom be constrained by a possible overall benefit to the community?

....

....

(3) What factors of your family medical history would you take into account before deciding whether to permit your child to receive the MMR vaccine, and why?

....

....

Unit 2B

The Measles, Mumps and Rubella vaccine: MMR

Part One (10 Marks)

Establishing a background knowledge of basic immunological terminology

(1) Match the following terms to the definitions provided on the answer sheet. (10 Marks)

No.	Term	Letter	Definition
1	Immune response	M	A selective response mounted by the immune system of vertebrates in which antibodies and/or cytotoxic cells are produced against invading foreign substances recognised by the body
2	Immunity	H	Resistance to the onset of disease after infection by harmful microorganisms or parasites
3	Primary immune response	J	The initial immune response to an antigen, which appears after a lag of several days.
4	Secondary immune response	D	The immune response elicited when an animal encounters the same antigen at some time. This response is more rapid, of greater magnitude and longer duration than the primary immune response
5	Vaccine	A	A harmless variant or derivative of a pathogen that stimulates a host's immune system to mount a defence against the pathogen
6	Antibody	F	An antigen-binding immunoglobulin, produced by B cells, that functions as the effector of the immune response
7	Antigen	L	A foreign macromolecule that does not belong to the host organism and that elicits an immune response
8	Immunoglobulin	C	One of the class of proteins comprising the antibodies.
9	Macrophage	I	An amoeboid cell that moves through tissue fibres, engulfing bacteria and dead phagocytes
10	Cell mediated	E	The type of immunity that functions in defence against fungi, protists, bacteria and inside host cells and against tissue transplants, with highly specialised cells that circulate in the blood and lymphoid tissue

(2) As a scientist, what evidence would you require to demonstrate a link between MMR and ASD? (2 Marks)

That the incidence of ASD was higher among children given MMR compound with those not given the MMR vaccine, and that the condition occurred soon after the administration of the vaccine.

Part Two (16 Marks)

Examination of the Data

In this part you are required to give quite scientific and factual answers based on the evidence provided in Figures 1- 3.

(1) In what year was vaccination for measles introduced in Scotland? (1 Mark)

Measles vaccination was introduced in Scotland in 1970.

(2) What evidence is there that measles epidemics can occur in spite of high levels of vaccination? (3 Marks)

Figure 1 shows periodic outbreaks of measles even beyond 1990, when over 90% of the population were vaccinated.

(3) In 1989, which was the more common disease in Scotland, mumps or rubella and how many notified cases were there of each?

Rubella was the more common disease in 1989.

In 1989 the numbers of notified cases were:
Measles = about 2,000
Mumps = about 3,000
Rubella = about 6,700

(4) How many notified cases of measles were there in Scotland in 1970? (1 Mark)

Measles cases in 1970 = over 25,000

(5) What trend did rubella notifications show between 1994 and 1997 and why do you think the trend took this form? (4 Marks)

1994 to 1995 cases go down, possibly due to campaign.
1995 to 1996 cases go back up for no clear reason because vaccination rate continues to climb.

1996 to 1997 cases go down again. This coincides with the introduction of the 'second dose' MMR.

(6) What evidence, if any, is there that public concern over MMR since 1998 has led to a decline in vaccination rate? (3 Marks)

There was a decline in vaccination uptake in 1998 from around 95% to around 93% but it slowly increased up to 2000.

(7) What evidence, if any, is there that decline in MMR vaccination rates has led to an increase in measles, mumps or rubella? (1 Mark)

There is no evidence on these three figures that the decline in uptake led to an outbreak of disease.

Part Three (8 Marks)

Benefits and problems associated with public immunisation programmes such as MMR

(1) If you had a child that was due for MMR vaccination :

(a) What further information would you want to know? (3 Marks)

There might be a lot of questions here related to single vaccines.
How effective are they?
Do other communities use single vaccines?
Are they less dangerous?

(b) What argument would you use to persuade another parent to your point of view? (2 Marks)

Obviously an open question but the graphs show that high uptake rates have been accompanied by considerable reduction of infection levels.

The other key point is that all three diseases can have unpleasant and even serious consequences.

(2) Some parents may not, for whatever reason, wish their child to be vaccinated.
How much should individual freedom be constrained by a possible overall benefit to the community? (1 Mark)

The balance of personal freedom against public responsibility is for individuals to judge.

(3) What factors of your family medical history would you take into account before deciding whether to permit your child to receive the MMR vaccine, and why? (2 Marks)

From the introduction it can be seen that MMR concerns particularly relate to autism and bowel disease. If a family had a history of these diseases or possibly a history of severe allergic reactions to any agent, then you might be concerned.

Unit 3

Forests that Need Fires

Your Matriculation Number: ....

Introduction

Forest fires are common especially in countries like Australia and USA where there are extended dry seasons. These fires, although they are now often caused by humans, have probably been a feature of such habitats for a sufficient time that plants and animals have evolved alongside fire and may show particular adaptations to it as an ecological factor.

You will be working individually.
Think about possible answers to the questions below.
Write your answers in the spaces on the sheets.

This exercise has four parts.

Part One

Temperature

(1) From the list of temperatures, choose the right one for each of the four situations:

1. Coal fire	......	(A) 10,000-15,000°C
2. Boiling water	......	(B) 5,500-6,000°C
3. Surface of the sun	......	(C) 900-11,000°C
4. A grassland fire	......	(D) 700-900°C
		(E) 100°C
		(F) 90°C

Write letters here

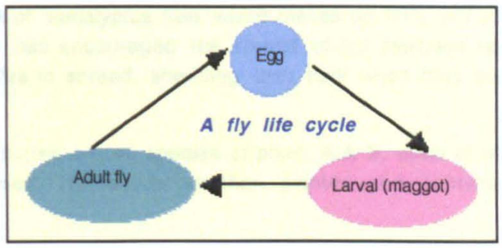
Please turn over

Part Two

Biology of the plant

Describe adaptations of a plant adapted to fire

If the life cycle of a fly is:



(1) Draw a diagram showing the life cycle of a plant, starting with the seed in the box below:

(2) Suggest how plants might protect themselves against fire.

....

....

....

(3) What stage of the plant life cycle might benefit from fire and why?

....

....

....

Please turn over

Part Three

Seed germination: Interpret data and design an experiment

Fires are a natural way of clearing old growth, causing organic matter to decompose rapidly into mineral components which fuel rapid plant growth, and recycling essential nutrients, especially nitrogen. Some species of trees also survive periodic blazes. The cones of Lodgepole and jack pines open and their seeds germinate only after they have been exposed to fire.

There are approximately 700 species of `eucalyptus tree, which makes up 90% of Australia's forests. At least 20,000 years of human grass burning in Australia has encouraged the spread of fire resistant species. Some eucalyptus species are largely fire-resistant but can help a fire to spread, shedding their bark when they burn and releasing flammable oils from their leaves.

The table shows an experiment conducted on two species of plant, A & B, each of which has seeds placed on a dish with some dry grass, which is then burned. The seeds are then planted and germination recorded, together with that of unburned controls.

		Plant Treatment	
		A	B
Treatment	Fire Treatment	Most germinate	Few germinate
	No Fire (control)	None germinate	Most germinate

(1) Describe the pattern shown by the data.

....

....

....

(2) Try to explain its biological significance.

....

....

....

(3) Design an experiment to determine how much heat the seeds of species A can survive.

....

....

....

Please turn over

Part Four

Management strategy : How will you manage a National Park?

You are charged with managing a National Park in a habitat that experiences periodic but unpredictable occurrence of fire?

(1) What would you do when fires broke out and why?

....

....

....

....

....

....

APPENDIX D

The First Stage - Tests Used

I. True-False Test 1

II. True-False Test 2

III. Structural Communication Grid

IV. Word Association Test

V. Perry Position Questionnaire

Your Matriculation Number

Tick to show whether you think each statement below is true or false

	Statement	TRUE	FALSE
1	Three main parts of a seed are: embryo, cotyledons and root.		
2	Germination is the development of a plant embryo into an independent plant with green leaves.		
3	All seeds need for germination is water, carbon dioxide and a suitable temperature.		
4	The seeds of some plants can survive exposure to fire.		
5	The germination of seeds may depend on a variety of environmental stimuli. These vary between species, but may include frost or fire.		
6	Stamens contain the flower's female sex cells (gametes).		
7	Pollen grains contain the plant's male sex cells (gametes).		
8	Cross-pollination is the transfer of pollen from an anther to a stigma in the same flower or in another flower on the same plant.		
9	Self-pollination is the transfer of pollen from an anther of one flower to a stigma in a flower on another plant of the same species.		
10	Fertilisation is the process by which the nucleus of a male sex cell (gamete) fuses with the nucleus of a female sex cell (gamete) to form a single cell called a zygote.		
11	Fertilisation in flowering plants takes place inside an ovule.		
12	If it were not for attack by wood boring insects, trees would not need thick bark.		

1.

Your Matriculation Number [ ]

Tick to show whether you think each statement below is true or false

	Statement	TRUE	FALSE
1	Anther is the structure containing embryo plant and food store formed from an ovule following fertilisation.		
2	fertilisation is a process by which a male gamete fuses with a female gamete.		
3	Fruit is the swollen region of flower's female sex organ containing ovules.		
4	Germination is the development of a plant embryo into an independent plant with green leaves.		
5	Ovary is the structure presents in a flower's anthers that contain male gamete.		
6	Ovule is the structure containing one or more seeds.		
7	Petal is the structure that protects unopened floral bud.		
8	Pollen grains are cells formed when a female gamete is fertilised by a male gamete.		
9	Pollination is a transfer of pollen grains from an anther to a stigma.		
10	Seed is the head of stamen containing pollen grains.		
11	Sepal is the brightly coloured scented structure which attracts insects to a flower.		
12	Zygote is the structure present in a flower's ovary that contains female gamete.		

Your Matriculation Number [ ]

The grid below contains parts of a flower. Look at the boxes below and answer the questions that follow by using the letters provided.

A Sepal	**B** Pollen	**C** Ovary
D Stigma	**E** Petal	**F** Anther
G Stamen	**H** Ovule	**I** Nectar

Select all the boxes which contain:

Q1 Male parts of a flower: ....

Q2 Female parts of a flower: ....

Q3 A part which protects an unopened flower: ....

Q4 A region to which pollen grains become attached: ....

Q5 Parts of a flower which attract insects: ....

Q6 Those parts of a flower which, together, will form seeds: ....

THINK OF A WORD

When you hear or see a word, it often makes you think of other words. In this study we should like to find out what other words are brought to your mind by some words used in plant germination.

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 that comes to your mind in the spaces provided. Fill up as many spaces as you can.

Continue in this way until you are told to turn to the next page.

There are no right or wrong answers.

Write as quickly as possible since you are only allowed 30 seconds for each page.

Thank you very much

Your Matriculation Number: ____________

Here is an example:

For the word: **FALCON**

Here are some possible words which come to mind

FALCON	1......BIRD
FALCON	2......FLY
FALCON	3......NEST
FALCON	4......CLAW
FALCON	5.......FEATHERS
FALCON	6.......BEAK
FALCON	7.......BALD
FALCON	8.......PREY
FALCON	9.......PRESIDENT
FALCON	10.....TREE

Here is another example:

PHOTOSYNTHESIS

PHOTOSYNTHESIS	1....PLANTS
PHOTOSYNTHESIS	2....CHLOROPHYL
PHOTOSYNTHESIS	3....CARBON FIXATION
PHOTOSYNTHESIS	4....SUN LIGHT
PHOTOSYNTHESIS	5.....O_2 PRODUCTION
PHOTOSYNTHESIS	6....CHEMICAL ENERGY
PHOTOSYNTHESIS	7....STARCH
PHOTOSYNTHESIS	8....TEMPERATURE
PHOTOSYNTHESIS	9....AMAZON FORESTS
PHOTOSYNTHESIS	10....LIFE

Your task is to write as many words as possible that come to your mind in the time available.

Do Not Turn Over Until Told to do so

GERMINATION

GERMINATION 1...

GERMINATION 2...

GERMINATION 3...

GERMINATION 4...

GERMINATION 5...

GERMINATION 6...

GERMINATION 7...

GERMINATION 8...

GERMINATION 9...

GERMINATION 10...

SEED

SEED	1..
SEED	2..
SEED	3..
SEED	4..
SEED	5..
SEED	6..
SEED	7..
SEED	8..
SEED	9..
SEED	10..

FLOWER

FLOWER	1..
FLOWER	2..
FLOWER	3..
FLOWER	4..
FLOWER	5..
FLOWER	6..
FLOWER	7..
FLOWER	8..
FLOWER	9...
FLOWER	10..

FRUIT

FRUIT	1..
FRUIT	2..
FRUIT	3..
FRUIT	4..
FRUIT	5..
FRUIT	6..
FRUIT	7..
FRUIT	8..
FRUIT	9..
FRUIT	10..

EMBRYO PLANT

EMBRYO PLANT 1..

EMBRYO PLANT 2..

EMBRYO PLANT 3..

EMBRYO PLANT 4..

EMBRYO PLANT 5..

EMBRYO PLANT 6..

EMBRYO PLANT 7..

EMBRYO PLANT 8..

EMBRYO PLANT 9..

EMBRYO PLANT 10..

POLLINATION

POLLINATION	1..
POLLINATION	2..
POLLINATION	3..
POLLINATION	4..
POLLINATION	5..
POLLINATION	6..
POLLINATION	7..
POLLINATION	8..
POLLINATION	9..
POLLINATION	10..

DORMANCY

DORMANCY	1..
DORMANCY	2..
DORMANCY	3..
DORMANCY	4..
DORMANCY	5..
DORMANCY	6..
DORMANCY	7..
DORMANCY	8..
DORMANCY	9...
DORMANCY	10..

OVARY

OVARY	1..
OVARY	2..
OVARY	3..
OVARY	4..
OVARY	5..
OVARY	6..
OVARY	7..
OVARY	8..
OVARY	9..
OVARY	10..

TREE BARK

TREE BARK	1..
TREE BARK	2..
TREE BARK	3..
TREE BARK	4..
TREE BARK	5..
TREE BARK	6..
TREE BARK	7..
TREE BARK	8..
TREE BARK	9..
TREE BARK	10..

OVULE

OVULE	1..
OVULE	2..
OVULE	3..
OVULE	4..
OVULE	5..
OVULE	6..
OVULE	7..
OVULE	8..
OVULE	9..
OVULE	10..

End

Your Matriculation Number ☐

Please tick one box on each line to show your opinion.

Your responses will not affect your grades in biology.

You can describe a racing car in this way:

quick ☑☐☐☐☐☐ slow
important ☐☐☑☐☐☐ unimportant
safe ☐☐☐☐☑☐ dangerous

The positions of the ticks between the word pairs show that you consider it as <u>very</u> quick, slightly more important than unimportant and <u>quite</u> dangerous.

Use the same method of ticking to show your opinions below.

Q1	In order to pass my courses, I need to study just what the lecturer tells me.							I do not have to rely totally on the lecturer. Part of my learning is to work things out myself.
Q2	I do not believe in just accepting what the lecturer says without question. Success involves thinking for myself.							I cannot be wrong if I accept what the lecturer says. If I question anything, I might end up failing.
Q3	I believe it is the job of the lecturer to supply me with all the knowledge I need.							The duty of the lecturer is not to teach me everything, but to help me to think for myself.
Q4	All one has to do in science is to memorise things.							Understanding science is the key part of science study.
Q5	I do not believe that all scientific knowledge represents the 'absolute truth'.							We cannot call anything scientific knowledge if it is not absolutely true.
Q6	In exams I prefer questions which are based on what the lecturer taught.							In exams, I like questions that give me the scope to go beyond what is taught and show my ability to think .
Q7	My studies should lead me to be able to work things out for myself.							My studies should lead me to know what to learn.
Q8	Usually, I find I learn more about a subject by discussing it with other students.							Usually, I find it more useful to work on my own.
Q9	It is a waste of time to work on problems which have no possibility of producing a clear-cut, unambiguous							I find benefit from thinking through problems where there is no clear-cut, unambiguous answer.

APPENDIX E

The Second Stage - Tests Used

I. Structural Communication Grid 1 (on *Forests that Need Fires*)

II. Structural Communication Grid 2 (on *Evolution*)

III. Concept Map (on *Photosynthesis*)

IV. Concept Map (on *Evolution*)

V. Word Association Test (on *Evolution*)

VI. Ranking Test (on *Evolution*)

Your Matriculation Number [ ]

The grid below contains adaptation of forests when exposed to fire. Look at the boxes below and answer the questions that follow by using the letters provided.

(Boxes may be used as many times as you wish).

causes organic matter to break down releasing minerals into the soil **A**	hard coated nuts **B**	conserves biodiversity of adapted species **C**
allows more light to penetrate to ground level **D**	may eliminate some marginal plant species **E**	sharp thorns or spines **F**
soft fruits containing small seeds **G**	roots buried deep in the soil **H**	thick bark, which is hard or spongy **I**

Select all the boxes which contain:

Q1 Fire in seasonally dry habitats ....

Q2 In damp habitats, microbial decay ....

Q3 Plants adapted to habitats where fires occur naturally, may show adaptations such as

....

Q4 Allowing natural fires to burn themselves out ....

Q5 Fire may be necessary to bring about germination in species that have ....

Q6 After flowering and fertilisation of ovules, a plant may produce ....

Your Matriculation Number [ ]

The grid below contains examples of reproductive barriers which isolate gene pools of biological species. Look at the statements in the boxes below and indicate, using the letters A to I, which of them makes a complete, correct sentence with each of the phrases listed Q1 to Q6.

(Boxes may be used as many times as you wish).

Species occupy the same geographic area, but live in separate habitats and do not meet. **A**	Species have incompatible sex cells **B**	Species possess unique, exclusive mating signals and courtship behaviours. **C**
Species have anatomically incompatible reproductive organs **D**	Hybrids fail to produce functional gametes. **E**	Mating or flowering occurs at different seasons or times of day. **F**
Impede mating between species or hinder fertilization of ova. **G**	Hybrid zygotes fail to develop or fail to reach sexual maturity. **H**	Offspring of hybrids have reduced viability or fertility. **I**

Q1 Habitat isolation ....

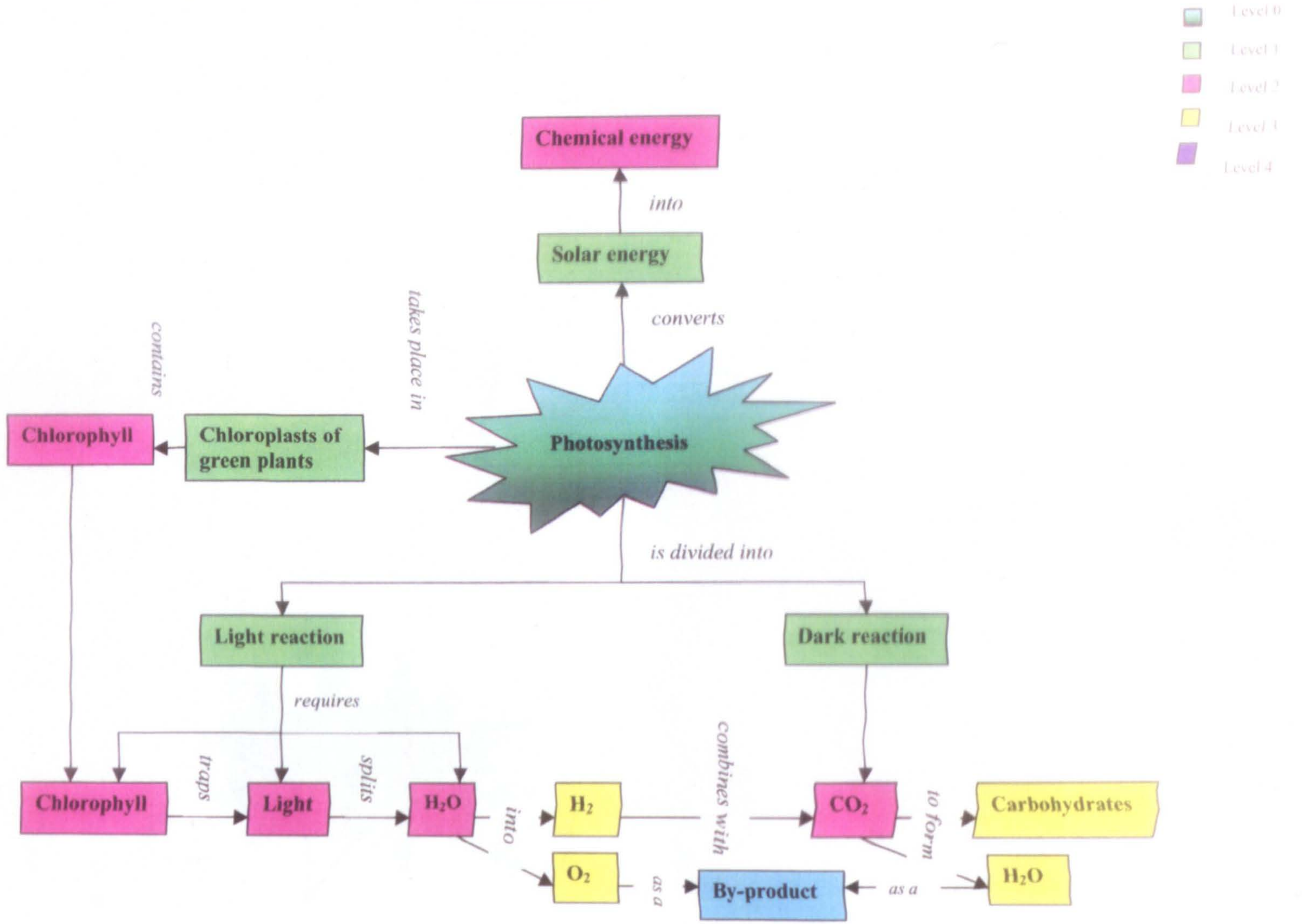
Q2 Gametic isolation ....

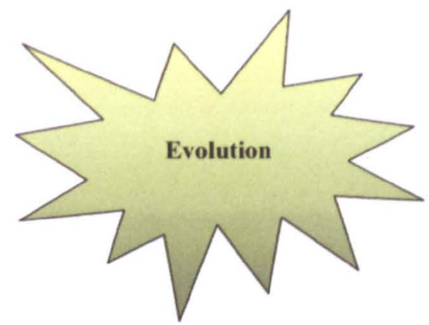
Q3 Temporal isolation ....

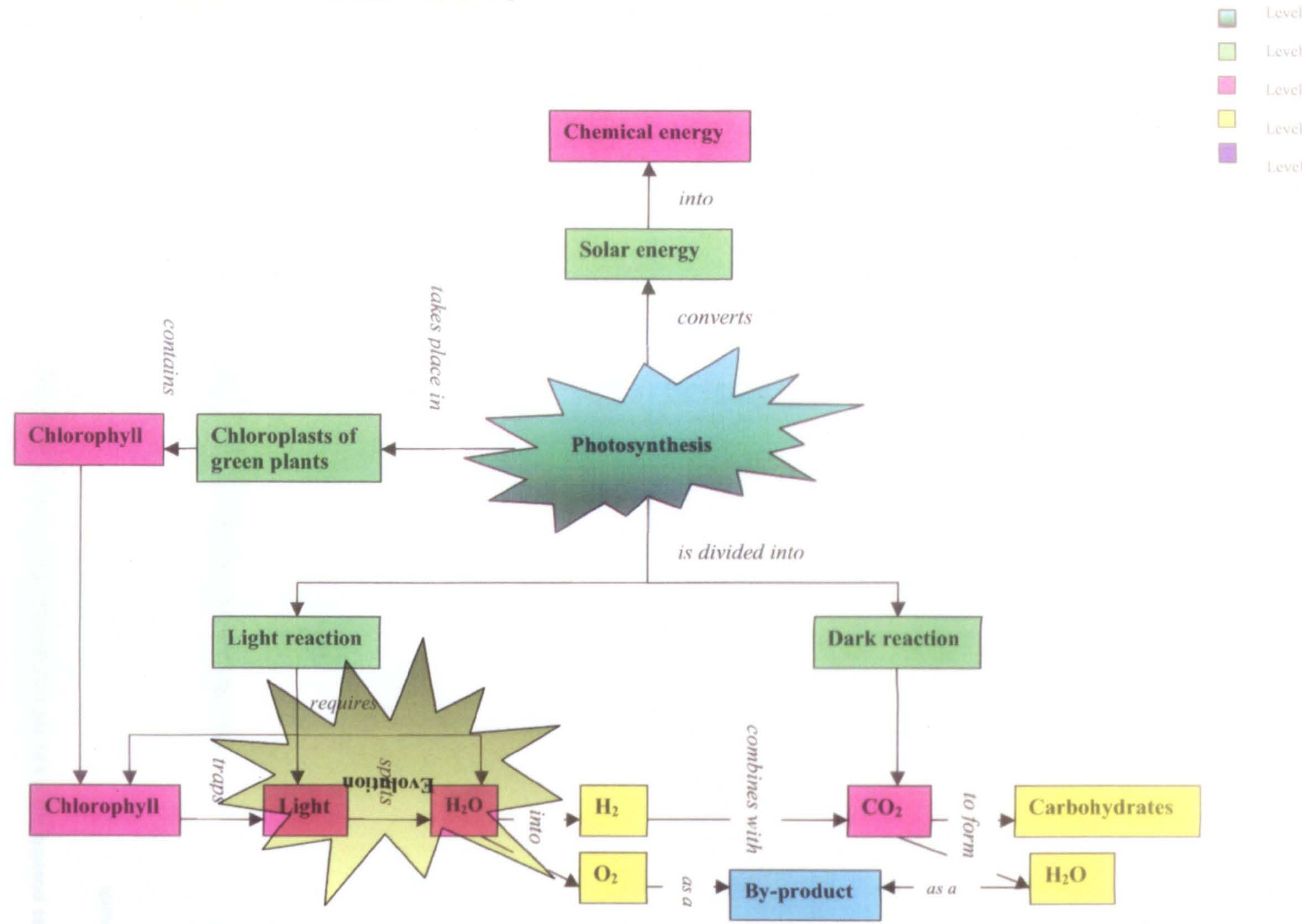
Q4 Mechanical isolation ....

Q5 Prezygotic barriers ....

Q6 Postzygotic barriers ....


Level 0
Level 1
Level 2
Level 3
Level 4
Chemical energy
into
Solar energy
converts
takes place in
contains
Chlorophyll
Chloroplasts of green plants
Photosynthesis
is divided into
Light reaction
Dark reaction
requires
Chlorophyll
traps
Light
splits
H_2O
into
H_2
combines with
CO_2
to form
Carbohydrates
O_2
as a
By-product
as a
H_2O


Evolution


Level 0
Level 1
Level 2
Level 3
Level 4
Chemical energy
into
Solar energy
converts
Photosynthesis
takes place in
Chloroplasts of green plants
contains
Chlorophyll
is divided into
Light reaction
Dark reaction
requires
Evolution
Chlorophyll
traps
Light
splits
H_2O
into
H_2
O_2
combines with
CO_2
to form
Carbohydrates
H_2O
as a
By-product
as a

THINK OF A WORD

When you hear or see a word, it often makes you think of other words. In this study we should like to find out what other words are brought to your mind by some words used in evolution.

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 that comes to your mind in the spaces provided. Fill up as many spaces as you can.

Continue in this way until you are told to turn to the next page.

There are no right or wrong answers.

Write as quickly as possible since you are only allowed 30 seconds for each page.

Thank you very much

Your Matriculation Number: ____________

Here is an example:

For the word: **FALCON**

Here are some possible words which come to mind

FALCON	1......BIRD
FALCON	2......FLY
FALCON	3......NEST
FALCON	4......CLAW
FALCON	5.......FEATHERS
FALCON	6.......BEAK
FALCON	7.......BALD
FALCON	8.......PREY
FALCON	9.......PRESIDENT
FALCON	10.....TREE

Here is another example:

PHOTOSYNTHESIS

PHOTOSYNTHESIS	1....PLANTS
PHOTOSYNTHESIS	2....CHLOROPHYL
PHOTOSYNTHESIS	3....CARBON FIXATION
PHOTOSYNTHESIS	4....SUN LIGHT
PHOTOSYNTHESIS	5.....O_2 PRODUCTION
PHOTOSYNTHESIS	6....CHEMICAL ENERGY
PHOTOSYNTHESIS	7....STARCH
PHOTOSYNTHESIS	8....TEMPERATURE
PHOTOSYNTHESIS	9....AMAZON FORESTS
PHOTOSYNTHESIS	10....LIFE

Your task is to write as many words as possible that come to your mind in the time available.

NATURAL SELECTION

NATURAL SELECTION	1..
NATURAL SELECTION	2..
NATURAL SELECTION	3..
NATURAL SELECTION	4..
NATURAL SELECTION	5..
NATURAL SELECTION	6..
NATURAL SELECTION	7..
NATURAL SELECTION	8..
NATURAL SELECTION	9..
NATURAL SELECTION	10..

FOSSIL RECORD

FOSSIL RECORD	1...
FOSSIL RECORD	2...
FOSSIL RECORD	3...
FOSSIL RECORD	4...
FOSSIL RECORD	5...
FOSSIL RECORD	6...
FOSSIL RECORD	7...
FOSSIL RECORD	8...
FOSSIL RECORD	9...
FOSSIL RECORD	10...

VARIATION

MUTATION

MUTATION	1...
MUTATION	2...
MUTATION	3...
MUTATION	4...
MUTATION	5...
MUTATION	6...
MUTATION	7...
MUTATION	8...
MUTATION	9...
MUTATION	10...

SPECIATION

SPECIATION	1..
SPECIATION	2..
SPECIATION	3..
SPECIATION	4..
SPECIATION	5..
SPECIATION	6..
SPECIATION	7..
SPECIATION	8..
SPECIATION	9..
SPECIATION	10..

SELECTIVE ADVANTAGE

SELECTIVE ADVANTAGE	1..
SELECTIVE ADVANTAGE	2..
SELECTIVE ADVANTAGE	3..
SELECTIVE ADVANTAGE	4..
SELECTIVE ADVANTAGE	5..
SELECTIVE ADVANTAGE	6..
SELECTIVE ADVANTAGE	7..
SELECTIVE ADVANTAGE	8..
SELECTIVE ADVANTAGE	9..
SELECTIVE ADVANTAGE	10..

MICRO-EVOLUTION

MICRO-EVOLUTION 1...

MICRO-EVOLUTION 2...

MICRO-EVOLUTION 3...

MICRO-EVOLUTION 4...

MICRO-EVOLUTION 5...

MICRO-EVOLUTION 6...

MICRO-EVOLUTION 7...

MICRO-EVOLUTION 8...

MICRO-EVOLUTION 9...

MICRO-EVOLUTION 10...

FITNESS

FITNESS	1..
FITNESS	2..
FITNESS	3..
FITNESS	4..
FITNESS	5..
FITNESS	6..
FITNESS	7..
FITNESS	8..
FITNESS	9..
FITNESS	10..

MORPHOSPECIES

MORPHOSPECIES	1...
MORPHOSPECIES	2...
MORPHOSPECIES	3...
MORPHOSPECIES	4...
MORPHOSPECIES	5...
MORPHOSPECIES	6...
MORPHOSPECIES	7...
MORPHOSPECIES	8...
MORPHOSPECIES	9...
MORPHOSPECIES	10...

GEOGRAPHICAL BARRIERS

GEOGRAPHICAL BARRIERS 1..

GEOGRAPHICAL BARRIERS 2..

GEOGRAPHICAL BARRIERS 3..

GEOGRAPHICAL BARRIERS 4..

GEOGRAPHICAL BARRIERS 5..

GEOGRAPHICAL BARRIERS 6..

GEOGRAPHICAL BARRIERS 7..

GEOGRAPHICAL BARRIERS 8..

GEOGRAPHICAL BARRIERS 9..

GEOGRAPHICAL BARRIERS 10..

End

Dogs and Evolution

Your Matriculation Number [ ]

Alice has been studying the breeding of wolf-like common ancestors which have given rise to varieties of dogs. She wants to know which are the most significant observations from the view point of an evolutionary biologist. Could you help her to get the correct answer. (Look at the statements below).

A Newspaper reports demonstrate that bull terriers are dangerous as pets. This is because they have been selected over generations for aggressiveness.

B The dingo was probably introduced to Australia as a domesticated dog which, on returning to the wild, became a hunter again, under the influence of natural selection.

C The occurrence of breeds of dogs as large as a St Bernard, and as small as a chihuahua demonstrates that size in dogs is determined by many gene loci.

D The existence of many breeds of dogs demonstrates the power of selection over generations to alter phenotypes.

E Darwin studied domesticated species such as dogs and pigeons, because he thought that artificial selection acted in a similar way to natural selection.

F The skill sheepdogs exhibit in sheepdog trials demonstrates how selection over generations has made it easier for humans to train them to round up sheep.

Rank these statements concerning domesticated dogs in order of their significance to the evolutionary biologists by placing the letters A, B, C...etc. in the boxes below. The letter which comes first is the most significant and the letter which comes last is the least significant from your point of view.

Most significant [ ] [ ] [ ] [ ] [ ] [ ] Least significant

Scoring of Ranking Test in the Second Stage (Total=10)

B	E	C	D	A	F
E	B	D	C	F	A
		1	2	3	4
B					
	B				
		B			
			B		
				B	
					B
			1	2	3
E					
	E				
		E			
			E		
				E	
					E
1				1	2
C					
	C				
		C			
			C		
				C	
					C
2	1				1
D					
	D				
		D			
			D		
				D	
					D
3	2	1			
A					
	A				
		A			
			A		
				A	

					A
4	3	2	1		
F					
	F				
		F			
			F		
				F	
					F

APPENDIX F

The Third Stage - Tests Used

I. Convergent/Divergent Test

II. Lateral Thinking Test 1

III. Lateral Thinking Test 2

IV. Ranking Test

V. Self-Report Questionnaire

THE CONVERGENT AND DIVERGENT TEST

Your Matriculation Number [ ]

These tests aim to measure your ways of thinking.
The results will NOT affect your academic work or exams in any way.

TEST 1 — 4 Minutes

When you are writing, it is often necessary to think of several different words having the same meaning, so that you do not have to repeat one word again and again. In this test you will be asked to think of words having meanings which are the same as or similar to a given word. The given words will be ones that are well known to you.

For example: If the word is **SHORT** you could write some of the words written below:

SHORT:	*Brief*	*Abbreviated*	*Concise*	*Momentary*	*Little*	*Limited*
	Deficient	*Abrupt*	*Petite*	*Small*	*Compact*	*Tiny*

Now try the following words. You probably will not be able to fill in all the spaces, but write as many words as you can think of.

1. **STRONG** :

....

....

....

2. **CLEAR** :

....

....

....

3. **DARK** :

....

....

....

TEST 2 — 4 Minutes

In this test you will be asked to write as many sentences as you can. Each sentence should contain the four words mentioned and any other words you choose:

For example: **TAKE** **FEW** **LAND** **LITTLE**

1. *Few crops take little land.*
2. *A few little boats take food to land.*
3. *Could you take a few little people with you to see my green land?*

All the four words are used in each sentence. The words must be used in the form that is given; for example, you cannot use 'taking' instead of 'take'. Notice that the sentences may be of any length. All sentences must differ from one another by more than merely one or two changed words, such as different pronouns or adjectives.

Now try the following words. Remember to number each new sentence as was done in the example above.

1. **WRITE** **WORDS** **LONG** **OFTEN**

....

....

....

....

2. **FRIEND** **MAN** **YEAR** **CATCH**

....

....

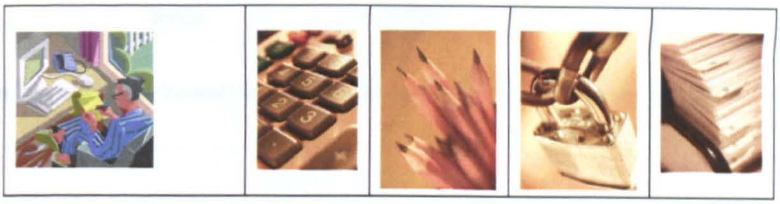
....

....

TEST 3 — 5 Minutes

This is a test of your ability to think up a number of different symbols that could be used to stand for certain words or ideas.

For example: The word is '**OFFICE**'. This word could be represented by *many symbols or drawings* as shown below. As you know there are many other symbols that could represent the word '**OFFICE**'?



Now draw as many symbols as you can think of (up to five) for each word or subject below.

Each drawing can be a complicated or as simple as you chose. (No artistry required)

1. ENERGY

2. HAPPINESS

3. FOOD CHAIN

4. SILENCE

TEST 4 **2 Minutes**

This is a test to see how many things you can think of that are alike in some way.

For example: What things are always **red** or that are red more than any other colour? You may use one word or several words to describe each thing.

Tomatos *Bricks* *Blood*

Go ahead and write all the things that are **'round'** or that are round more often than any other shape.

....

....

....

TEST 5 — 2 Minutes

This is a test of your ability to think rapidly of as many words as you can that begin with one letter and end with another.

For example: The words in the following list all begin with '**S**' and end with '**N**'.

Sun *Spin* *Stain* *Solution*

Now try thinking of words beginning with **'G'** and ending with '**T**'. Write them on the lines below. Names of people or places are not allowed.

....

....

....

TEST 6 — 3 Minutes

This is a test to see how many ideas you can think of about a topic. Be sure to list all the ideas you can think about a topic whether or not they seem important to you. You are not limited to one word. *Instead you may use* a word or a phrase to express each idea.

For example: '**A train journey**'. Examples are given below of ideas about a topic like this.

Number of miles *Suitcases* *The railway stations* *People in the train*

Now list all the ideas you can about '**Working in laboratories**'.

....

....

....

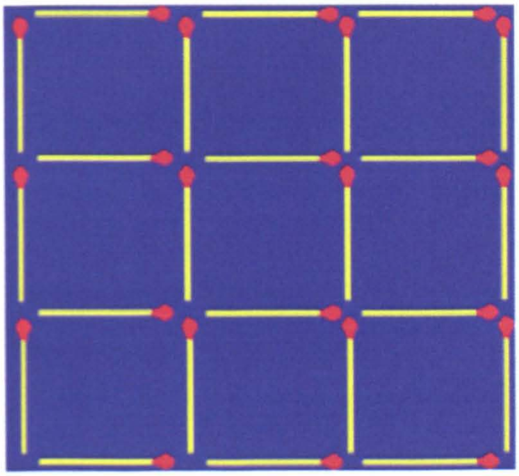
END OF TESTS

THINK LATERALLY

Your Matriculation Number

1. Look at the picture below:

   Remove 8 matches to leave just 2 squares with no extra matches showing.



2. It is possible to see patterns in numbers.

   For example: 3, 7, 12, 18, 25

7	=	3	+	4
12	=	7	+	5
18	=	12	+	6
25	=	18	+	7

   Look at the following set of numbers. Write down the next number in each series.

   a. 2 4 6 10 14 22

   b. 2 3 5 8 13

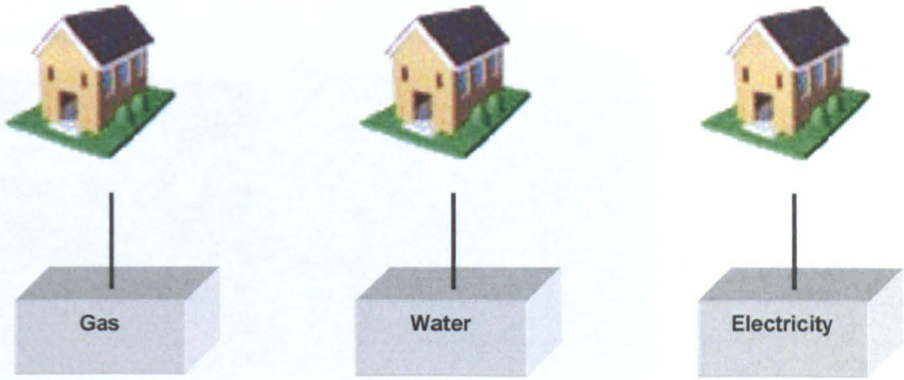
   c. 2 8 18 32

3. What colour should the square be?

....

Please Turn Over

4. A builder builds three houses, each of which requires an electricity supply, mains water and gas. For safety reasons, the three supplies must not cross each other. Can you link all these supplies to the all houses without any of the three pipes crossing each other?



5. Ice is less dense than water.

Therefore, ice will float on water.

Form of Water	Density (gcm^{-3})
Ice	0.917
Water at 0^0C	0.999
Water at 4^0C	1.000

Imagine that water could form crystals which were ***more*** dense than liquid water.

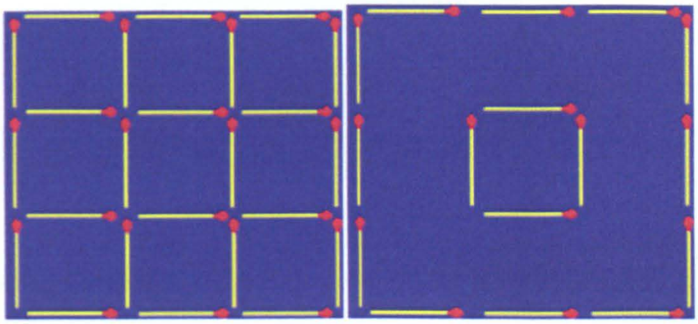
Write down all the implications (biological or other) if this were to happen.
(Diagrams can be used when appropriate – use the space in any way you like.)

THINK LATERALLY

Your Matriculation Number

1. Look at the picture below:

   Remove 8 matches to leave just 2 squares with no extra matches showing.



2. It is possible to see patterns in numbers.

For example: 3, 7, 12, 18, 25

7	=	3	+	4
12	=	7	+	5
18	=	12	+	6
25	=	18	+	7

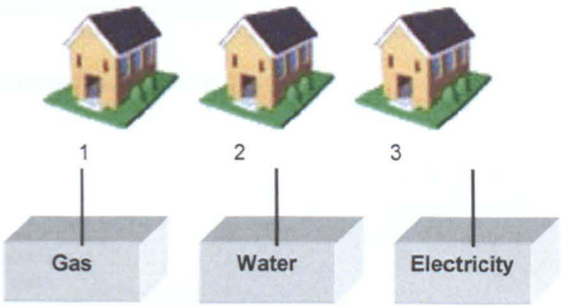
Look at the following set of numbers. Write down the next number in each series.

a.	2	4	6	10	14	22	**26**
b.	2	3	5	8	13	**21**	
c.	2	8	18	32	**50**		

3. What colour should this square be?

   Green

4. A builder builds three houses, each of which requires an electricity supply, mains water and gas. For safety reasons, the three supplies must not cross each other. Can you link all these supplies to the all houses without any of the three pipes crossing each other?



4. Ice is less dense than water.

Therefore, ice will float on water.

Table 1

Form of Water	Density (gcm^{-3})
Ice	0.917
Water at $0^{0}C$	0.999
Water at $4^{0}C$	1.000

Imagine that water could form crystals which were ***more*** dense than liquid water.

Write down all the implications (biological or other) if this were to happen.
(Diagrams can be used when appropriate – use the space in any way you like.)

The biological consequences of 'heavy ice'.

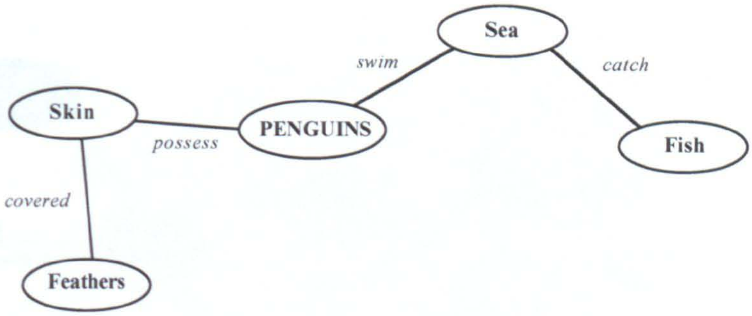
1. Species that currently live any part of their lives on the top of ice that floats on water would be without that habitat, and would either not have evolved or done so in a quite different way. This includes several seal species, penguin species, and polar bears.

2. Aquatic species that currently spend their time under the ice in winter (or all year round), would be in the water layer above the ice. This would cut them off from using the mud or other substrate on the floor of the sea or lake. Many species, both vertebrate and invertebrate, use the sediment layer for feeding or hiding. Once cut off in the water above the ice they could not do this or once trapped below it, they would be there until the Spring thaw.

A physical consequence of sinking ice would probably be a delay in the formation of ice on a sea or lake bed, but then a delay in the its disappearance as the heat of the sun would have difficulty in getting to it.

Your Matriculation Number [ ]

Here is a way to show some information about penguins :



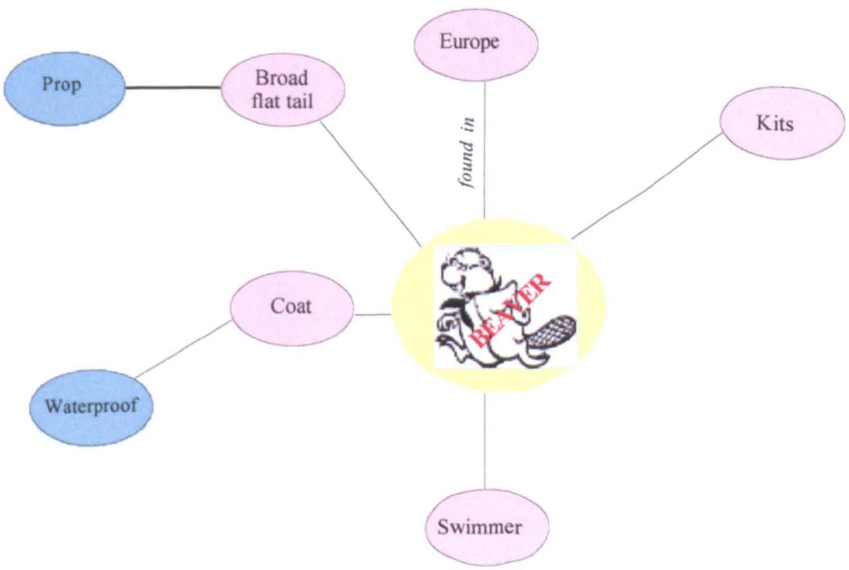
Notice how words are used to link features (e.g. swim, covered,......)

Use the same method to give as much information as you can about beavers.

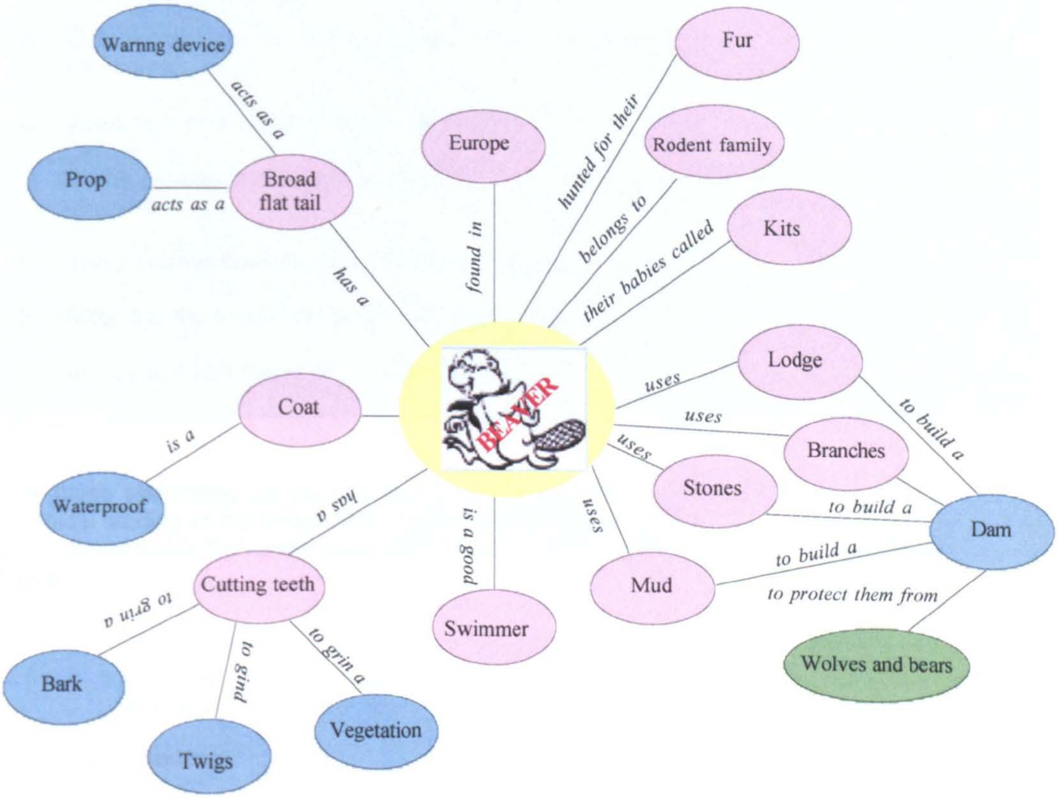
Here are some words to help you. You may use them and as many other words as you can.

Add words to the links as well

Rodent family	Bark	Dam	Vegetation
Warming device	Stones	Lodge	Cutting teeth
Wolves and bears	Twigs	Mud	Branches



Your Matriculation Number



Levels of Biological Organisation

Your Matriculation Number [ ]

Biologists distinguish different levels of organisation from biochemical to ecological.

A The photosynthetic pigment chlorophyll is contained in chloroplasts.

B Oak woodlands in Britain have greater diversity of insect species than spruce plantations.

C Adenine is one of four nucleotides in DNA.

D In the human population of Europe, about 15% are of the blood type Rhesus(Rh)-negative.

E The pancreas contains cells that secrete insulin in humans.

F Mitosis is the normal process of cell division.

G In robins, both parents feed the young.

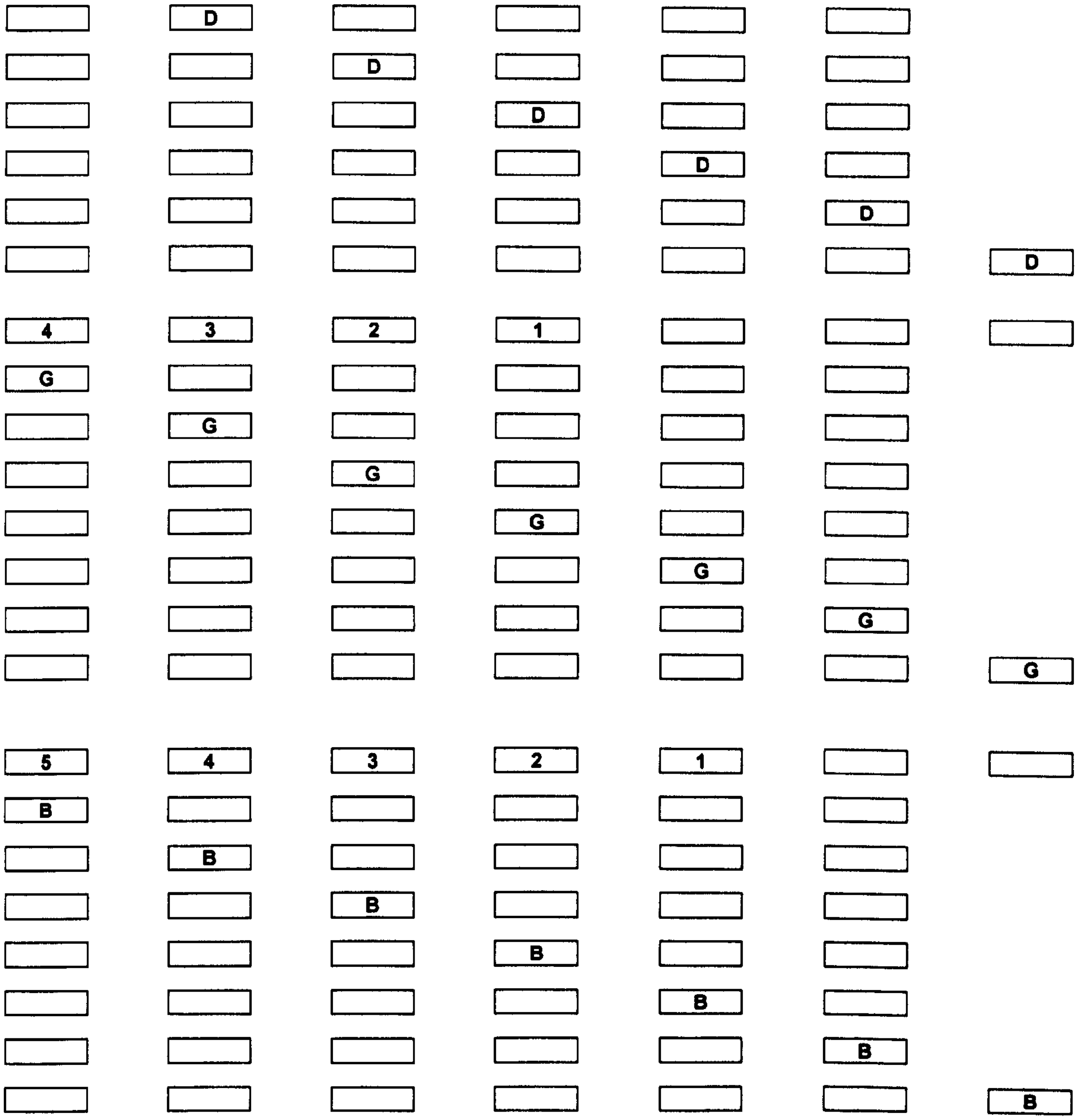
Rank these statements concerning levels of organisation in order of their level from biochemical to ecological starting at the lowest level by placing the letters A, B, C...etc. in the boxes below. The letter which comes first is the lowest level and the letter which comes last is the highest level from your point of view.

Biological level
(Lowest level)

Ecological level
(Highest level)

Scoring of Ranking Test in the Third Stage (Total=15)

C / A	A / C	F / E	E / F	D / G	G / D,B	B / D
		1	2	3	4	5
C						
	C					
		C				
			C			
				C		
					C	
						C
			1	2	3	4
A						
	A					
		A				
			A			
				A		
					A	
						A
1				1	2	3
F						
	F					
		F				
			F			
				F		
					F	
						F
2	1				1	2
E						
	E					
		E				
			E			
				E		
					E	
						E
3	2	1				1
D						



D
D
D
D
D
D
4 3 2 1
G
G
G
G
G
G
G
5 4 3 2 1
B
B
B
B
B
B
B

What Do You Think About Problems?

Your Matriculation Number [ ]

This survey is designed to reveal how you describe yourself when you are solving any problem.
Your participation will help us to improve learning.
Your responses will not affect your grades in biology.

***You can describe a racing car in this way*:**

quick	☑	☐	☐	☐	☐	☐	slow
important	☐	☐	☑	☐	☐	☐	unimportant
safe	☐	☐	☐	☐	☑	☐	dangerous

The positions of the ticks between the word pairs show that you consider it as <u>very</u> quick, slightly more important than unimportant and <u>quite</u> dangerous.

Think about the problems you have just attempted and the way you solve problems.

Please tick ***one*** box on each line to show your opinion.

I prefer to solve problems on my own							I prefer to work with a group when I solve problems
I prefer to try problems which follow clear procedures							I prefer to try open-ended problems
I feel uncertain when I solve open-ended problems							I feel confident when I solve open-ended problems
I'm happy to take a risk while I attempt problems							I'm not happy to take a risk while I attempt problems
I cannot be bothered with problems on unfamiliar topics							I like problems in new areas on knowledge
Pictures and diagrams help me solve problems							Pictures and diagrams do not help me solve problems
I find the problems more difficult without clear instructions							I find the problems easier without any instructions
Discussions during problem solving work enhance my understanding							Discussions during problem solving work do not help me in understanding
I usually make notes while solve problems							I rarely make notes while solve problems
I cope well with uncertainty in problems							I do not cope well with uncertainty in problems
I prefer step-by-step instructioned problems							I do not like step-by-step instructioned problems
I believe that the instructions are good starting point in solving problems							I do not want to be tied done when solving problems
I don't enjoy doing problem solving							I enjoy doing problem solving

APPENDIX G

Statistical Data of the First, Second & Third Stages

Representation Tables of:

I. The First Stage : Correlation

II. The Second Stage : Correlation

III. The Third Stage : Correlation

Correlations

		Knowledge	Understanding	Implication	Experiment	Analysis	Unit 3	TF1
Knowledge	Pearson Correlation	1	.069	.028	-.027	.019	.262**	.028
	Sig. (2-tailed)	.	.084	.479	.505	.641	.000	.640
	N	642	639	640	616	626	642	273
Understanding	Pearson Correlation	.069	1	.277**	.042	.169**	.779**	.191**
	Sig. (2-tailed)	.084	.	.000	.304	.000	.000	.002
	N	639	639	637	613	623	639	272
Implication	Pearson Correlation	.028	.277**	1	.192**	.185**	.623**	.180**
	Sig. (2-tailed)	.479	.000	.	.000	.000	.000	.003
	N	640	637	640	616	625	640	272
Experiment	Pearson Correlation	-.027	.042	.192**	1	.124**	.335**	.036
	Sig. (2-tailed)	.505	.304	.000	.	.002	.000	.568
	N	616	613	616	616	604	616	260
Analysis	Pearson Correlation	.019	.169**	.185**	.124**	1	.518**	.063
	Sig. (2-tailed)	.641	.000	.000	.002	.	.000	.312
	N	626	623	625	604	626	626	261
Unit 3	Pearson Correlation	.262**	.779**	.623**	.335**	.518**	1	.256**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000
	N	642	639	640	616	626	642	273
TF1	Pearson Correlation	.028	.191**	.180**	.036	.063	.256**	1
	Sig. (2-tailed)	.640	.002	.003	.568	.312	.000	.
	N	273	272	272	260	261	273	273

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		Knowledge	Understanding	Implication	Experiment	Analysis	Unit 3	TF2
Knowledge	Pearson Correlation	1	.069	.028	-.027	.019	.262**	.014
	Sig. (2-tailed)	.	.084	.479	.505	.641	.000	.848
	N	642	639	640	616	626	642	178
Understanding	Pearson Correlation	.069	1	.277**	.042	.169**	.779**	.241**
	Sig. (2-tailed)	.084	.	.000	.304	.000	.000	.001
	N	639	639	637	613	623	639	176
Implication	Pearson Correlation	.028	.277**	1	.192**	.185**	.623**	.102
	Sig. (2-tailed)	.479	.000	.	.000	.000	.000	.174
	N	640	637	640	616	625	640	178
Experiment	Pearson Correlation	-.027	.042	.192**	1	.124**	.335**	.050
	Sig. (2-tailed)	.505	.304	.000	.	.002	.000	.515
	N	616	613	616	616	604	616	174
Analysis	Pearson Correlation	.019	.169**	.185**	.124**	1	.518**	-.063
	Sig. (2-tailed)	.641	.000	.000	.002	.	.000	.411
	N	626	623	625	604	626	626	175
Unit 3	Pearson Correlation	.262**	.779**	.623**	.335**	.518**	1	.202**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.007
	N	642	639	640	616	626	642	178
TF2	Pearson Correlation	.014	.241**	.102	.050	-.063	.202**	1
	Sig. (2-tailed)	.848	.001	.174	.515	.411	.007	.
	N	178	176	178	174	175	178	178

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		Knowledge	Understanding	Implication	Experiment	Analysis	Unit 3	WAT
Knowledge	Pearson Correlation	1	.069	.028	-.027	.019	.262**	-.144*
	Sig. (2-tailed)	.	.084	.479	.505	.641	.000	.016
	N	642	639	640	616	626	642	282
Understanding	Pearson Correlation	.069	1	.277**	.042	.169**	.779**	.190**
	Sig. (2-tailed)	.084	.	.000	.304	.000	.000	.001
	N	639	639	637	613	623	639	282
Implication	Pearson Correlation	.028	.277**	1	.192**	.185**	.623**	.135*
	Sig. (2-tailed)	.479	.000	.	.000	.000	.000	.024
	N	640	637	640	616	625	640	281
Experiment	Pearson Correlation	-.027	.042	.192**	1	.124**	.335**	.017
	Sig. (2-tailed)	.505	.304	.000	.	.002	.000	.787
	N	616	613	616	616	604	616	268
Analysis	Pearson Correlation	.019	.169**	.185**	.124**	1	.518**	.115
	Sig. (2-tailed)	.641	.000	.000	.002	.	.000	.057
	N	626	623	625	604	626	626	275
Unit 3	Pearson Correlation	.262**	.779**	.623**	.335**	.518**	1	.196**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.001
	N	642	639	640	616	626	642	282
WAT	Pearson Correlation	-.144*	.190**	.135*	.017	.115	.196**	1
	Sig. (2-tailed)	.016	.001	.024	.787	.057	.001	.
	N	282	282	281	268	275	282	282

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

		Knowledge	Understanding	Implication	Experiment	Analysis	Unit 3	SCG
Knowledge	Pearson Correlation	1	.069	.028	-.027	.019	.262**	-.025
	Sig. (2-tailed)	.	.084	.479	.505	.641	.000	.674
	N	642	639	640	616	626	642	280
Understanding	Pearson Correlation	.069	1	.277**	.042	.169**	.779**	.294**
	Sig. (2-tailed)	.084	.	.000	.304	.000	.000	.000
	N	639	639	637	613	623	639	279
Implication	Pearson Correlation	.028	.277**	1	.192**	.185**	.623**	.207**
	Sig. (2-tailed)	.479	.000	.	.000	.000	.000	.001
	N	640	637	640	616	625	640	279
Experiment	Pearson Correlation	-.027	.042	.192**	1	.124**	.335**	.036
	Sig. (2-tailed)	.505	.304	.000	.	.002	.000	.563
	N	616	613	616	616	604	616	268
Analysis	Pearson Correlation	.019	.169**	.185**	.124**	1	.518**	-.056
	Sig. (2-tailed)	.641	.000	.000	.002	.	.000	.357
	N	626	623	625	604	626	626	275
Unit 3	Pearson Correlation	.262**	.779**	.623**	.335**	.518**	1	.254**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000
	N	642	639	640	616	626	642	280
SCG	Pearson Correlation	-.025	.294**	.207**	.036	-.056	.254**	1
	Sig. (2-tailed)	.674	.000	.001	.563	.357	.000	.
	N	280	279	279	268	275	280	280

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		Unit 3	TF1	TF2	WAT	SCG
Unit 3	Pearson Correlation	1	.256**	.202**	.196**	.254**
	Sig. (2-tailed)	.	.000	.007	.001	.000
	N	642	273	178	282	280
TF1	Pearson Correlation	.256**	1	.a	.209*	.331**
	Sig. (2-tailed)	.000	.	.	.047	.002
	N	273	273	0	91	87
TF2	Pearson Correlation	.202**	.a	1	.a	.512**
	Sig. (2-tailed)	.007	.	.	.	.000
	N	178	0	178	0	94
WAT	Pearson Correlation	.196**	.209*	.a	1	.096
	Sig. (2-tailed)	.001	.047	.	.	.346
	N	282	91	0	282	99
SCG	Pearson Correlation	.254**	.331**	.512**	.096	1
	Sig. (2-tailed)	.000	.002	.000	.346	.
	N	280	87	94	99	280

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

Nonparametric Correlations

Correlations

			Unit 3	Perry1	Perry2	Perry3	Perry4	Perry5
Kendall's tau_b	Unit 3	Correlation Coefficient	1.000	.099*	-.016	.055	-.013	-.033
		Sig. (2-tailed)	.	.037	.739	.246	.800	.479
		N	642	267	267	267	267	267
	Perry1	Correlation Coefficient	.099*	1.000	-.200**	.228**	.185**	-.083
		Sig. (2-tailed)	.037	.	.000	.000	.001	.095
		N	267	267	267	267	267	267
	Perry2	Correlation Coefficient	-.016	-.200**	1.000	-.091	-.181**	.100*
		Sig. (2-tailed)	.739	.000	.	.076	.001	.048
		N	267	267	267	267	267	267
	Perry3	Correlation Coefficient	.055	.228**	-.091	1.000	.219**	-.064
		Sig. (2-tailed)	.246	.000	.076	.	.000	.200
		N	267	267	267	267	267	267
	Perry4	Correlation Coefficient	-.013	.185**	-.181**	.219**	1.000	-.093
		Sig. (2-tailed)	.800	.001	.001	.000	.	.078
		N	267	267	267	267	267	267
	Perry5	Correlation Coefficient	-.033	-.083	.100*	-.064	-.093	1.000
		Sig. (2-tailed)	.479	.095	.048	.200	.078	.
		N	267	267	267	267	267	267
	Perry6	Correlation Coefficient	.049	.171**	-.091	.169**	.215**	-.115*
		Sig. (2-tailed)	.293	.001	.071	.001	.000	.019
		N	267	267	267	267	267	267
	Perry7	Correlation Coefficient	-.140**	-.149**	.282**	-.178**	-.133*	.171**
		Sig. (2-tailed)	.004	.004	.000	.000	.014	.001
		N	267	267	267	267	267	267
	Perry8	Correlation Coefficient	.077	.046	.005	.043	-.018	.000
		Sig. (2-tailed)	.101	.349	.922	.379	.734	.994
		N	267	267	267	267	267	267
	Perry9	Correlation Coefficient	-.015	.111*	-.169**	.172**	.224**	-.189**
		Sig. (2-tailed)	.756	.028	.001	.001	.000	.000
		N	267	267	267	267	267	267

Correlations

			Perry6	Perry7	Perry8	Perry9
Kendall's tau_b	Unit 3	Correlation Coefficient	.049	-.140**	.077	-.015
		Sig. (2-tailed)	.293	.004	.101	.756
		N	267	267	267	267
	Perry1	Correlation Coefficient	.171**	-.149**	.046	.111*
		Sig. (2-tailed)	.001	.004	.349	.028
		N	267	267	267	267
	Perry2	Correlation Coefficient	-.091	.282**	.005	-.169**
		Sig. (2-tailed)	.071	.000	.922	.001
		N	267	267	267	267
	Perry3	Correlation Coefficient	.169**	-.178**	.043	.172**
		Sig. (2-tailed)	.001	.000	.379	.001
		N	267	267	267	267
	Perry4	Correlation Coefficient	.215**	-.133*	-.018	.224**
		Sig. (2-tailed)	.000	.014	.734	.000
		N	267	267	267	267
	Perry5	Correlation Coefficient	-.115*	.171**	.000	-.189**
		Sig. (2-tailed)	.019	.001	.994	.000
		N	267	267	267	267
	Perry6	Correlation Coefficient	1.000	-.109*	.080	.297**
		Sig. (2-tailed)	.	.030	.100	.000
		N	267	267	267	267
	Perry7	Correlation Coefficient	-.109*	1.000	.052	-.196**
		Sig. (2-tailed)	.030	.	.296	.000
		N	267	267	267	267
	Perry8	Correlation Coefficient	.080	.052	1.000	-.093
		Sig. (2-tailed)	.100	.296	.	.059
		N	267	267	267	267
	Perry9	Correlation Coefficient	.297**	-.196**	-.093	1.000
		Sig. (2-tailed)	.000	.000	.059	.
		N	267	267	267	267

*. Correlation is significant at the .05 level (2-tailed).

**. Correlation is significant at the .01 level (2-tailed).

The Correlation of the Second Stage

Correlations

		Unit 3	SCG1	SCG2	Ra	WAT	CM(N)	CM(L)
Unit 3	Pearson Correlation	1	.358**	.152*	-.043	.235**	.124	.134
	Sig. (2-tailed)	.	.000	.030	.529	.003	.117	.089
	N	642	200	205	214	162	162	162
SCG1	Pearson Correlation	.358**	1	.294**	.143	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.000	.	.004	.145	.	.	.
	N	200	200	95	105	0	0	0
SCG2	Pearson Correlation	.152*	.294**	1	.167	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.030	.004	.	.083	.	.	.
	N	205	95	205	109	0	0	0
Ra	Pearson Correlation	-.043	.143	.167	1	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.529	.145	.083	.	.	.	.
	N	214	105	109	214	0	0	0
WAT	Pearson Correlation	.235**	.[a]	.[a]	.[a]	1	.394**	.402**
	Sig. (2-tailed)	.003	.	.	.	.	.000	.000
	N	162	0	0	0	162	162	162
CM(N)	Pearson Correlation	.124	.[a]	.[a]	.[a]	.394**	1	.993**
	Sig. (2-tailed)	.117	.	.	.	.000	.	.000
	N	162	0	0	0	162	162	162
CM(L)	Pearson Correlation	.134	.[a]	.[a]	.[a]	.402**	.993**	1
	Sig. (2-tailed)	.089	.	.	.	.000	.000	.
	N	162	0	0	0	162	162	162
Evo-Q1a	Pearson Correlation	.107	.221*	.214*	.006	.290*	.085	.059
	Sig. (2-tailed)	.074	.026	.032	.954	.016	.489	.630
	N	281	102	101	109	68	68	68
Evo-Q1b	Pearson Correlation	.215**	.351**	.136	-.091	.089	.217*	.219*
	Sig. (2-tailed)	.000	.001	.194	.381	.413	.044	.041
	N	282	87	93	95	87	87	87

Correlations

		Evo-Q1a	Evo-Q1b
Unit 3	Pearson Correlation	.107	.215**
	Sig. (2-tailed)	.074	.000
	N	281	282
SCG1	Pearson Correlation	.221*	.351**
	Sig. (2-tailed)	.026	.001
	N	102	87
SCG2	Pearson Correlation	.214*	.136
	Sig. (2-tailed)	.032	.194
	N	101	93
Ra	Pearson Correlation	.006	-.091
	Sig. (2-tailed)	.954	.381
	N	109	95
WAT	Pearson Correlation	.290*	.089
	Sig. (2-tailed)	.016	.413
	N	68	87
CM(N)	Pearson Correlation	.085	.217*
	Sig. (2-tailed)	.489	.044
	N	68	87
CM(L)	Pearson Correlation	.059	.219*
	Sig. (2-tailed)	.630	.041
	N	68	87
Evo-Q1a	Pearson Correlation	1	.[a]
	Sig. (2-tailed)	.	.
	N	281	0
Evo-Q1b	Pearson Correlation	.[a]	1
	Sig. (2-tailed)	.	.
	N	0	282

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

The Correlation of the Third Stage

Correlations

		Unit 3	LT1	Ra	LT2	C/D
Unit 3	Pearson Correlation	1	.353**	.048	.186*	.182*
	Sig. (2-tailed)	.	.000	.595	.037	.012
	N	525	207	126	126	191
LT1	Pearson Correlation	.353**	1	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.000	.	.	.	.
	N	207	207	0	0	0
Ra	Pearson Correlation	.048	.[a]	1	.193*	.[a]
	Sig. (2-tailed)	.595	.	.	.030	.
	N	126	0	126	126	0
LT2	Pearson Correlation	.186*	.[a]	.193*	1	.[a]
	Sig. (2-tailed)	.037	.	.030	.	.
	N	126	0	126	126	0
C/D	Pearson Correlation	.182*	.[a]	.[a]	.[a]	1
	Sig. (2-tailed)	.012	.	.	.	.
	N	191	0	0	0	191

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

Correlations

		Q1	Q2	Q3	Q4	Q5	Q6	C/D
Q1	Pearson Correlation	1	.374**	.365**	.242**	.099	.330**	.718**
	Sig. (2-tailed)	.	.000	.000	.001	.173	.000	.000
	N	191	191	191	191	191	191	191
Q2	Pearson Correlation	.374**	1	.352**	.397**	.176*	.244**	.593**
	Sig. (2-tailed)	.000	.	.000	.000	.015	.001	.000
	N	191	191	191	191	191	191	191
Q3	Pearson Correlation	.365**	.352**	1	.353**	.021	.399**	.686**
	Sig. (2-tailed)	.000	.000	.	.000	.778	.000	.000
	N	191	191	191	191	191	191	191
Q4	Pearson Correlation	.242**	.397**	.353**	1	.163*	.362**	.654**
	Sig. (2-tailed)	.001	.000	.000	.	.024	.000	.000
	N	191	191	191	191	191	191	191
Q5	Pearson Correlation	.099	.176*	.021	.163*	1	-.034	.357**
	Sig. (2-tailed)	.173	.015	.778	.024	.	.638	.000
	N	191	191	191	191	191	191	191
Q6	Pearson Correlation	.330**	.244**	.399**	.362**	-.034	1	.652**
	Sig. (2-tailed)	.000	.001	.000	.000	.638	.	.000
	N	191	191	191	191	191	191	191
C/D	Pearson Correlation	.718**	.593**	.686**	.654**	.357**	.652**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.
	N	191	191	191	191	191	191	191

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Nonparametric Correlations

Correlations

			Unit 3	SRQ1	SRQ2	SRQ3	SRQ4	SRQ5	SRQ6
Kendall's tau_b	Unit 3	Correlation Coefficient	1.000	-.014	-.093	.000	.032	-.187**	.043
		Sig. (2-tailed)	.	.838	.173	1.000	.634	.006	.538
		N	525	127	127	127	127	127	127
	SRQ1	Correlation Coefficient	-.014	1.000	.022	.065	-.052	-.002	.033
		Sig. (2-tailed)	.838	.	.762	.365	.468	.974	.657
		N	127	127	127	127	127	127	127
	SRQ2	Correlation Coefficient	-.093	.022	1.000	.341**	-.195**	.280**	.023
		Sig. (2-tailed)	.173	.762	.	.000	.007	.000	.759
		N	127	127	127	127	127	127	127
	SRQ3	Correlation Coefficient	.000	.065	.341**	1.000	-.208**	.190**	.095
		Sig. (2-tailed)	1.000	.365	.000	.	.004	.008	.203
		N	127	127	127	127	127	127	127
	SRQ4	Correlation Coefficient	.032	-.052	-.195**	-.208**	1.000	-.225**	.099
		Sig. (2-tailed)	.634	.468	.007	.004	.	.002	.184
		N	127	127	127	127	127	127	127
	SRQ5	Correlation Coefficient	-.187**	-.002	.280**	.190**	-.225**	1.000	-.178*
		Sig. (2-tailed)	.006	.974	.000	.008	.002	.	.018
		N	127	127	127	127	127	127	127
	SRQ6	Correlation Coefficient	.043	.033	.023	.095	.099	-.178*	1.000
		Sig. (2-tailed)	.538	.657	.759	.203	.184	.018	.
		N	127	127	127	127	127	127	127
	SRQ7	Correlation Coefficient	-.117	-.013	.364**	.314**	-.165*	.189*	.296**
		Sig. (2-tailed)	.090	.861	.000	.000	.025	.010	.000
		N	127	127	127	127	127	127	127
	SRQ8	Correlation Coefficient	-.013	-.283**	.017	-.049	.039	-.068	.227**
		Sig. (2-tailed)	.847	.000	.819	.507	.598	.357	.003
		N	127	127	127	127	127	127	127
	SRQ9	Correlation Coefficient	.091	.003	-.050	.195**	.056	-.147*	.040
		Sig. (2-tailed)	.176	.968	.492	.007	.436	.041	.592
		N	127	127	127	127	127	127	127
	SRQ10	Correlation Coefficient	.093	.009	-.286**	-.416**	.359**	-.249**	.006
		Sig. (2-tailed)	.170	.898	.000	.000	.000	.001	.936
		N	127	127	127	127	127	127	127
	SRQ11	Correlation Coefficient	-.148*	-.055	.419**	.209**	-.140	.189**	.121
		Sig. (2-tailed)	.030	.443	.000	.004	.053	.009	.109
		N	127	127	127	127	127	127	127
	SRQ12	Correlation Coefficient	-.043	-.083	.417**	.147*	-.037	.070	.203**
		Sig. (2-tailed)	.531	.258	.000	.046	.619	.346	.008
		N	127	127	127	127	127	127	127
	SRQ13	Correlation Coefficient	.041	-.087	.153*	.252**	-.326**	.350**	-.072
		Sig. (2-tailed)	.539	.220	.032	.000	.000	.000	.329
		N	127	127	127	127	127	127	127

Correlations

			SRQ7	SRQ8	SRQ9	SRQ10	SRQ11	SRQ12	SRQ13
Kendall's tau_b	Unit 3	Correlation Coefficient	-.117	-.013	.091	.093	-.148*	-.043	.041
		Sig. (2-tailed)	.090	.847	.176	.170	.030	.531	.539
		N	127	127	127	127	127	127	127
	SRQ1	Correlation Coefficient	-.013	-.283**	.003	.009	-.055	-.083	-.087
		Sig. (2-tailed)	.861	.000	.968	.898	.443	.258	.220
		N	127	127	127	127	127	127	127
	SRQ2	Correlation Coefficient	.364**	.017	-.050	-.286**	.419**	.417**	.153*
		Sig. (2-tailed)	.000	.819	.492	.000	.000	.000	.032
		N	127	127	127	127	127	127	127
	SRQ3	Correlation Coefficient	.314**	-.049	.195**	-.416**	.209**	.147*	.252**
		Sig. (2-tailed)	.000	.507	.007	.000	.004	.046	.000
		N	127	127	127	127	127	127	127
	SRQ4	Correlation Coefficient	-.165*	.039	.056	.359**	-.140	-.037	-.326**
		Sig. (2-tailed)	.025	.598	.436	.000	.053	.619	.000
		N	127	127	127	127	127	127	127
	SRQ5	Correlation Coefficient	.189*	-.068	-.147*	-.249**	.189**	.070	.350**
		Sig. (2-tailed)	.010	.357	.041	.001	.009	.346	.000
		N	127	127	127	127	127	127	127
	SRQ6	Correlation Coefficient	.296**	.227**	.040	.006	.121	.203**	-.072
		Sig. (2-tailed)	.000	.003	.592	.936	.109	.008	.329
		N	127	127	127	127	127	127	127
	SRQ7	Correlation Coefficient	1.000	.139	.026	-.378**	.461**	.365**	.179*
		Sig. (2-tailed)	.	.067	.726	.000	.000	.000	.014
		N	127	127	127	127	127	127	127
	SRQ8	Correlation Coefficient	.139	1.000	.150*	.048	.000	.068	.027
		Sig. (2-tailed)	.067	.	.043	.519	.996	.371	.712
		N	127	127	127	127	127	127	127
	SRQ9	Correlation Coefficient	.026	.150*	1.000	.052	.036	.066	.027
		Sig. (2-tailed)	.726	.043	.	.476	.622	.372	.701
		N	127	127	127	127	127	127	127
	SRQ10	Correlation Coefficient	-.378**	.048	.052	1.000	-.337**	-.148*	-.292**
		Sig. (2-tailed)	.000	.519	.476	.	.000	.046	.000
		N	127	127	127	127	127	127	127
	SRQ11	Correlation Coefficient	.461**	.000	.036	-.337**	1.000	.487**	.266**
		Sig. (2-tailed)	.000	.996	.622	.000	.	.000	.000
		N	127	127	127	127	127	127	127
	SRQ12	Correlation Coefficient	.365**	.068	.066	-.148*	.487**	1.000	.103
		Sig. (2-tailed)	.000	.371	.372	.046	.000	.	.157
		N	127	127	127	127	127	127	127
	SRQ13	Correlation Coefficient	.179*	.027	.027	-.292**	.266**	.103	1.000
		Sig. (2-tailed)	.014	.712	.701	.000	.000	.157	.
		N	127	127	127	127	127	127	127

**. Correlation is significant at the .01 level (2-tailed).

*. Correlation is significant at the .05 level (2-tailed).

APPENDIX H

Statistical Graphs of the First, Second & Third Stages

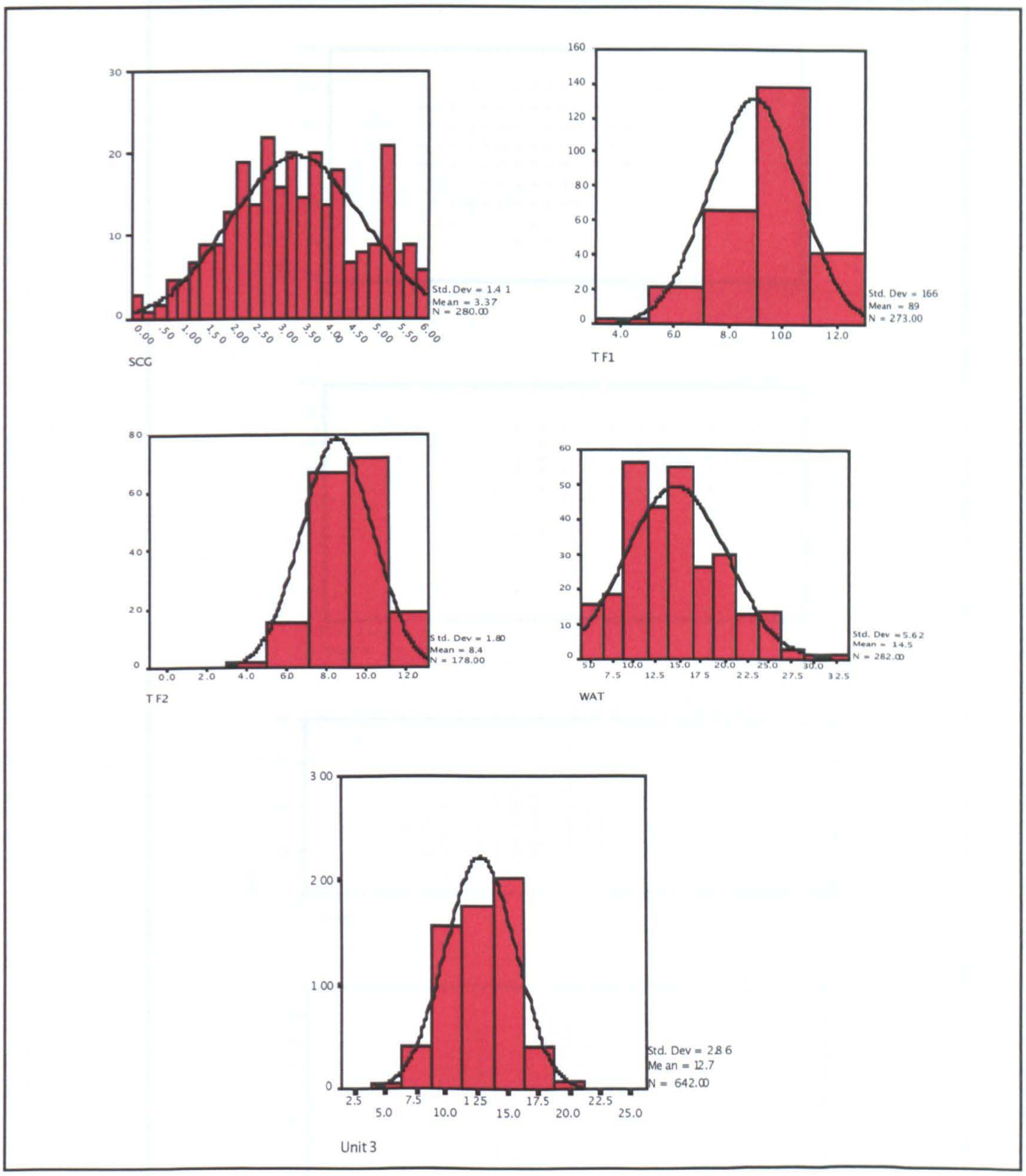
Representation Graphs of:

I. The First Stage : Histogram & Scatterplot

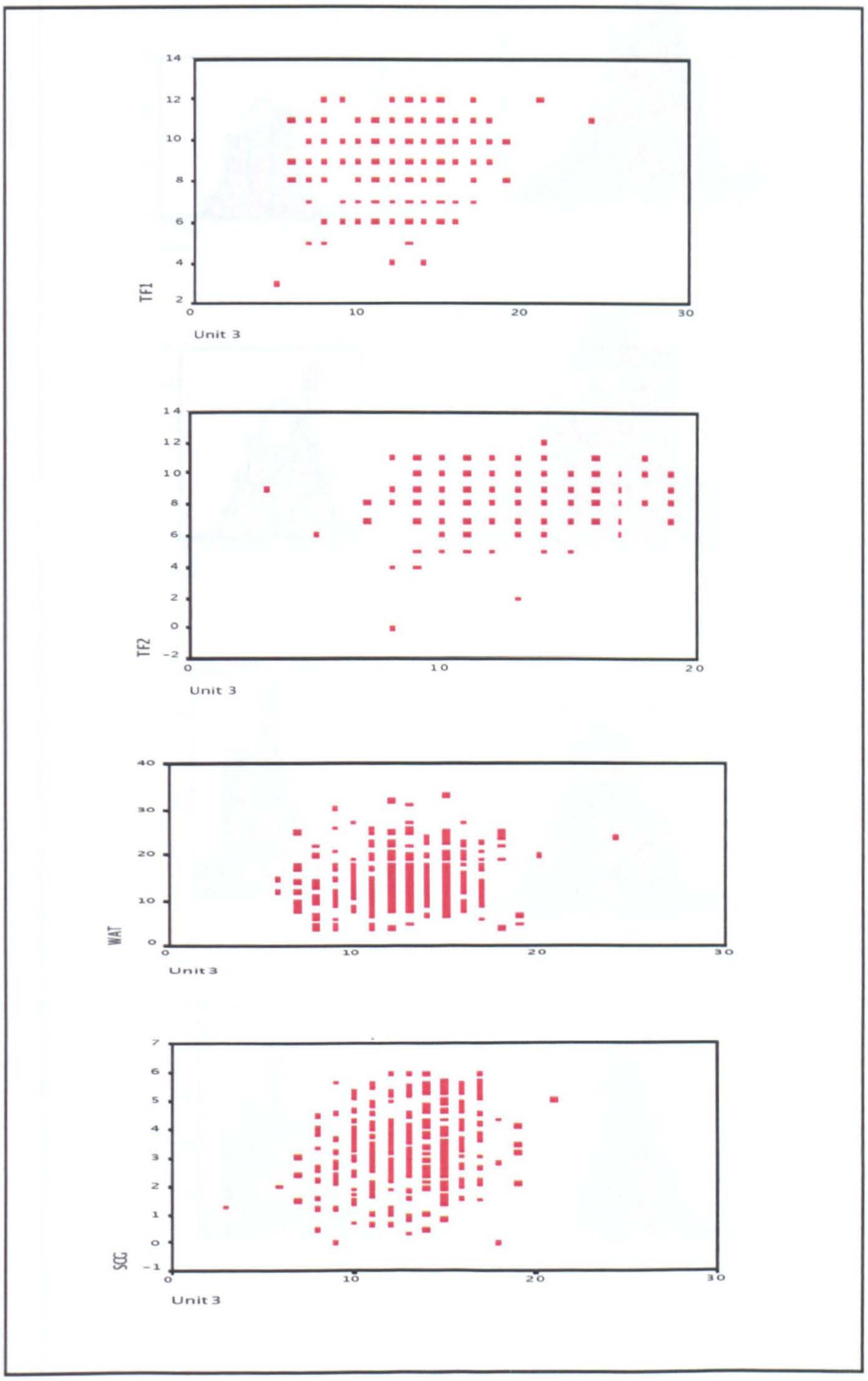
II. The Second Stage : Histogram & Scatterplot

III. The Third Stage : Histogram & Scatterplot

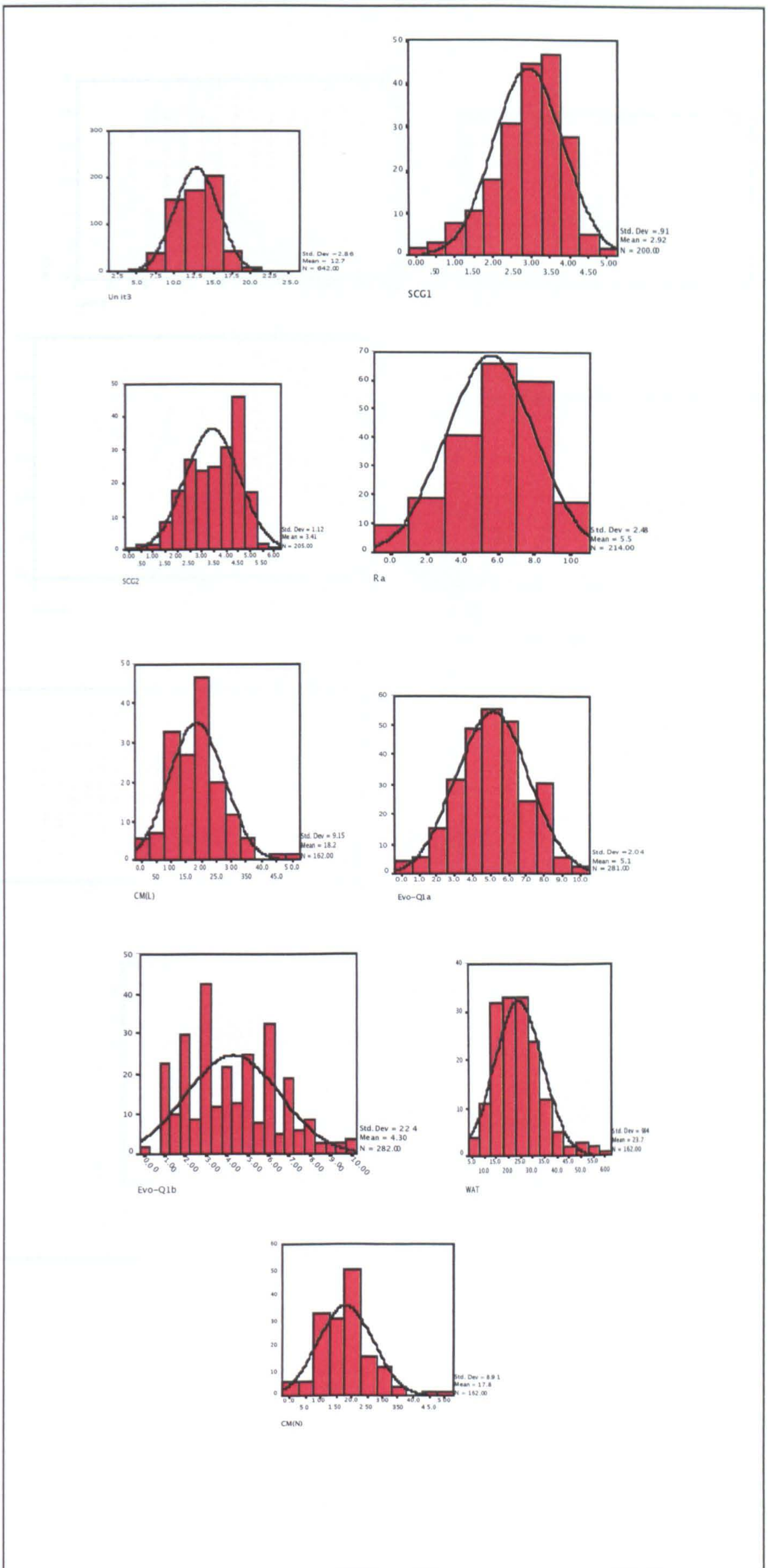
Representation Histograms of the First Stage



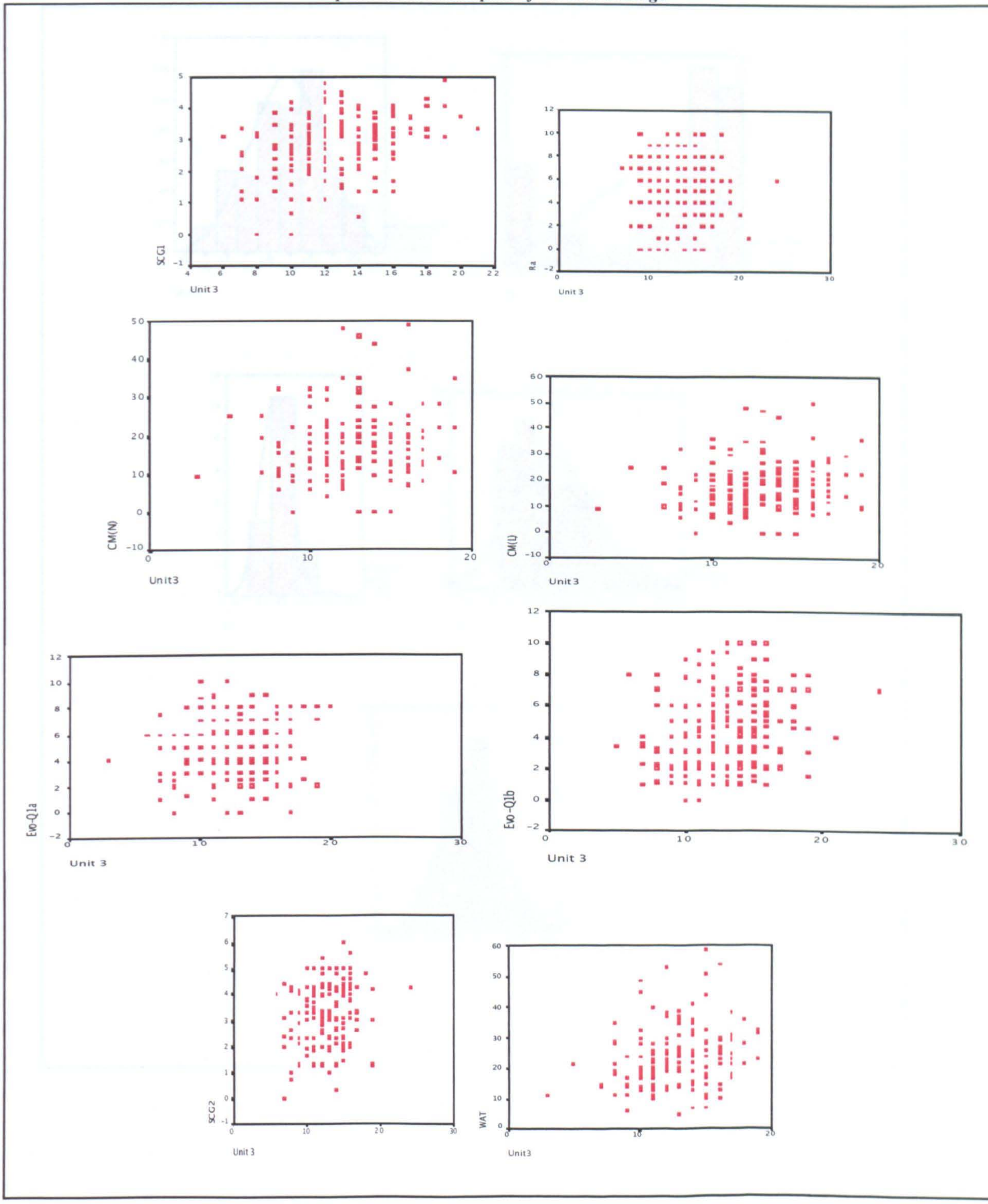
Representation Scatterplots of the First Stage



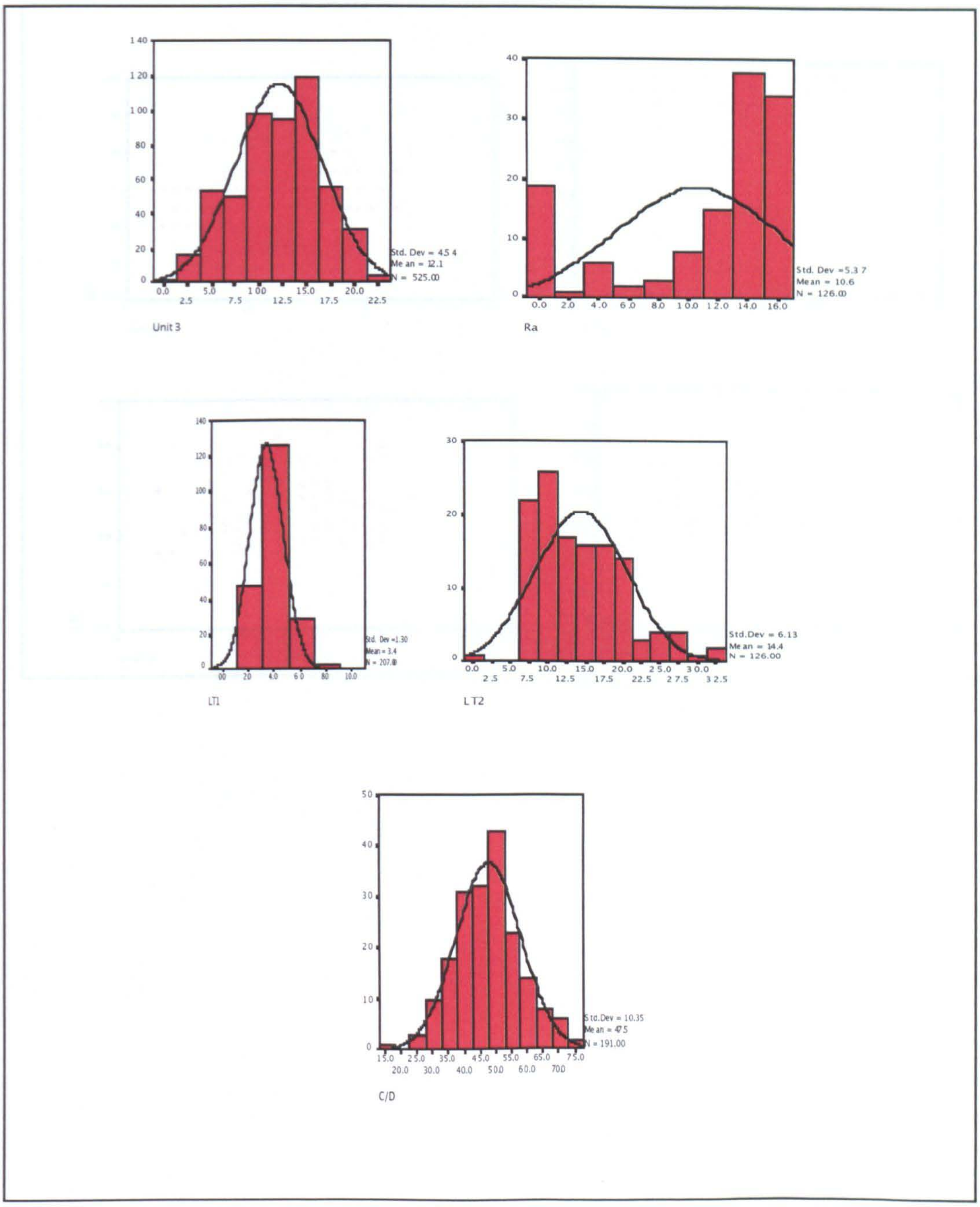
Representation Histograms of the Second Stage



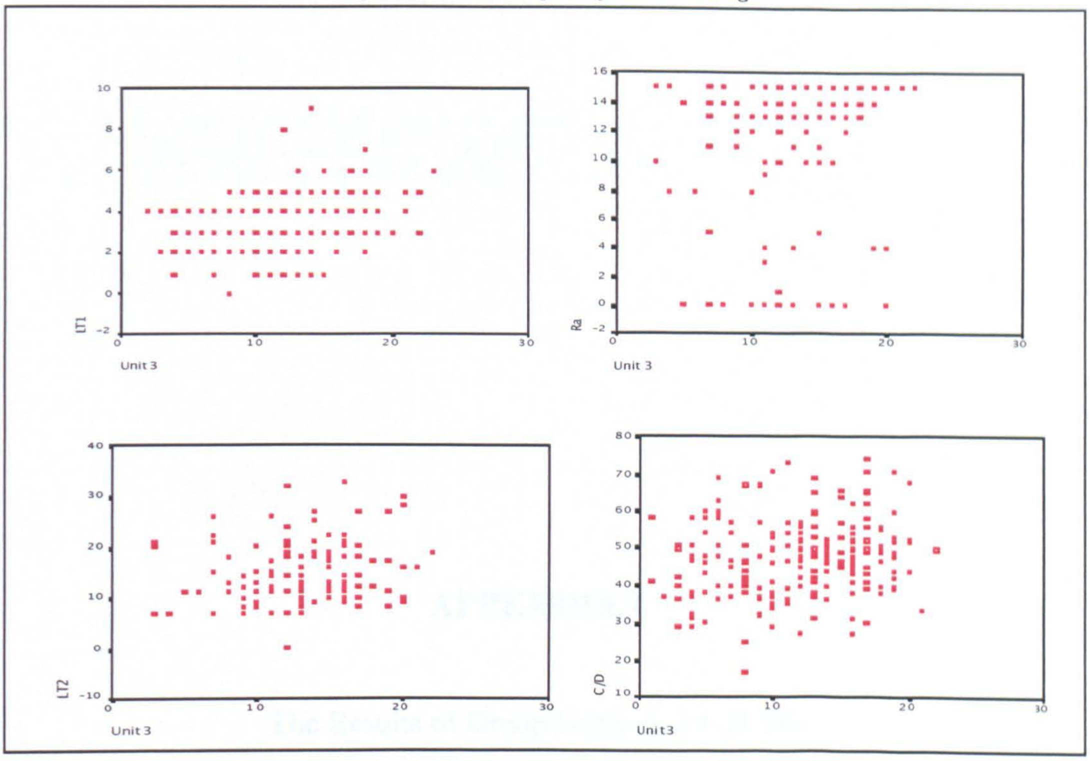
Representation Scatterplots of the Second Stage



Representation Histograms of the Third Stage



Representation Scatterplots of the Third Stage



APPENDIX I

The Results of Group Units (1, 2A & 2B)

I. The result of group units:

   Unit 1: A Model Organism

   Unit 2A : The Chicken Run

   Unit 2B : MMR Vaccine

II. Statistical results of group units:

   Unit 1: A Model Organism

   Unit 2A : The Chicken Run

   Unit 2B : MMR Vaccine

Unit 1 (A Model Organism)

Group No.	Pre-test 14	Part 1 6	Part 2 8	Part 3 3	Part 4 5	Total 36
1	13	1	4	3	3	24
2	11	-	4	3	5	23
3	12	3	4	3	1	23
4	12	-	4	3	2	21
5	12	-	4	3	2	21
6	11	-	3	3	4	21
7	10	3	4	3	-	21
8	11	-	4	3	2	20
9	8	3	4	3	2	20
10	11	-	4	3	2	20
11	10	-	4	3	2	19
12	10	-	4	2	2	18
13	11	-	3	3	1	18
14	10	-	4	2	1	17
15	9	-	4	3	1	17
16	7	2	3	3	2	17
17	11	-	4	0	2	17
18	8	-	4	3	2	17
19	8	1	2	3	2	16
20	10	-	3	2	0	15

Unit 2A (The Chicken Run)

Group No.	Part 1 10	Part 2 6	Part 3 4	Total 20
1	3	4	1	8
2	3	3	1	7
3	2	3	1	6
4	2	4	0	6
5	3	2	1	6
6	1	5	0	6
7	3	2	1	6
8	0	5	0	5
9	1	2	2	5
10	3	1	1	5
11	1	2	1	4
12	0	4	0	4
13	1	2	1	4
14	1	2	1	4
15	1	2	1	4
16	1	2	-	3
17	1	2	0	3
18	2	1	0	3
19	0	1	1	2
20	1	1	0	2

Unit 2B (MMR Vaccine)

Group No.	Part 1 16	Part 2 16	Part 3 8	Total 40
1	12	12	4	28
2	15	8	3	26
3	10	12	3	25
4	13	10	2	25
5	10	10	5	25
6	12	8	5	25
7	11	9	3	23
8	13	7	3	23
9	11	7	3	21
10	10	6	5	21
11	11	8	2	21
12	11	6	3	20
13	13	4	3	20
14	11	7	2	20
15	9	6	4	19
16	10	4	4	18
17	8	5	4	17
18	10	5	2	17
19	9	4	4	17
20	9	4	3	16

Descriptive statistics of group units (1, 2A & 2B)

	Unit 1	*Unit 2A*	*Unit 2B*
Total Score	36	20	40
Sample	20	20	20
Mean	18.5	4.7	21.4
Standard Deviation	2.5	1.6	3.5
Mean (%)	**51**	**24**	**54**

APPENDIX J

Other Unit

I. *Photosynthesis*

Plant Life on Max

In a recent American space probe, they detected a star system with a planet, which they called Max. The probe managed to make estimates of a number of features of the planet:

Planet	Earth	Max
Orbital period	365 days	1.88 Earth yrs
Axis tilt	23.5°	34.0°
Day length	24 hrs	30 hrs
Gravitational acceleration	9.8 m/s^2	9.0 m/s^2
Air pressure	101325 Pa	9753 Pa
Nitrogen	78.0 %	70.0 %
Oxygen	21.0 %	16.0 %
Carbon Dioxide	0.01-0.1 %	5.0 %
Water vapour	0 - 0.7 %	~1.0 %
Ammonia	0.1 %	0.5 %
Methane	0.0002 %	0.5 %

In some ways, Max is rather like Earth. The atmosphere is almost as deep as Earth (0.95 of the depth); and pressure at sea level is very slightly less. The space probe indicated considerable cloud (water vapor) cover and some oceans. The land appears to be fairly flat although some mountains were observed. The temperature on the surface of the planet seems to vary between –65° C at the poles in winter to +55° C at the equator. The probe indicated the presence of what looked like plant life but its nature could not be observed. A preliminary analysis of the composition of the planet suggests the balance of the elements on the planets is rather like Earth.

You will be working as a group of three or four.

Your task is to discuss the possible nature of plant life on planet Max and it might relate to plant life on Earth.

Task 1

As a group, discuss the process of the photosynthesis. What are the key factors that allow photosynthesis to take place? List them.

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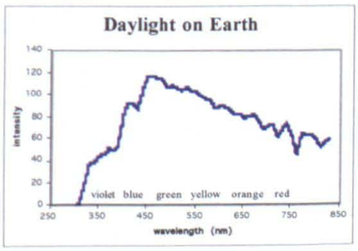
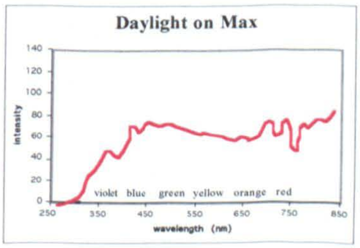
Task 2

Look at the graphs showing the pattern of wavelength light on Earth and on Max.





Discuss how the light on Max might affect plant life.

Task 3

Look at the elements in the atmosphere of Max and in the surface soil. List the main elements required for plant life. In what way do you think plant life might be differ on Max when compare with Earth.

Elements required: ,,

Task 4

Photosynthesis depends on the presence of chlorophyll. Looking at the all evidence you have been giving. Is it likely that chlorophyll will be present on plant life on Max?

Task 5

Suppose that plants from Earth were transported to Max. Are they likely to survive? In what ways will native plants on Max differ from plants on Earth?