SCHEMA THEORY AND PROBLEM-SOLVING IN BIOLOGY

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DECLARATION

I declare that "SCHEMA THEORY AND PROBLEM-SOLVING IN BIOLOGY" is my own work, that it has not been submitted for any degree or examination at any other university, and that all sources used or quoted have been indicated and acknowledged by complete references.

MR. S. CHETTY

Name

SChetty

Signature

NOVEMBER , 1996

DEDICATION

To

DR. J. S. RHODES and PROF. A.J.L. SINCLAIR,

my supervisor and co-supervisor respectively,

for their encouragement and inspiration.

and to

MY WIFE AND CHILDREN,

for their support, and especially their patience

and understanding for all the hours that should

have been spent with them.

ABSTRACT

There is ongoing research to understand why some students experience difficulty in solving problems. There is an equal concern over students that do arrive at correct solutions to problems, but who are unable to justify their answers. This has led to an important conclusion that "correct answers do not necessarily measure students' understanding in science".

It is against this background that this mini-thesis reports the findings from a study that examined biology problem-solving in the light of the schema theory. The study focused primarily on the influence of cognitive structures called schemata, on biology problem-solving.

The collection of data centred mainly around the influence of, and the relationship between, the conceptual and procedural knowledge required in problem-solving. This was done within the context of identifying expert-novice differences. Some of the secondary aims of this study included the influence of text-book use and problem-representation, on problem-solving performance. Based on the concepts and procedures used by expert problem-solvers in this research, a small-scale intervention programme was designed, to explicitly teach this knowledge and strategies to novices, so as to improve their problem-solving performance.

Both quantitative and qualitative data were collected, by questionnaire and personal interview, respectively. Using the clinical interview technique, an interview protocol was obtained for each of six standard nine students in a secondary school, as they attempted three problems on genetics. In addition, another 70 standard nine students of the same school were asked to complete a questionnaire, after they engaged in the same problem-solving exercise that was presented to the students during the interview.

The study revealed that expert problem-solvers have, not only greater domain-specific knowledge than the novices, but that this knowledge is better organised to aid retrieval and application. Furthermore, the novices lacked the repertoire of problem-solving strategies that characterised the experts.

The intervention program, although attempted on a small scale, proved successful in transforming novice problem-solving behaviours towards that of an expert. With increased practice, greater efficiency could be achieved.

Based on the above, and the direct influence that text-book use and problem representation was found to have on problem-solving, a number of pedagogical implications were elaborated.

KEY-WORDS

Biology Education

Schema Theory

Cognition

Problem-Solving

Expert-Novice Differences

Genetics Problem-solving

Conceptual knowledge

Procedural knowledge

Heuristics

Algorithms

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1. INTRODUCTION

The imparting of knowledge and the teaching of cognitive skills form the rationale for the existence of educational institutions. One of the most important cognitive skills is, no doubt, problem-solving ability. If according to Popper "all organisms are constantly, day and night, engaged in problem-solving, then schools should help children with this (Popper, 1972, p42)". Problem-solving pervades almost all areas of instruction; reading and writing have important problem-solving components. Williams and Hollan (1980) view even a rudimentary process as retrieving information from long-term memory as a problem-solving activity.

The influence of politics on education in South Africa has had, to a lesser or greater degree, a detrimental effect on the promotion of thinking skills at school level (Mathfield, 1992, p18). Writers refer to the cognitive disabling effects of the policy of separate education departments based on race (Skuy, Mentis, Nkwe, Arnott and Hickson, 1990). Black pupils especially, have suffered from a legacy of disproportionate allocation of funds and deprivation of equal opportunities in all spheres of formal education, including the development of cognition (Skuy *et al*, 1990). There is an obvious need to release latent potential and to empower previously disempowered learners (Botha and Cilliers, 1993).

Scientific knowledge is growing and changing at such a rate that it is difficult to expect that the facts students learn in their science classes will equip them with the knowledge they need for responsible citizenship (Kuhn, 1993). It has therefore been emphasised that as one of its more important goals, science instruction should foster the reading, writing, and thinking strategies necessary to solve problems and construct new understandings (Glynn, Yeany, and Britton, 1991; Kuhn, 1993).

Instruction in problem-solving generally emphasises well-structured problems -the kind that is clearly presented with all the information needed at hand and an appropriate algorithm available that guarantees a correct answer. But many of the problems we face in real life, and all the important social, political, economic and scientific problems in the world are ill-structured (Simon, 1974a, 181-201). Simon (1980) points out that it is necessary to teach generalised procedures for problem-solving, in view of the enormous changes in the world's knowledge that can take place during a lifetime. He further claims that powerful general methods [of problem-solving] do exist and they can be taught in such a way that they can be used in new domains where they are relevant" (Frederiksen, 1984, p363).

Why is it then that educators do not teach problem-solving directly? Gagne (1980, p15) hypothesised that educators today do not consider learning to think as an important goal. Another possible reason is that educators have not found a method that can successfully teach problem-solving, a view shared by many psychologists.

Researchers today agree that most students do not develop thinking and learning strategies unless they receive explicit instruction in their use (Gall, Gall, Jacobsen and Bullock, 1990). Walters, Seidel and Gardner (1994) indicate that to facilitate genuine reflective thinking, the teacher must make time for it. In addition, the students' efforts must be guided until they become comfortable with the process and its benefits.

Pfeiffer, Feinberg and Gelber (1987, p100) feel that researchers have focussed too much attention on *what to teach* rather than on *how to teach*. They state further that learning problem-solving skills requires much practice and active participation by the student. They think that general problem-solving can be taught, but only if the role of the teacher in the learning process is redefined i.e. not seen as just a "giver" of knowledge to passive students, but as a coach, a manager, a motivator (Pfeiffer et al., 1987, p101/102). This view is reaffirmed by Edmonson and Novak who state that the expectation of the science teacher must change from dispensers of knowledge to developers of self-regulated learners, thinkers, and problem-solvers (Edmonson and Novak, 1993).

Frederiksen (1984, p398) observed that there have been few investigations in classroom settings concerned with the application of cognitive theory to instruction. He stated that there is a need for a great deal of research on instruction in which various ideas from cognitive theory are tried out and evaluated in educational settings.
It is one of the aims of this research to determine the extent to which cognitive

theory on problem-solving impacts upon the practice of, and instruction in biology problem-solving.

Simon and Hayes (1976) remark that there is no substitute for having the requisite knowledge, if one is to solve a problem. In Greeno's (1973) model of problem-solving, knowledge is used mainly to construct a network of relationships connecting the features and variables in the problem with that of the desired solution. It is information retrieved in long-term memory that is used to modify the problem structure held in working memory so as to establish a corrected network among these problem elements. The two kinds of information stored in the long-term memory can be described as procedural knowledge and conceptual knowledge, and are often referred to together as representing an individual's prior knowledge (Frederiksen, 1984, p378).

This model of problem-solving is based on the use of cognitive structures called schemata. These are structures which represent bodies of information available to the problem-solver, and which depend on the problem-solvers prior experience and knowledge. People tend to activate particular schemata for use in given situations, depending upon their perceptions and their expectations. Schemata are used to classify information to allow one to know what to expect and how to act (Ruddell, 1993, p19/20).

The schema theory places emphasis on the use of existing knowledge in conjunction with new information to create more new knowledge. In other words, it involves "thinking with what one knows". Based on this notion, several researchers have stressed the need to take account of the nature and coherence of students' existing mental models and / or conceptions, as this could alleviate the formation of misconceptions (Chi, 1993 ; Chi and Slotta, 1993 ; Chi, Slotta and de Leeuw, 1994). Schema theory, based on a cognitive information processing view, was chosen as a framework for this research as it boasts many advancements over the previous behavioral tradition and traditional cognitive views. This is discussed in the next chapter as an introduction to the schema theory.

Although the concept of schemata is less than perfectly defined, and that some researchers have found various shortcomings, there is enough research supporting the schema process to make it a valuable contributor to the learning and understanding of problem-solving behaviour (Kulhavy, Peterson and Schwartz, 1986, p118).

The aspect of problem-solving within the schema theoretic background was chosen, to address many concerns regarding science teaching in many schools. I have noticed, and many colleagues have agreed, that with each new generation of students, there seems to be a growing inability to solve problems in biology. Despite teachers' awareness of various views of learning, the 'transmission view' seems to be pervading many science lessons in secondary schools (Scott, Dyson and Gater, 1987). According to this view, emphasis is placed on correct solutions to problems without any consideration for how it was arrived at.

In class tests, students who arrive at incorrect solutions to a problem are simply shown the correct solution without any effort to explain how the correct solution was arrived at. No attempt is made to understand how or why the student arrived at an incorrect response. Also, in our obsessive quest for correct solutions, we have encouraged rote memorisation. The students are able to provide the solution but are not able to justify their answer. It is evident that simply to know that a student has obtained a wrong or correct answer is not necessarily informative. Knowledge of the steps that they use to solve problems as well as the conceptual knowledge that they use to justify the procedures would be useful. With such information gathered from students involved in problem-solving exercises, it is possible to make substantive suggestions for the alteration of science instruction so as to allow for meaningful science learning.

It is within this context that, in this research, the influence of Schema Theory on biology problem-solving shall be investigated with a view to illuminating the following :-

- Influence of procedural knowledge in biology problem-solving

- Influence of conceptual knowledge in biology problem-solving

- The interrelationships between the conceptual knowledge possessed by problem-solvers and their knowledge of the procedures they use to solve problems in biology

- The clinical interview as a learning tool

- Problem-solving tendencies of expert and novice problem-solvers

- The relationship between text-book use and biology problem-solving

- The influence of problem representation in problem-solving

- Provision of instruction in biology problem-solving

2. OVERVIEW OF RELEVANT LITERATURE

2.1. SOME ISSUES IN SCIENCE

2.1.1. A Science of Science Education

Science education researchers acknowledge the importance of studying students' understanding as they learn science (Tierney, 1987). As a result, the issue of student cognition has come to dominate research on the psychology of learning science (Gilbert and Swift, 1985). Recent advances in psychological research on learning science have led researchers to argue that there is now a "science of science education" available, which offers useful implications for science education (Cleminson, 1990; Linn, 1986).

Cognitive science offers new hope and direction for science-education research concerned with improving thinking and learning skills (Good, 1989; Lohman, 1989). Cognitive science seeks to explain the information-processing intricacies of human knowledge and reasoning. Knowledge of students' information-processing behaviours can be used to develop science teaching strategies that facilitate the construction of more effective cognitive networks - networks that connect procedural (process) and declarative (content) knowledge in ways most conducive to solving problems, achieving conceptual understanding, and facilitating subsequent learning (Lavoie, 1993).

2.1.2. The Content / Process Dilemma

There has been considerable controversy in science education literature regarding the relative importance of prior, domain-specific, *declarative knowledge* and domain-general, *procedural knowledge*. (Hafner and Stewart, 1989; Kyle and Shymansky, 1989; Linn, 1990; Niaz, 1992).

Millar and Driver (1987) endorse domain-specific knowledge, as they consider that the "process" view of science has not taken adequate account of the influence of the learner's prior knowledge on learning activities. They contend that improvement in problem-solving performance depends not on the exercise of a general skill but on the development of the learner's content specific knowledge (Millar and Driver, 1987, p50).

Burbules and Linn (1991, p238) recommend a "repertoire of problem-solving approaches and scientific methods, and the skill to shift from one to another in light of the question or problem encountered". They suggest that for science to go beyond "the memorisation of facts and formulas", there should be "less of a focus on the content of science learning, and more on the process of investigation, synthesising new information, and elaborating hypotheses" (Burbules and Linn, 1991, p238).

Most science educators do agree that the dichotomy between a too great emphasis on *content* (declarative / conceptual knowledge), as expounded by Millar and Driver (1987), and a too great emphasis on *process* (procedural knowledge), as expounded by Burbules and Linn (1991) is an artificial one (Niaz, 1995, p 419). Instead of being mutually exclusive strategies, the two could very well complement each other. It is in this light that Kuhn, Amsel and O'Loughlin (1988, p20) wrote that prior knowledge guides the search through the hypothesis space and hence shapes the process of scientific reasoning.

2.1.3. Science and teaching of concepts

An especially serious problem for biology education is that too few studies of children's understanding of scientific concepts are part of a co-ordinated research programme. Much research has been done in physical science but little in biology about children's conceptions. Work done in biology has mostly focussed on single concepts (Lucas, 1995, p195/197). This signals that science teaching in schools should consist of a set of unconnected topics which, when learned, are left unreinforced while a new theme is presented. Very few studies look at a complete system of interacting concepts that typifies theory in the sciences (Lucas, 1995, p197). In a study by Gess-Newsome and Lederman (1995, p301) it was found that though most teachers recognised the integrated nature of biology, few used such conceptions to guide practice purposefully.

Science researchers recommend that teachers choose only a few concepts to emphasise, selecting those that will provide a lasting foundation for understanding other information, then orchestrate instruction so that students will encounter these concepts in multiple contexts and in a variety of situations (Rutherford and Ahlgren, 1990). The National Research Council of the United States (NRC, 1990, p6) in this regard also argued that "the high school biology course should be a synthetic treatment of important concepts and of how these concepts can shape our understanding of ourselves and our planet". This ideal was acted upon by the Biological Sciences Curriculum Study (BSCS, 1993, p viii) which called for an "increased concentration on major unifying principles of biology."

2.1.4. Science and the text

Within the science curriculum, the science text-book dominates what is learned and what is taught (Spiegel and Barufaldi, 1994). Current estimates are that 75 to 90% of classroom instruction is structured around textbooks (Lloyd, 1990; Wood, 1988). It is through learning from text that some of the highest goals in science education can be achieved : to think critically, reason logically, and ultimately solve problems (Lavoie, 1993; Ogens, 1991).

Students who have to learn science face an unfamiliar subject area and, in addition, need to acquire science learning skills which may be different from skills needed to learn in other academic areas (Ryan, 1989; Singer and Donlan, 1989). When in addition, science learning takes place through interaction with textually-represented information, the situation becomes increasingly more complex and demanding for the learner.

2.1.5. Science and problem-solving

Hodson (1992), states that "scientific knowledge is sought and constructed not 'for its own sake', but for its value in solving problems" (In Wesso, 1995, p5). Problem-solving ability is closely tied to both the purpose of science, and understanding and performance in science. Researchers such as Marstropieri and Scruggs (1992) have advocated the development of problem-solving and reasoning skills in individuals through science learning activities (In Wesso, 1995, p5). Researchers are currently giving much attention describing the learning of science by focussing on the cognitive processes and procedures that students employ in solving scientific problems. This has led to reasoning and problem-solving performance being viewed as determiners of science learning (Eylon and Linn, 1988).

2.1.6. Outcomes-based education

In South Africa, there is presently an initiative by the Department of National Education to phase in a new emphasis on education by the year 1998. The new approach is known as outcomes-based education (OBE). An outcome is defined as a high quality demonstration of observable or internal integrated learning processes that occurs at the culminating point of a set of varied learning experiences.

The new approach aims to democratise the curriculum decision-making process. It was felt that whatever learning presently takes place is dictated by an ill-defined curriculum, and the pace at which the material is covered is driven by the calender, rather than student need. Such a system is therefore input driven rather than outcome-based.

Seven critical or essential outcomes have been elaborated for OBE, as follows :-

- Identify and solve problems in which responses display that decisions using critical and creative thinking have been made
- Work effectively with others as a member of a team, group, organisation, community
- Collect, analyse, organise and critically evaluate information
- Communicate effectively using visual, mathematical and/or language skills in the modes of oral and/or written presentation
- Organise and manage oneself and ones activities responsibly and effectively
- Use science and technology effectively and critically, showing responsibility towards the environment and the health of others
- Demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation (SAQA, 1996)

It is evident from all seven essential outcomes above that the new approach places strong emphasis on the development of problem-solving capabilities.

With OBE, the traditional subject boundaries disappear with the emergence of 8 learning areas, which are more representative of the real world that the students are a part of. The learning area of relevance to this research is the NATURAL SCIENCES LEARNING AREA. In each learning area a number of focuses/themes will be identified as being relevant. The student will then encounter these focuses over a number of years at school, but at increasingly complex levels.

The Natural Sciences Learning Area Committees (LAC's), set up at National and Provincial level, were then charged with the task of translating the seven critical outcomes of OBE into Learning area outcomes for the Natural Sciences. The Natural Sciences, in the new provision for education, will therefore also promote the development of problem-solving abilities (LAC - Natural Sciences, 1996).

2.2. SCHEMA THEORY

2.2.1. Introduction

Earlier psychological conceptions of learning and cognition were dominated by behavioral learning theories and traditional cognitive theories.

The behavioral tradition emphasised a mechanistic conception of learning where stimuli acted as forces which forced the learner to engage in various behaviors. The learner was not self-activated and only responded to environmental forces. Prior knowledge influenced new learning mainly through indirect processes such as positive or negative transfer because of similarity of stimuli between situations (Andre and Phye, 1986, p2).

The traditional cognitive view held that thinking and mental activity were the fundamental facts of human existence, and hence the basis around which adequate psychological theories of cognition and learning were to be built. The learner was seen as being actively involved in trying to understand the environment. New learning was based on using prior knowledge to understand new situations and changing prior knowledge structures to deal with new situations (Andre and Phye, 1986, p2/3).

The cognitive information-processing (CIP) view represents an integration of the behavioral and traditional cognitive positions. It holds that learning and behaviour emerge from an interaction of the environment and the previous experience and knowledge of the learner. The learner both responds to and acts upon the environment.

According to the cognitive information-processing view, learning is seen as the formation of associations among mental structures called schemata, as well as the acquisition of new schemata. Discussion of the processes occurring in the mind is central to this view. Frequent use is made of informal observations and logical analyses of mental activities for the generation of hypotheses (Andre and Phye, 1986, p3).

The general approach of the CIP view provides educators with a way of describing goals that goes beyond mere changes in behaviour. Rather, it suggests that the goals of education are to make changes in the cognitive structures (schemata) of students. Schools attempt to produce in students cognitive structures that provide them with socially common knowledge and ways of analysing and dealing with problems (Andre and Phye, 1986, p16).

2.2.2. Cognitive Processing

In the construction of a theory of human behaviour, cognitive scientists use what is generally referred to as information processing models. Such models attempt to describe how information is stored in memory, how transformations of this stored information may occur, and how stored information is retrieved for use in further learning and problem-solving (Stewart, 1985). Since all of these are the object of consideration in the schema theory, an outline of human cognitive processing is necessary here.

During problem-solving, information from the written materials is received by our sensory register, which functions in perceptual processing, pattern recognition and feature extraction (Stewart, 1985). The perceived information is then processed in the working memory, where higher order learning operations are carried out. Working memory is a limited information store which retains the immediate interpretation of events, and holds information while reorganisation and storage occur in long-term memory.

Since only a few operations can be performed concurrently in the working memory, its processing capacity is limited to the amount of information a person can simultaneously co-ordinate during problem-solving (Pulos, 1993). It has thus been suggested that a smaller working memory may lead to poorer performance in tasks of higher cognitive functioning, such as reading.

One way in which problem-solvers overcome the limits of processing capacity when dealing with complex knowledge is by "chunking". Miller (1956) introduced the term "chunks" to refer to the discrete units of information that could be consciously held in working memory and transformed and integrated. He proposed that a maximum number of these chunks is approximately seven. Mandler (1967) developed a different definition of processing capacity and identified it as five. Subsequently, Simon (1974b) suggested another definition which places emphasis on the time required to memorise a chunk.

To facilitate higher order concept acquisition, chunks of information are assembled in the mind into a higher order chunk or unit of information. Chunking reduces the load on mental capacity and simultaneously opens up additional mental capacity that allows the acquisition of still more complex and inclusive concepts (Lawson, 1994).

Once information has been processed in short term memory, it is rehearsed, integrated in various ways with the information in long term memory, and then stored in long term memory for future use (Britton, Glynn and Smith, 1985). Long term memory is virtually unlimited in its capacity for storing categorised, hierarchically organised information. A set of executive processes allows for and monitors the interaction between the working memory and long term memory, such as during information storage and retrieval (Glynn, Yeany and Britton, 1991).

When reasoning in working memory about a phenomenon, the student draws upon relevant facts, principles and skills stored in long term memory. When reading text materials, besides skills in a particular domain, the student needs to access reading skills to construct the intellectual products in working memory (Glynn and Muth, 1994). Component reading processes involved in text comprehension include word recognition, lexical access (accessing word meaning in a mental dictionary), semantic and syntactic analysis, text integration, inference, identification of text relations (patterns), and elaboration (connecting new and existing information) (Glynn and Muth, 1994; Just and Carpenter, 1987).

In addition to reading skills, a number of memory management operations are required to facilitate comprehension. These operations include "prefetching" (activation of text relevant information and schema in advance of reading), and "demand fetching" (the activation that occurs during the course of reading) (Britton et al., 1985).

Processing of information in short-term memory may be either automatic or controlled. Controlled processing involves the conscious processing of information, frequently referred to as working memory. Automatic processing involves over-learned schema or sequences stored in long-term memory. Once activated, automatic processing occurs independently of a learner's conscious control. These automatic sequences located in long-term memory were originally learned via conscious effort i.e. through controlled processing. Because a controlled process utilises short-term store in working memory, it is capacity limited. (Phye, 1986, p145). A consistent finding from expert-novice research is that many aspects of experts' problem-solving processes have become relatively routine or automatic. This frees attentional capacity so that other activities can take place at the same time (Bransford, Goldman and Vye, 1990, p15).

2.2.3. The Schema theory itself

According to schema theory, the use of past experience to deal with new experience is a fundamental feature of the way in which the human mind works. The schema theory also contends that the knowledge we have stored in our memory i.e. prior knowledge, is organised as a set of schemas (Cohen, Eyesenck and Le Voi, 1986, p26). A schema may be considered a kind of cognitive structural representation of something that can be defined as a whole or complete entity - classes of objects, events, situations (Mandler and Johnson, 1977, Stein and Glenn, 1979; Steffensen, Joag-Dev and Anderson, 1979). The original notion of a schema dates back to the cognitive psychologist Sir Frederick Bartlett (1932), the physiologist Sir Henry Head (1920) and more indirectly back to the philosopher Immanuel Kant (1781), who argued that concepts only had meaning insofar as they could relate to knowledge the individual already possessed (in Leahey and

Harris, 1985, p193).

The above notion of a schema situates the schema theory within a constructivistic framework. The constructivistic view of learning and memory holds that the derivation of meaning from language involves an interaction between a message and a person's knowledge and experience. We do not receive the meaning of a message. Instead, we must construct a meaning by interpreting a message in the light of our own knowledge. The constructivistic interpretation of learning and memory is at the core of the cognitive explanation of understanding. Something is understood when it has been integrated in a meaningful way into the learner's existing knowledge structure. When the learner does not have any relevant knowledge that can be used to construct an interpretation of a message, memorisation may occur, but understanding will not (Royer, 1986, p87).

According to the schema theory, schemata contain sets or placeholders into which particular instances can be instantiated. When information is encountered, as in reading, a person comprehends it by filling the slots of the appropriate schemata. All the information required is not directly present and hypotheses/inferences must be continually made to instantiate the schemata in order to make sense of incoming information (Rubin, 1977; Collins, Brown and Larkin, 1980). A reader who has a well elaborated schema about a topic can more easily instantiate newly acquired information into that schema. As a result processing can proceed more rapidly. The process of reading thus implies that textual input is mapped against existing knowledge structures (Rumelhart and Ortony, 1977).

This encoding of new information in terms of existing schemata is called accretion. Sometimes tuning, or schema evolution occurs when a schema is modified in the light of new information or as a result of using it in different situations. Further still, restructuring may occur by which new schemata are created (Shuell, 1990, p538).

Although there is a lot of variability about the way the term schema is used, most schema theorists agree with four basic principles of how schemata become involved in the encoding process :-

- *Selection* : Two factors are relevant in determining the selection of information for encoding. One is simply whether or not an appropriate schema already exists in memory. If no relevant schema is available, both comprehension and memory will be poor. Further, if some people have more information available than others, such as a rich network of schemata, they will comprehend and remember more than those with less knowledge (Leahey and Harris, 1985, p194/5).

  A second reason that the appropriate schema might not be available would be that it may not be activated from long-term memory, even though it may exist there (Leahey and Harris, 1985, p194/5).

- *Abstraction* : This is a process by which details tend to be lost in a reduction of information into main points, with the schema indicating relative importance of different pieces of information.

- *Interpretation* : This results from the elaboration during or just after encoding. One major characteristic of schemata is that they have slots or variables where specific information is "filled in" when the schema is instantiated, that is, when it is used to accept or retrieve information about a particular instance.

- *Integration* : This is a process by which information is combined into relatively holistic representations. Inferences are drawn to relate previously unrelated information. Even the schemata themselves may be integrated, embedded within each other, thus allowing for a hierarchical structure of schematic information (Leahey and Harris, 1985, p195).

During encoding the student has to analyse written information from the text materials. This is known as bottom-up processing or data-driven processing since it relies on data received by the senses from the written materials. Information received in this way is often incomplete and ambiguous. The use of information stored in memory in the form of prior knowledge is known as top-down or conceptually driven processing (Cohen et al., 1986, p26). In practice, the two sorts of processing operate in combination. Specific incoming data instantiate the schemata through bottom-up processing, while top-down processing facilitates their assimilation to the extent that they are consistent with the reader's anticipations. This is known as interactive processing, and has been expressed by Vygotsky as the interaction between the systemic and logically organised *scientific concepts* of the child with the unsystematic and highly contextual *spontaneous concepts* from everyday experiences (Landa, 1976, p278).

In an attempt to understand the role of prior knowledge in reading / problem-solving, a distinction has been drawn between formal schemata (background knowledge of the formal, organisational structure of the text), and content schemata (background knowledge of the content of a text). When a reader is unable to activate an appropriate schema, this could be attributed to the lack of structural/linguistic clues in the text to allow for effective bottom-up processing or to inadequate content clues (Sinclair, 1985, p8).

Since a schema provides general knowledge about objects, events etc., its vagueness decreases its usefulness. One more specific form of a schema is a *frame* which consists of general knowledge about the properties of particular objects and locations. (Cohen et al., 1986, p28). The frame as a form of mental representation was put forward by Marvin Minsky as part of his Frame-system theory. (Minsky, M., 1977, p355). A frame is a data-structure for representing a stereotyped situation. Attached to each frame are several kinds of information. When one encounters a new situation, the selected frame may be adapted to fit reality (Minsky, M., 1977, p355).

If the broad schema from earlier becomes more specified to include general knowledge about particular kinds of events, then they are called *scripts*. (Cohen, et al., 1986, p28). Schank and Abelson (1977, p421) introduced the term "scripts" and "plans" as a refinement of what they regarded as Minsky's too general "frames". A script is a structure that describes an appropriate sequence of events in a particular context. Scripts handle stylized everyday situations and are not subject to much change. Scripts make it possible for inferences to connect each input conceptualisation in a story to all others that relate to it. Scripts also facilitate the organisation of new inputs in terms of previously stored knowledge (Schank and Abelson, 1977, 423/425).

Plans as opposed to scripts, are responsible for the deliberate behaviour that people exhibit. Plans describe the set of choices that a person has when he sets out to accomplish a goal. A plan can also be regarded as a series of actions that will realize a goal (Schank and Abelson, 1977, p428).

2.3. PROBLEM-SOLVING

2.3.1. What is problem-solving?

A *problem* is a situation in which the individual wants to do something but does not know the course of action needed to get what he or she wants (Newell and Simon, 1972; Andre, 1986, p170). *Problem-solving* usually refers to behaviour and thought processes directed toward the performance of some intellectually demanding task (Nickerson, Smith and Perkins, 1985, p65).

Problems differ both in difficulty and in the nature of the skills required to solve them. (Nickerson et al., 1985, p66). Furthermore, a problem can sometimes be solved in radically different ways. Firstly, by an analytic approach, a solution is arrived at which suffices to answer the specific question that was asked, but does not generalise readily to related cases. This approach equates to a kind of thinking that the Gestalt approach calls *reproductive thinking*, because old habits or behaviours are simply reproduced as the problem-solver simply applies past solutions to a problem (Mayer, 1983, p36).

Secondly, by an intuitive approach, a solution is reached which has considerable generality. It applies beyond the immediate problem to a whole class of problems. Something of an insight seems to be required (Nickerson et al., 1985, p67). This approach equates to a kind of thinking that the Gestalt approach calls *productive thinking* wherein a new organisation is produced (Mayer, 1983, p36).

2.3.2. Stages in problem-solving

There have been many attempts to break the thinking process down into several smaller stages. Wallas (1926) suggested four stages :-

- Preparation - involving the gathering of information and preliminary attempts at a solution
- Incubation - which involves putting the problem aside to work on other activities or sleep
- Illumination - occurs when the key to the solution appears

- Verification - entails checking out the solution to make sure it "works"

More recently, Polya (1957) has introduced a series of steps in problem-solving. Polya's four steps are :-

- *Understanding the problem* - the solver gathers information about the problem and tries to establish what is given from what is required.

- *Devising a plan* - the solver tries to use past experience to find a method of solution. This may involve restating the goals or the givens in a new way and thus involves "working backwards" or "working forwards"

- *Carrying out the plan* - the solver tries out the plan of solution, checking each step.

- *Looking back* - the solver tries to check the result by using another method, or by seeing how it all fits together.

Polya's steps are similar to Wallas' in general form. Polya's "understanding" step is similar to Wallas' preparation phase, his "devising a plan" step includes some of Wallas' preparation phase and both the incubation and illumination phases, and the "carrying out the plan" and "looking back" steps relate to Wallas' verification (Mayer 1983, p 44/45).

A number of theorists argue that there are a variety of components of the problem-solving process that should be emphasised during training. Five such components have been emphasised in Bransford and Stein's (1984) IDEAL approach : *i*dentify, *d*efine, *e*xplore, *a*ct, *l*ook and learn. (Vye, Delclos, Burns and Bransford, 1988, p351). A number of programs aimed at improving intelligence places strong emphasis on developing metacomponents of thinking and problem-solving.

The Instrumental Enrichment Program of Feuerstein, Rand, Hoffman and Miller (1980) describe one of the goals of the program as the production of insight as to the importance of various metacognitive processes. This constitutes an effort to improve individuals' understanding of relationships between particular strategic actions and problem-solving outcomes.

Sternberg's (1986) Intelligence Applied program places the strongest emphasis on the issue of metacomponents. Much of Sternberg's training is aimed at increasing students' abilities to identify potential problems during the planning stages of problem-solving to understand how different definitions of problems lead to different strategies, and to monitor the effects. Sternberg explicitly describes each metacomponent, whereas Feuerstein et al. (1980) places more emphasis on specific cognitive operations (Vye et al., 1988, p354/355).

2.3.3. Prior Knowledge and Problem-solving

Resnick (1984) states that prior knowledge organised into schemas comes in various forms :-

- specific knowledge about the topic of the text,
- general world knowledge about social relationships and causal structures and,
- knowledge about the organisation of text

To this list, Paris, Lipson and Wixson (1983) adds the levels of knowledge that students need about strategies : declarative, procedural and conditional.

A major conclusion from research is that high level expertise requires a great deal of domain-specific knowledge. Experts do not simply have more knowledge about an area than novices, they also seem to have organised that knowledge in ways that are qualitatively different (Bransford, Goldman and Vye, 1990, p15).

Recent studies of problem-solving ability across a variety of scientific domains have demonstrated what Novak (1977, p217) had already concluded in 1964 : that "problem-solving ability is dependent upon the adequacy of specific relevant concepts in the student's cognitive structure". Smith, M.U. (1991) found that :-

> "the performance of the solver is determined by the relevant knowledge that he has and its accessibility. First, an adequate, well organised, and easily accessible conceptual/schematic knowledge of the relevant content domain is required. This knowledge serves as the basis upon which the solver analyzes the problem, reasons toward a solution, and assesses the appropriateness of the solution".

This view reinforces that of Kintsch (1991) who believes that prior knowledge is a significant factor in problem-solving and comprehension of text. Research in these two areas have acknowledged the role of both declarative (conceptual) and procedural knowledge (eg. Baumann and Schmitt, 1986; Greeno and Simon, 1984). Declarative knowledge, or *knowing about*, represents the problem-solvers schemata or existing knowledge for concepts and generalisations about a topic. Procedural knowledge, or *knowing how*, is the set of skills and strategies the problem-solver possesses for reaching a solution.

Acquiring procedural knowledge does not ensure that declarative knowledge will be acquired and vice versa. There is therefore a need to develop instruction that leads to both procedural and declarative knowledge and not to the slighting of one for the other (Andre, 1986, p191).

With these two types of knowledge, Ruddel and Speaker (1985) depicted the interaction of a third type of knowledge in a theoretical model they developed : conditional knowledge. The problem-solvers conditional knowledge enables him or her to know when to apply which knowledge and for what reason.

Numi (1994) found ample evidence to suggest that prior knowledge of the readers acts both as a facilitator and barrier to problem-solving in reading. Readers who used their knowledge directly or indirectly, to resolve problems, found such knowledge useful and were likely to deal with the problems successfully. However, the same knowledge at other times constrained the readers and misled them or led to distortion or confusion in interpreting the textual item (Numi, 1994, p118). In another study, Champagne, Gunstone and Klopfer (1983, p178) found that it was not the students' lack of prior knowledge that made the learning of "mechanics" difficult, but rather their conflicting knowledge.

Glaser (1984) noted that initially problem-solving and thinking was considered in terms of sequentially activated skills not tied to a particular domain of knowledge. He observed the later emergence of a new perspective - one that emphasises an integral connection between the cognitive activity of problem-solving and thinking, and knowledge within a specific content area. From this perspective, problem-solving is not thought of as a domain-free set of cognitive activities, but instead is linked, and perhaps even restricted to, a particular domain of knowledge. This domain-specific view of problem-solving and thinking is linked to cognitive theory whilst the domain-free perspective was linked to learning theory (Royer, 1986, p88).

A large body of research (e.g. Glaser, 1984) provides strong support for the notion that effective problem-solvers rely heavily on domain specific knowledge. Feuerstein in his Instrumental Enrichment program, argues that one of the "deficient cognitive functions" that commonly hampers performance, is the lack of conceptual and verbal tools necessary to think effectively about particular domains of inquiry. He also emphasises the importance of "efficiency" in being able to access and use these tools. Feuerstein avoided the use of domain-specific knowledge and thus avoided this bottleneck in problem-solving. The disadvantage, however, is that applications of strategies and skills learned in these environments may not be transferred to specific academic areas (Vye et al., 1988, p356/7).

Sternberg's Intelligence Applied program also acknowledges the important role of specific knowledge in problem-solving. Sternberg argues that, because knowledge is so important in problem-solving, it is imperative that students learn how to acquire new knowledge on their own. He emphasises three processes that are important for acquiring new information : *locating* the important information to be learned, and *combining* and *comparing* it with existing knowledge in order to make it more meaningful (Vye et al., 1988, p358).

The trend during the 1980's has been toward the integration of thinking instruction in the content areas (e.g. Jones and Idol, 1990; Resnick and Klopfer, 1989; Schwartz, 1987). Even current theories continue to imply rather extreme domain specificity (Holyoak, 1991). Prior to this teachers were expected to form "bridges" for their students that made clear how various strategies may be applied in a specific content area. The new integrated approach however can be viewed as an effort to systematise the "bridging exercises" that theorists such as Feuerstein believe are crucial to overall success (Bransford et al., 1990, p21).

2.3.4. Reading and Problem-solving

A number of researchers conceived the notion of reading being akin to thinking and thus characterised reading as "getting", and viewed its purpose to stimulate a reader's thinking powers (Stauffer, 1969, p8).

According to Gates (1949), reading is not a simple mechanical skill but rather an essentially thoughtful process. He goes on to say that it should be developed as a complex organisation of patterns of higher mental processes, and that it should embrace all types of thinking, evaluating, judging, reasoning, imagining and problem-solving (In Stauffer, 1969, p9).

Current views on reading are in line with earlier views of its relationship with thinking. The reading process is considered to be an interactive social event that involves internal regulation, is influenced by context, and utilises higher order thinking processes such as analysis, synthesis and evaluation (Bloome, 1991; Carey, 1986).

The kinship between reading and thinking has motivated several authors to advocate that reading may be one of the best media for cultivating techniques of thinking (Flynn, 1989; Stauffer, 1969). It is evident that reading and thinking are mutually dependent, such that each one supports and contributes to the development of the other.

Stauffer (1969) likens purposeful reading to problem-solving in that both involve three phases :-

- confrontation by a problem,

- reading to find a solution and

- finding or failing to find a solution

This reading / problem-solving connection was shared by Thorndike (1917) who felt that understanding a paragraph is like solving a problem. It consists in selecting the right elements of the situation and putting them together in the right relations, and also with the right amount of weight of influence or force on each. He further elaborated that during this process the mind has to select, repress, soften, emphasise, correlate and organise, all under the influence of the right mental set or purposes or demand (In Wesso, 1995, p4).

Knowledge is sought and constructed from written materials not as an end in itself. Rather, as many authors have stated, it is a means of improving a student's ability to think critically, reason logically, and ultimately, solve problems. Models of students' cognitive processing as they reason about phenomena and as they process text, may help one to understand how reading can serve as a conceptual tool for helping students to engage in complex reasoning and problem-solving activities (Wesso, 1995, p1/2/6).

In a study carried out by DiGisi and Willet (1995, p123) it was found that biology teachers viewed both reading and inquiry activities as important to learning biology, but they appeared unsure of how to incorporate reading comprehension strategies into their science instruction. Reforms in science education neglect learning science from reading, yet scientists and science educators agree that reading all types of materials is an essential component of doing science (DiGisi and Willet (1995, p123). It has been suggested, that in some schools, textbooks drive the science curriculum rather than the reverse (Woodward and Elliott, 1990) and that text-book use promotes the memorisation of facts and details rather than fostering authentic scientific behaviour (Armbuster, 1992/3).

Polya (1957), in outlining various stages in problem-solving, listed "understanding the problem" as the first phase. Good reading comprehension depends on the employment of effective reading strategies and is essential in grasping the essential aspects of any problem. (Mayer, 1983, p44/45).

The use of certain strategies by itself is not a guarantee that a reader will be successful in dealing with reading problems. In other words, it is what supports the strategy that is crucial. A strategy is only efficient to the extent that the requisite factors that make it operational are available and are positively resourceful (Numi, 1994, p118). Some strategies commonly used by readers shall be briefly reviewed here.

○ *Underlining*

Underlining is one of the strategies that could help the reader selectively attend to the problem statement. Underlining may be useful in locating the components of the problem that may be important, such that more attentional resources can be expended on these critical features, whilst other non-critical features can be ignored (Piontkowski and Calfee, 1979). Several studies (e.g. Idstein and Jenkins, 1972; Stordahl and Christensen, 1956) have failed to produce a special advantage for underlining. Rickards and August (1975) however, have found underlining to be beneficial when limits were placed on how much underlining could be done.

○ *Asking questions*

Asking questions is sometimes useful in that it forces one to try to make explicit what one might otherwise take for granted. Attention to the problem at hand can be influenced by the questions teachers ask students or the learners ask themselves (Osborne and Wittrock, 1983, p499). Fraze and Schwartz (1975, p 628-635) stress the importance of encouraging students to ask themselves questions. They believe that this would encourage students to develop strategies to direct their own study.

○ *Re-reading*

Studies show that when good readers are working with text books and other complicated material, they frequently re-read sentences and paragraphs to get the full meaning (Whimbey and Lochhead, 1982, p139).

The first reading of a problem statement, for example, may allow one to get an overview of the problem, whilst a subsequent reading would help one to focus on the essence of the problem. This seems to indicate a planned and systematic approach to problem-solving.

○ *Making logical inferences*

The inability to make inferences prevents the problem-solver from accessing all the information needed to obtain a solution. This probably stems from a deficiency in the strategies which serve to promote the gathering of relevant information. Hansen (1981) and Hansen and Pearson (1983) helped students to learn to draw inferences by teaching them how to integrate prior knowledge and text knowledge. Deliberate, conscious attempts therefore, can be made in teaching inferential strategies.

The "Knowledge as Design" paradigm of Perkins (1985, p5/6) proposes four questions that could be used to promote understanding of a design. These include : a) the purpose of the design, b) structure of the design, c) model cases of it, and d) arguments that explain and evaluate it. Teaching and learning within this perspective could transform the student into a strategic reader who is able to connect information into a coherent structure that facilitates logical inference.

2.3.5. Search Strategies / Problem-solving strategies

Search processes refer to the mental operations that problem-solvers employ to think about the representation of goals and givens to try to transform the given into goals. Two such search processes, viz. *algorithms* and *heuristics* shall be considered in terms of its value in finding a solution (Andre, 1986, p181).

2.3.5.1. Algorithms

Algorithms are specific procedures that are guaranteed to produce a solution so long as the algorithm is relevant to the problem. It can be regarded as a step-by-step prescription for accomplishing a particular goal. Algorithms usually represent the last phase of problem-solving. When we use an algorithm we are usually pretty sure that the approach will work (Andre, 1986, 181/182).

With the sole use of an algorithm as a search process, a correct solution will be arrived at, but this does not demonstrate that the problem-solver was able to conceptualise the problem and hence reach a solution with understanding.

Algorithms have three properties (Landa, 1976) :-

- Specificity : all of the actions of any problem-solver are completely specified so that all solvers use the same series of steps to arrive at the same answer.

- Generality : the algorithm will function to solve any problem in a class of problems.

- Resultivity : with proper input data, any problem in the class that the algorithm was designed to solve will always be solved correctly.

In spite of the pejorative connotation often attached to algorithmic problem-solving, it has some potential to help students increase the meaningfulness of their conceptual knowledge, especially if used in combination with other search processes (Stewart, 1988, p241/242).

2.3.5.2. Heuristics

Heuristics are rules of thumb that problem-solvers have found useful. Heuristics indicate likely directions to pursue or approaches to follow. They may lead to a problem solution, but are not guaranteed to do so (Andre, 1986, p181). It facilitates in a specific way the recall and organisation of knowledge and operations which can be of use in finding a solution to a problem. It does this by allowing the problem-solver to become more active and thus more independent in the problem-solving process. This independence allows the problem-solver to become more creative in the search for a solution (Landa, 1976, p166). It is this creative aspect of problem-solving that makes a heuristic different from an algorithm. It is also this creative aspect that allows the problem-solver to significantly reduce the number of possible search paths to a solution (Landa, 1976, p115). The problem-solver is taught to think about his thinking and thus to monitor his own progress, giving this approach a metacognitive flavour.

Furthermore, the heuristic approach stresses that to be a successful information processor/problem-solver, one needs to have knowledge as well as the ability to manage one's intellectual resources effectively. It is thus clear that knowledge representation forms such as schemas, frames and plans, amongst others, would significantly influence the ability to intuitively reduce the number of search paths to the solution of a problem. This is achieved by possessing what Schoenfeld terms "managerial skills" (Nickerson, et al., 1985, p195).

The more general a heuristic is, the more independent and creative is the thinking that is required of the problem-solver. Conversely, the more specific a heuristic becomes, the lesser the flexibility and creativity that is allowed to the problem-solver, and the procedure becomes more algorithmic than heuristic (Landa, 1976, p167). Through the use of a heuristic a problem-solver creates the conditions necessary for efficient retrieval of information from the relevant schemas in storages. The retrieved knowledge and elicited skills then direct the action of the problem-solver towards a solution (Landa, 1976, p167).

Polya (1957) developed heuristics for use in mathematical problem-solving. Because of the generality of these heuristics, they are applicable more generally to problems in other disciplines too. Polya's heuristics can be considered within his prescriptive model of problem-solving, which distinguishes four stages, which were introduced in some detail earlier when various stages in problem-solving were considered. Polya provides heuristics for each stage in the problem-solving process (Nickerson et al., 1985, p75). Newell and Simon (1972), attempted to develop a general theory of human problem-solving. The heuristics developed by Newell and Simon also cater for the various stages of problem-solving expounded by Polya (Nickerson et al., 1985, p79).

The extent to which the heuristics developed in one context are likely to be applicable in other contexts remains questionable. Furthermore, it has been argued that if training with respect to heuristics is to be effective, it must focus not only on the heuristics themselves but on their implementation in a variety of contexts so as to promote transfer (Nickerson et al., 1985, p82).

The heuristics approach attributes great importance to finding a good representation for a problem. A case can be made that every heuristic essentially works by altering one's problem representation. An alternate method of representing a problem allows the problem-solver to see the problem from a different perspective. Moreover, not all representations of the same problem are necessarily equally conducive to solutions. (Nickerson et al., 1985, p83/4). Kotovsky, Hayes and Simon (1985), and Kotovsky and Simon (1990) published an extensive series of studies examining why two isomorphic problems can vary in difficulty. They demonstrated that limitations on temporary memory were a primary source of difficulty and that some problem representations help us circumvent this limitation more than others do. Good representations allow us to represent blocks of planned moves as a single "chunk" of memory. They also allow us to represent our position in the problem space more efficiently (Lesgold, 1988, p195).

Whimbey and Lochhead identified and described methods that good problem-solvers use by studying expert and novices involved in problem-solving (Nickerson, et al., 1985, p206). It is from this experience that they developed an approach where students are asked to work in pairs. This approach is called the peer-pair problem-solving technique. One member of the pair takes on the role of problem-solver and the other the role of listener. They are then required to switch roles for the subsequent problem. The problem-solvers role is to read the problem aloud and to continue talking throughout the entire solution process. The listeners role is to keep the problem-solver talking and to continually probe for more detailed descriptions of the problem-solver's thought process. The listener must not solve the problem or give hints to the problem-solver; his function is solely to demand greater clarity (Lochhead, 1987, p177/178).

Metacognitive awareness and reflection are important aspects of effective problem-solving, but it is a difficult skill for students to sustain when they are worrying about the problem at the same time. Peer-pair problem-solving splits metacognitive awareness into two roles; that of problem-solver and listener. The social process of reflection achieved in pairs is then internalised by the student and thus made personal. Perkins expressed this idea of social reflection aptly when he stated that "the need for the two to communicate captures thoughts that otherwise would stream by in the rapids of moment-to-moment cognition" (Perkins, 1992, p142).

This social-interaction perspective of Whimbey-Lochhead's approach seems to be in contrast with Piaget, who feels that learning occurs in an unassisted interaction between the child's mental schemas and the objects of the external world. This approach, however, is in keeping with Vygotsky's view that a child is neither a passive recipient of knowledge offered by the teacher, nor an independent thinker who arrives at his or her own solutions, but rather a participant in learning activities shared by children and adults (Kozulin, 1994, p273/274). Furthermore, Vygotsky stated that what children can do with the assistance of others, and this he called the "zone of potential development", might be in some sense even more indicative of their mental development than what they can do alone (Naude, 1987, p32).

There are several advantages associated with the peer-pair problem-solving technique that helps develop metacognitive skills in the individual and thus makes it heuristically useful.

Firstly, thinking aloud slows down the thinking process, making it more explicit and more accurate (Whimbey and Lochhead, 1984, p2). Thinking is a "hidden skill", but by thinking aloud one exposes one's own thought process to oneself and to others, making it possible for one's approach to be analysed and criticised (Whimbey and Lochhead, 1982, p21) (Nickerson et al., 1985, p209). Vocalizing one's thoughts forces one to be more careful and thorough in analysing ideas (Whimbey and Lochhead, 1982, p23). This approach therefore allows for the development of good analytical reasoning abilities.

Secondly, learning to become a good listener allows one to learn from other peoples' reasoning skills and to pay more careful attention to one's own methods of thought (Whimbey and Lochhead, 1984, p2).

Thirdly, by being able to analyse one's own method of thought, one would be able, not only to locate errors in one's reasoning, but also to find the reason why they were made, so that there is less chance of making the same kind of mistake again. (Whimbey and Lochhead, 1984, p2).

2.3.6. Expert versus Novice problem-solvers

Researchers have often characterised the difference between expert problem-solvers and novices in the hope that techniques can be developed for intervention so as to transform novices into experts.

An expert is defined as any individual who is highly skilled or knowledgeable in a given domain (Bruer, 1993, p8). This suggests that expertise depends on well organised, domain-specific knowledge that arises only after extensive experience has been gained in a particular area.

Whimbey and Lochhead identified four ways in which problem analyses and reasoning processes of novices break down :-

- failure to observe and use all relevant facts
- failure to approach the problem in a systematic step-by-step manner
- failure to spell out relationships fully
- sloppiness and inaccuracy in collecting information and in carrying out mental activities (Nickerson et al., 1985, p207).

Whimbey and Lochhead stress that this resulting lack of accuracy and thoroughness in thinking is the primary source for errors in problem-solving (Nickerson et. al., 1985, p207). They feel further that novice problem-solvers are not aware of how they solve or fail to solve problems, and that they do not need to be taught methods which they follow in an almost mindless fashion, but rather they need to be taught to think about whatever method they happen to choose (Lochhead, J., 1987, p176). This suggests the need for what Perkins (1989, p7) refers to as reflective intelligence, which he describes as the general moves one employs to direct ones thinking. Lochhead (1987, p176) states that a problem-solver who reflects upon his method can learn from mistakes and make progress even when guided by faulty intuitions.

Through the peer-pair method of listening to experts solve problems, Whimbey and Lochhead expounded five characteristics of good problem-solvers, viz :-

- positive attitude
- concern for accuracy
- breaking the problem into parts
- avoiding guessing
- activeness in problem-solving (Nickerson et al., 1985, p207).

When learners encounter new information, they need to restructure their knowledge. In restructuring knowledge, experts represent relations among concepts different from the relations that novices represent among them. Patterns among these new relations motivate the creation of new abstract concepts and schemata that are either not represented by novices at all or are not very accessible to them (Carey, 1986; Chi, Glaser and Rees, 1982; Smith, E.L., 1991).

Stewart and Van Kirk (1990), from studies involving genetics, state that expert problem-solvers :

- use strategies which are more domain-dependent, forward-working, and knowledge-producing;

- show an initial devotion to qualitative analysis, including the development of representations of the problem at both empirical and theoretical levels;

- apply discipline-dependent principles as part of the problem-solving method; and

- structure their knowledge hierarchically.

Novice problem-solvers on the other hand:

- access principles sequentially in an unplanned manner;

- take a formula approach to problem-solving; and

- use general heuristics that are applicable to a wide range of problems.

(Stewart and Van Kirk, 1990, p 575/588).

Chi, Feltovich and Glaser (1980) found that novices tend to rely on the superficial features of the problems, possibly because they lacked appreciation of what information was relevant for solving the problem, while experts tended to categorise problems using the essential information required to generate a solution. It is argued that experts have planning knowledge not held by novices, knowledge which facilitates their problem-solving (Linn, 1986, p165).

A recent study of biology problem-solving by Hurst and Milkent (1996) detected a clear difference in skill use patterns between experts and novices. The experts were found to employ a systematic problem-solving approach, evaluating a number of alternative solutions, and reviewing their answer for logical inconsistencies. They were also able to apply cause-effect relationships and other declarative knowledge relevant to the problem.

Novices in the same study were less-able to identify cause-effect relationships or to retrieve relevant knowledge from memory. Even when they had the necessary content knowledge, they were not able to apply it correctly. They also approached the problem haphazardly, seldom evaluating more than one possible solution (Hurst and Milkent, 1996, p548).

Can the status of novices and experts sometimes be reversed? Dole et al. (1991) state that all readers, both novices and experts, use their existing knowledge and a range of cues from the text and the situational context in which the reading occurs to build or construct a model of meaning from the text. According to this view, even novice readers can behave like experts when presented with texts and tasks for which they possess appropriate knowledge. Conversely, even expert readers can be reduced to novices when presented with obscure or ambiguous texts.

Research on expert-novice differences has mainly focussed on how experts solve familiar problems. Far less is known about the skills and knowledge used by experts when they are confronted with novel problems within their area of expertise. Research shows that even when domain knowledge is lacking, experts solve a problem within their area of expertise by dividing the problem into a number of sub-problems that are solved in a particular order. The lack of domain knowledge is compensated for by using abstract knowledge structures and domain-specific heuristic strategies. When experts solve novel as opposed to familiar problems, it was found that the form of their reasoning remains intact, but the content of their reasoning suffers due to a lack of domain knowledge (Schraagen, 1993, p285).

3. RESEARCH METHODOLOGY

My personal experiences as a secondary school biology teacher as well as comments from colleagues indicate that students experience severe difficulties in solving genetics problems. Difficulties of students in solving genetics problems were also identified by a number of researchers (Tolman, 1982; Kinnear, 1983; Smith and Good, 1984); Thomson and Stewart, 1985; Hackling, 1986; Chetty, 1995). It is against this background that the three problems included in APPENDIX 8.1. were chosen for a problem-solving exercise in this research.

Genetics is widely recognised as being a conceptual foundation for the understanding of evolution and thus biology itself. In this regard, Dobzhansky (1983, p1) remarked that "Nothing in Biology is understandable except in the light of genetics". Furthermore, results from previous genetics-learning studies and need assessments demonstrate the need for more intensive research in biology education in general, and genetics learning in particular (Simmons and Lunetta, 1993, p153).

Genetics problem-solving research initially focussed on describing the procedural and conceptual knowledge required to allow problem-solvers to reason from causes to effects. In this type of research, many students were found to be able to obtain correct answers without being able to justify them (Finkel, 1996, p346). This led to a conclusion that "correct answers do not necessarily measure students' understanding of genetics"(Stewart and Hafner, 1994, p286). Much genetics research has focussed on the differences between expert and novice problem-solvers (eg. Smith and Good, 1984; Hafner, 1991; Simmons and Kinnear, 1991; Simmons and Lunetta, 1993).

Although problem two in APPENDIX 8.1. involved a monohybrid genetics cross, and was the focus of the problem-solving exercise, problems 1 and 3 which are related to genetics were also included. This decision was firstly guided by research conducted by Finley, Stewart and Yarroch (1982) where they attempted to investigate teachers' perceptions of important and difficult science content. They found that Mendelian genetics and the chromosome theory of heredity were found to be both difficult and important for students to learn. In addition there were content areas that are a part of genetics, such as meiosis and reproduction, that were judged difficult for students to learn. The three problems chosen, together involve a number of intersecting biological concepts. It was envisaged that more valuable information would be obtained about students' conceptual understanding by using three different but conceptually similar problems.

A second rationale for including three problems is its correspondence with three major topics that students encounter in Standard nine, viz. MEIOSIS, GENETICS, and PLANT REPRODUCTION. This, it was hoped would give students a fair opportunity at displaying their problem-solving ability rather than the restricted possibilities offered by a single problem. Also, any generalisations about a students' approach to problem-solving could be more reliably made using three problems as opposed to one.

A third rationale for the inclusion of three problems was the different form in which each problem was represented. It was meant to represent as wide a variety as possible of the representation types which students encounter when they solve problems. It was also hoped that some relationship could be established between students' preference for a particular representation type and their performance in a problem involving that particular representation type. Furthermore, the various representation types make demands on different procedural skills, and hence a clearer picture of the students procedural knowledge could also be constructed.

In this research the clinical interview technique was adopted for the problem-solving exercise. The think aloud protocols arising from the application of this technique provide the raw material out of which can be built a cognitive map, which reflects the cognitive processes the subjects used to solve the problem (Lin, 1982, p2). It is a technique that can give us knowledge about the process rather than just the end result of problem-solving. Admittedly, verbal protocols are not a complete record of the internal processes involved in problem-solving, but they do provide invaluable information about them.

Criticism has been levelled against the reliability of clinical interviews, but it has been counter-argued that a protocol can be validated if there is a close correspondence between the statements in the protocol and the subjects' behaviour (Ericsson and Simon, 1980). Another criticism involves the difficulty that subjects with limited processing capacities would experience in incorporating thinking aloud into their problem-solving activities (Linn, 1986, p160). Ericsson and Simon, however, compared the performance of subjects on problem-solving tasks with and without current probing and concluded from their findings that verbal protocols do not significantly influence performance in most cases.

The interviews were, to a large extent, of a tutorial nature. Concurrent probing helped guide the subjects toward the solution strategies they might otherwise not have considered (Konold and Well, 1981). This was necessary, since the nature of assistance provided could help illuminate the nature of the students' difficulty in the problem-solving exercise.

Six students were interviewed for this part of the research, four of whom were males and the other two females. They were required to solve the three problems reflected in APPENDIX 8.1. Each student was given one problem at a time on a page, with sufficient space to show any working or planning of a solution. They were asked to think aloud as they worked through the problem. In addition a probing technique was employed to encourage clarification or to provide guidance.

All 6 students interviewed were from two standard nine biology classes that I teach, and are between 16-17 years old. Being my students, they felt comfortable and relaxed during the interview, despite it being a novel experience for all of them. This state, of course, also stemmed from their knowledge that they were not being assessed for examination purposes. The students were informed that the results of the interview were to be incorporated into my research report and that these results would impact greatly on providing suggestions for improving teaching and learning in genetics in particular, and other related aspects in general.

The interviews were carried out in the school library with a tape recorder in full view. Each interview lasted approximately 25-35 minutes. Both the student and I sat side-by-side at a table to create an atmosphere of working together, rather than opposite each other.

From a group of students who volunteered to be interviewed, six students were selected who showed varying degrees of success in biology, based on their average performance during the first nine months of the standard nine year, as reflected in FIGURE 1.

STUDENT NO.	% OBTAINED
ONE	90 %
TWO	85 %
THREE	65 %
FOUR	58 %
FIVE	40 %
SIX	35 %

FIGURE 1 : Average performance of students interviewed in first 9 months of Std. 9 biology

The six students chosen thus represented high, average and low achievers in class biology tests and examinations.

Initially 9 students were involved in the problem-solving exercise, three from each ability range described above, but on analysing the transcript of their interviews, it was found that the six transcripts chosen for inclusion in this research report were representative of the findings in the three transcripts that were omitted.

The interview protocols were analysed according to the information processing model, which holds that a cognitive process can be seen as a sequence of internal states successively transformed by a series of information processes. Furthermore, it contends that information is stored in several memories having different capacities and accessing characteristics (Ericsson and Simon, 1984, p5). Verbatim transcripts of the recorded tapes have been included in APPENDICES 8.3. to 8.8. In this way the data is preserved in a "hard" form so that any inferences made during the analysis could be accepted or refuted by another interpreter (Ericsson and Simon, 1984, p4). Both an indepth analysis as well as a general analysis were undertaken to determine how a particular individual thinks through a problem, and to understand what characteristics all the students interviewed, share in this regard (Konold and Well, 1981, p10).

In addition to the clinical interview technique, each of the remaining 70 standard nine students was given a questionnaire to complete after attempting solutions to the same three problems presented to the students during the interview. None of the students involved in the interview session were asked to complete the questionnaire. A copy of this questionnaire has been included as APPENDIX 8.2. An analysis of the questionnaire was done question-wise.

Based on their solutions to the problems, the 70 students were then classified as successful or unsuccessful problem-solvers. For the purpose of this study the successful problem-solvers have been referred to as experts, whilst the unsuccessful problem-solvers have been referred to as novices.

The three problems presented in the interview and questionnaire, in essence, consisted of 5 sub-questions in total. Students who had either solutions to all the problems correct or only one sub-question incorrect were classified as experts. Students who had two or more sub-questions incorrect were regarded as novices. The analysis was done according to these two groups to reflect differences that may occur between them. It was intended that this would approximate the expert-novice studies that many researchers have used. It was also envisaged that a comparison would be made with results that emerged from the interview analysis. This helps overcome criticism from some people that the clinical interview lacks generalisability since only a small number of subjects are interviewed (Linn, 1986, p160).

Based on the findings of the interview and questionnaire analysis, both the strengths and weaknesses of the problem-solvers were noted. This was used as a basis for designing an intervention programme to remediate the weaknesses. The programme was intended to explicitly teach the novices the problem-solving skills used by the experts, so as to bring them closer to expert performance. A series of observations were made and tests administered to assess any progress made in problem-solving ability.

4. RESEARCH OUTCOMES

4.1. Analysis of Interview Protocols

With a view to establishing a relationship between existing schemata and problem-solving in biology, the interview protocols were analysed for the procedural and conceptual knowledge that the students used in solving the genetics and genetics-related problems presented to them. In addition, any interrelationships between conceptual knowledge possessed by the students and their knowledge of the procedures they used to solve problems were sought.

Prior to making a detailed analysis of student problem-solving behaviour it is necessary to have models of successful problem-solving behaviour that are developed both from the content of instruction , and from the knowledge of student problem-solving behaviour. The models developed by Stewart,J. (1982) and Chetty (1995) were used to guide the gathering of data on problem-solving in genetics, as well as in analysing data with a view to formulating predictions about problem-solving behaviour. The model developed by Stewart,J. (1982) is especially useful in providing a map of the conceptual knowledge that teachers expect students to be able to use to justify the steps in a problem solution. The conceptual knowledge in the model also helps to standardise the analysis.

For easy reference, the student and teacher exchanges in the transcripts in APPENDICES 8.3. to 8.8. have been numbered sequentially.

To facilitate an interpretation of the analysis that follows, the relative success of each of the students at the given problems is shown in FIGURE 2 in terms of the amount of assistance rendered.

Very little or no assistance	:	Student 1 and 2
Some assistance	:	Student 3 and 4
Copious assistance	:	Student 5 and 6

FIGURE 2 : Amount of assistance required by student during the problem-solving interview

It is interesting to note at this point that the degree of assistance required decreased with the increasing performance of these students in Biology, as reflected in FIGURE 1.

4.1.1. CONCEPTUAL KNOWLEDGE

4.1.1.1. Terminology

Besides having the necessary procedural knowledge in carrying out each step of the genetics format, the students also required the necessary conceptual knowledge in deciding what to include in each step. A combination of these two types of knowledge and when to use which type, i.e. conditional knowledge, is essential for success. The genetics format procedure (P1, meiosis, G1, fusion, F1) is like an algorithm, where the output of one step becomes the input of the next step. This is both useful and dangerous since, if one step is wrong, it has a ripple effect through the entire problem. Conceptual knowledge therefore, helps in achieving success at what to include in each step. In this problem, familiarity with a number of genetics terms formed a large part of the conceptual knowledge necessary.

From an analysis of the protocol, a percentage has been assigned to each student with regard to their knowledge of the terminology required for successful problem-solving. These percentages, which is an indication of the students' level of conceptual understanding are reflected in FIGURE 3. The percentages were calculated as follows:-

$$\frac{\text{No. of correct responses}}{\text{No. of queries posed}} \times 100\ \%$$

Student	Knowledge of terminology
1	100%
2	100%
3	62%
4	50%
5	43%
6	43%

FIGURE 3 : Student's knowledge of genetics terminology

Student 1 and 2 attained 100% with regard to genetics related terminology, which seems to correspond with the absence of, or the minimal assistance they required, which in turn corresponds with their success in obtaining correct solutions.

Student 3 and 4 only demonstrated a 62% and 50% knowledge respectively of genetics related terminology, which seems to have impacted on their problem-solving ability.

Student 5 and 6 both attained 43% with regard to their conceptual background in solving the given problems. This explains the copious assistance they required, as illustrated in FIGURE 2.

A teacher would expect a student to use the following concepts in solving the three problems used in this research : genotype; phenotype; dominant; recessive; gene; allele; chromosome; chromosome; heterozygous; homozygous; segregation; meiosis; fertilisation; parent; offspring; sporophyte; gametophyte; haploid; and diploid. This great demand for conceptual understanding is increased as the students are further expected to understand relationships among the various concepts including :-

* How dominant and recessive are related to genotype and phenotype and to heterozygous and homozygous.

* How segregation and independent assortment of allele symbols in the problem parallel the events of meiosis.

* That fertilisation represents the joining of segregated and independently assorted alleles from two parents

Interestingly, a ranking of the students according to their knowledge of genetics terminology from FIGURE 3, corresponds with the ranking in FIGURE 2 regarding the students' success at solving the given problems as well as with the general performance of the students reflected in FIGURE 1.

4.1.1.2. <u>Construction of a key</u>

Student 1 (par. 50) and student 2 (par. 50) were quick to recognise a relevant cue, "hybrid" and spontaneously recalled what it meant. A knowledge of what this term meant allowed them to infer that black was dominant and white was recessive. This information

Some of these students experienced problems with the construction of a key as a result of a deficiency in the conceptual knowledge necessary to do so.

4.1.1.3. Genotypes and phenotypes

Student 1 (par. 52-56) and student 2 (par. 60) demonstrated a clear understanding of the difference and the relationship between genotype and phenotype, and hence their success at this stage.

Student 3 (par. 81) was able to recall the definitions of genotype and phenotype yet represented the phenotype in terms of genes in par. 79. This reflects that he had the necessary prior knowledge about these two concepts, but that probably the conceptual relationships in his long-term memory are not well organised to show relationships. As a result of this he was unable to activate the appropriate schemata spontaneously when determining the parental phenotypes.

Student 4 (par. 68-70) and student 5 (par. 85-87) showed a lack of understanding of genotype and phenotype. Further in par. 93-96 student 5 assumes the parents have the same genotype when in fact it was stated that they were of the same colour only. This confirms that she has interchanged the meanings of genotype and phenotype.

Student 6 (par. 121) was able to recall the meaning of phenotype yet did not use this information in writing the phenotype of the parent (par. 117), where he used a capital "B" instead of the word "black". The concept of phenotype was, however, appropriately used later in the formation of the offspring genotypes and phenotypes (par. 149).

This analysis once again indicates the conceptual knowledge deficiencies among the low achievers.

4.1.1.4. Meiosis

A knowledge of the process of meiosis was required for all three problems presented to the students. The students' knowledge of the following meiosis-related events / terminology were assessed :-

- definition of meiosis
- significance of meiosis
- halving effect of meiosis
- events of Anaphase I of meiosis
- number of cells formed at end of meiosis
- difference between chromatid and chromosome
- difference between haploid and diploid

Student 1 (par. 6) correctly focussed on the chromosomes in the diagram in problem 1.1. as a relevant cue. Their moving apart indicated to the student that meiosis was represented rather than mitosis. This observation also confirms that the student was able to distinguish between a chromosome and a chromatid which is important in establishing the number of chromosomes in the cells resulting from meiosis.

After identifying the process as meiosis he then very quickly established that four cells would be the end result (par. 10). This was a pre-requisite in reducing the number of search paths to the solution. With this information two alternatives were already eliminated by student 1 (par. 12) since they had two cells each.

In par. 22 student 1 was able to comment on the halving effect of meiosis but he chose "B" as the answer even though it did not show the expected "two chromosomes" after the halving process. This seemed to have resulted from impulsivity, and indicates that the student had the appropriate schema, but that it had not been instantiated when required. Later in the interview the student appropriately used the halving effect of meiosis to explain the conversion of diploid to haploid (par.96), as well as to explain the presence of one rather than two genes per characteristic in each gamete (par. 66). Assigning chromosome number values to "haploid" and "diploid" in problem 3.2. confirms the students understanding of these terms and the difference between them (par. 100). This was essential in evaluating the alternatives in the table provided.

Student 2 (par. 2) also spontaneously identifies the process in problem 1 as being meiosis, using the moving apart of the chromosomes as a clue. A knowledge of these events of Anaphase 1 (also in par. 44) led her to the correct deduction. It also confirms her ability to differentiate between a chromosome and a chromatid. This, together with a knowledge of the halving effect of meiosis (par. 12), enabled her to determine how many chromosomes should be present in the final cells. Together with information recalled that four cells would result, student 2 had no problem in narrowing down her choice in problem 1.1. to "D" (par. 19/20), which was in fact the correct answer.

The significance of the halving effect of meiosis was also clearly demonstrated in the formation of gametes with one gene for a characteristic (par. 64-68), and in the formation of haploid spores from diploid spore mother cells (par. 82-88). Using meiosis to separate haploid from diploid parts, student 2 (par. 95) was easily able to evaluate information in the table in problem 3.2. to swiftly reach a correct solution.

Student 3 was able to identify the phase in problem 1.1. as being Anaphase of meiosis from the moving apart of the chromosomes (par. 4/12). In par. 14/18 the student correctly recalls the halving effect of meiosis, but draws a vertical line down the cell, giving the impression that two cells will result instead of four. The exchanges in par. 23-25 also confirm that the student did not know how many cells would result. Without a knowledge of this information, he was not able to immediately eliminate A and C and hence chose C as his answer first (par.6).

Although the halving effect of meiosis was mentioned (par. 14), it was not used in the formation of gametes (par. 91) where two genes for a characteristic were allocated to each gamete instead of one. Only in par. 97 did the student appropriately explain why the gamete should have one gene for each characteristic, but only after being reminded.

A knowledge of the halving effect was demonstrated when student 3 correctly located where meiosis occurred in problem 3 (par. 109) based on the haploid to diploid transition. This allowed him to successfully assign chromosome numbers to the other parts listed in the table in problem 3 and hence arrive at a solution.

Student 4 (par. 2) correctly identified the drawing in problem 1.1. as representing anaphase and meiosis based on the moving apart of the chromosomes (par. 10). The recognition of chromosomes rather than chromatids moving apart gives the impression that the student can differentiate between these two structures. In par. 24-30 however, he identified eight chromosomes in the diagram for problem one instead of four chromosomes. It is clear that the chromatids were counted as chromosomes. The contribution of DNA replication in doubling the genetic material seems not to have been related to the appearance of each chromosome as two chromatids. Student 4 therefore chose "B" as an answer even though it had only one chromosome (two chromatids) instead of two chromosomes. On the positive side "B" as a choice indicates that a knowledge of four cells as the end result of meiosis was known (par. 12). After support was provided in differentiating between chromatid and chromosome, and using knowledge of the halving effect of meiosis, the student correctly isolated "D" as the answer (par. 38).

and spores as diploid. Despite earlier use of the halving effect of meiosis, she stated that meiosis occurs to form spore mother cells. This error resulted from not knowing that the spore mother cells are diploid. In par. 135 the student used the halving effect successfully to explain how diploid spore mother cells form haploid spores.

Student 6 (par. 10-12) correctly identified the cell in problem 1.1. as representing meiosis using the moving apart of the homologous chromosomes as a cue. In par. 16 the student stated that two cells result at the end of meiosis which accounts for him impulsively choosing "C", which had two cells, as an answer (par. 6). His response in par. 32 confirms his expectation of two cells as the end result of meiosis when he drew a vertical line down the original cell in problem 1.1. to obtain two daughter cells.

This reflects a general failure to recognize that meiosis involves two nuclear divisions and that two cells result after the first division.

Student 6 also identifies 8 chromosomes in the cell instead of eight chromatids (par. 45). Only when the number of chromatids was asked for did he realize that he had mistaken the chromatids for chromosomes. In par. 30, "D" was offered as an answer. This was the correct answer but not well founded since, although the student showed evidence of knowing of the halving effect of meiosis (par. 51), the mistaking of chromosomes for chromatids would not have led to "D" as an answer. In par. 187, the zygote was considered to be haploid. This reflects a poor understanding of the concepts of "haploid" and "diploid" as they are related to the concept of "meiosis" and "fusion". Although this student showed some understanding of each of these concepts individually at various times in the problem-solving exercise, there seemed to be some difficulty in identifying conceptual relations. Only later in par. 197-205, with support received up to that time, did he successfully relate the various concepts.

4.1.1.5. Fusion

Student 1 (par. 72) was able to explain the presence of two genes per characteristic in the offspring despite the gametes having only one gene each for that characteristic. He attributed this change to "fusion" which had a doubling effect when the gametes came together. This understanding is crucial in achieving success in solving genetics problems. This was also evidenced for student 3 in par. 117 when the zygote was considered to have twenty chromosomes instead of 10 as a result of doubling, and for student 5 who spoke of haploid fusing with haploid to become diploid (par. 149). Student 4 (par. 105/106) also successfully explained the significance of fusion as that of bringing the genes from the two gametes together.

Further, student 1 (par. 94), student 2 (par. 89), student 3 (par. 107), student 4 (par. 125/126) and student 5 (par. 141) were able to identify the result of fusion i.e. the zygote. This allowed them to more easily locate the occurrence of fusion in the flow diagram , as well as to consider all parts after fusion as being diploid, in problem 3. Although student 6 (par. 185) identifies the zygote as being a result of fusion, he is unable to link this with the doubling effect of fusion when he states (par. 189) that the zygote will be haploid. In contrast to this he was earlier able (par. 149), in problem 2, to represent the offspring with two genes instead of one after fusion. This success could have been attributed to carrying out a procedure without understanding what or why it was done.

It is evident from the above that the students interviewed had a fairly good understanding of the result and significance of meiosis.

4.1.2. PROCEDURAL KNOWLEDGE

4.1.2.1. Genetics Format

Student 1 (par. 52-74) and student 2 (par. 60-70) demonstrated a thorough knowledge of the genetics format. Such prior knowledge is of a procedural nature, indicating that they knew how to move from one step to the next in solving the problem. This, together with their rich conceptual knowledge accounts for the relative ease with which they solved the problems.

Student 3 (par. 79), student 5 (par. 85) and student 6 (par. 117) knew when "genotype" and "phenotype" should appear in the format, but interchanged the meanings of these two terms when solving the problem. Student 5 regarded "genotype" as being the outward appearance of an individual (par. 87), whilst students 3 (par. 81) and 6 (par. 121) knew the definitions of genotype and phenotype, yet failed to use these terms appropriately in the problem. It is evident from student 3 and 6 that a knowledge of the format does not guarantee a solution but that knowledge about the topic plays an integral role.

Student 4 (par. 82) and student 6 (par. 93) started the genetics format with "F1" instead of "P1" despite both students knowing that "P1" represented the "parents" when asked about it.

All of the above comments reflect a strong inter-dependency of procedural and conceptual knowledge for successful problem-solving.

4.1.2.2. Interpretation of graphical information

In analysing the graph presented for question 1.2., all 6 students made an attempt to look at the information presented in the form of the dependent and independent variables. Student 1, 2, 3 and 6 were all able to identify the distance of chromosomes at point A and B as being constant. This was inferred by the students in many ways. Student 1 (par. 32) commented that the graph was flat, whilst student 2 (par. 38) stated that "B" was in the same line as "A". Student 3 (par. 51) discovered that the distance of "A" was the same as that of "B" from the poles, whilst student 6 (par. 79) stated that "A" and "B" were at the same level. Student 4 and 5 did not seem to have grasped the phenomenon of "constancy" from the graph. This was evident in the comment of student 4 (par. 40) that "it can't be A .... B could be a possible answer" when considering distance of chromosomes from the poles, so this student was unaware that A and B were the same distance from the poles. In a similar way student 5 (par. 59) chooses "B" as an answer whereas "A" was equally eligible in terms of distance from the poles.

Students 1, 2, 3 and 4 were able to infer that the distance of chromosomes from the poles was decreasing towards point C and explained this in terms of the "graph going down". These students were able to use the "going down" as a heuristic to make the necessary inference, just as some students used the graph being "flat" to make an inference about constancy. This again highlights the intimate way in which conceptual and procedural knowledge interact in successful problem-solving.

Student 1 (par. 32-36) and student 3 (par. 43-57) made constant reference to positions within the cell as the graph was being interpreted and this seems to have facilitated their understanding. Although student 2 (par. 22) did make reference to the cell, there were problems with the graphical interpretation, and as admitted by this student (par. 24), she could not "picture it in a graph form". She was then urged to picture it in terms of the cell as she had started doing. Student 2 then makes a correct statement about point "A" but with poor reasoning. She had regarded the Y-axis as being the poles rather than making an interpretation within the framework of the cell drawn. With assistance (par. 29-36) this problem was rectified.

The comment made by student 2 (par. 48) is symptomatic of a problem that probably many problem-solvers experience. She stated that "I think I isolate my subjects. In Physics I can deal with it, but in Biology -I just don't relate graphs to Biology". This is a clear call for help in increasing the transferability of procedural skills that we desire in our students.

A very useful heuristic was made use of by student 4 (par. 46) where an alternative representation of the problem was drawn. The drawing was that of the cell and included the four points A to D appearing on the graph. The points were made within the cell according to their distance from the poles, according to the graph. This seems to have facilitated the path to a solution for student 4.

Student 5 (par. 49) chose "D" as an answer stating incorrectly that the chromosomes were far apart from the poles. Also, student 6 (par. 69) states incorrectly that at "A" the chromosomes are close to the poles. This seems to indicate that both these students are not easily able to interpret graphical information. It appears that they regarded "A" as being closest to the poles because it appeared first in the graph i.e. closest to the Y-axis, and "D" as being far away from the poles because it is furthest away from the Y-axis. They did not make use of the distance above the X axis as an indication of the distance of chromosomes from the poles.

4.1.2.3. Interpretation of flow diagram

All the students except student 5 read the information provided in the flow diagram in the correct direction i.e. in the direction of the arrowheads. Student 5 (par. 117) read the flow diagram in the reverse direction. This procedural mistake impacted upon reaching a solution. "Meiosis" (par. 121) was therefore written before, rather than after, the "spore mother cells". Also, "fusion" (par. 139) was written before "sperm and egg", instead of after.

Student 1 and 2 made use of connectors i.e. words (concerning process, location, function etc) that helped link one term to another in the flow diagram. This facilitated their understanding of the information provided and hence made problem-solving easier. In addition these connectors acted as advance organisers for student 1 and 2 as the placement of "meiosis" occurred even before the instruction to do so was read, since it was used by the students as a connector.

The other students made either no or limited use of connectors in linking together the various parts of the flow diagram to create a meaningful whole. A deficiency in such relational thinking may have been a factor that delayed the search for a solution.

4.1.2.4. Interpretation of tabular information

Student 1 showed very clearly how procedural and conceptual knowledge together makes problem-solving efficient. He used the sporophyte/gametophyte difference to highlight the haploid/diploid difference, which he then mathematically converted to actual chromosome numbers (par. 100). He then evaluated each part on the table very systematically and effectively eliminated "A" and "B" immediately. By a further elimination of "C", "D" was arrived at as the answer.

The same can be said of student 2, 3 and 4 who differentiated between haploid and diploid parts. A useful heuristic was used by student 2 in this instance : "everything after meiosis will be haploid whilst everything after fusion will be diploid" (par. 97). She then determined the 4 chromosome numbers she required and simply matched this against what the table provided to find the solution.

Student 6 used the same approach as students 2, 3 and 4 except that he did not carry out a further elimination when he arrived at "C" and "D" as possible answers. He did not search the table for further information that could provide the basis for eliminating either "C" or "D".

The incorrect response of student 5 (par. 157) cannot be attributed to problems in reading information off the table, but rather to lack of a planned approach to problem-solving as well as poor conceptual knowledge. Once a heuristic was provided by the teacher (par. 160) the student was able to differentiate between haploid and diploid and hence arrive at a solution.

4.2. ANALYSIS OF QUESTIONNAIRE

The questionnaire was analysed question-wise.

4.2.1. Question 1 : Method of learning from text-book

METHOD OF LEARNING FROM THE TEXT BOOK	EXPERT (n=26)	NOVICE (n=44)
Mainly by memorising information	8%	39%
Mainly by making notes from it	15%	18%
Mainly by identifying key ideas	12%	16%
Mainly by constructing flow diagrams	11%	5%
Mainly by reading and understanding	54%	22%
Mainly by another method	0%	0%

TABLE 1 : Method employed by students when learning from the text book

According to TABLE 1, the main method employed by expert problem-solvers when learning from a text-book consisted of reading and understanding information from the text, whilst the novice problem-solvers relied more heavily on memorising information from the text book. This seems to suggest that the expert problem-solvers made a conscious attempt to relate textual information with previously acquired knowledge in order to make meaning. In contrast, the novice problem-solvers were not pre-occupied with meaning-making since no attempt was made to relate the textual information to prior knowledge, and they hence relied heavily on memorising the information in the text book. Such a method would prove useful when the recall of knowledge is required, but would have limited value when it has to be applied to a problem-solving situation. This phenomenon had also emerged during the interview session, where some students knew the definition of certain terms, but were not able to apply this knowledge in solving the genetics problem.

4.2.2. Question Two : What other method did you use?

No students responded with any other method than was listed in Question One of the interview schedule.

4.2.3. Question Three : How do you find the content in your book?

CONTENT IN TEXT BOOK	EXPERT (n=26)	NOVICE (n=44)
Very Difficult	4%	23%
Difficult	31%	54%
Reasonably Easy	50%	23%
Very Easy	15%	0%

TABLE 2 : Students' perception of the content in the text-book

According to TABLE 2, the majority (65%) of the expert problem-solvers found the content in the text book either reasonably or very easy, whilst the majority of the novice problem-solvers (77%) found the content in the text-book either difficult or very difficult. The students perception of the text-book content seems to correspond with the method that was employed in using the text-book. Since the majority of the novices found the content difficult or very difficult, they had no option but to memorise the information present. Their difficulty in understanding the textual information could be due to the lack of contextual clues, content clues, or the lack of the desired prior knowledge that could help assimilate the new information.

It is evident that the ease with which an expert problem-solver uses a text-book corresponds with his problem-solving ability whereas novices find text-books difficult to use. This seems to indicate that the skills required in text interpretation are similar to the required in problem-solving.

4.2.4. Question Four : Text comprehension

Text comprehension was focussed on since the skills / procedures / processes involved in comprehending text is similar to those involved in comprehending a problem that has to be solved.

USE OF TEXT BOOK	EXPERT (n=26)		NOVICE (n=44)	
	YES	NO	YES	NO
Do you find the content interesting?	69%	31%	43%	57%
Do you find it easy to apply the content to answering questions in assignments/tests?	77%	23%	41%	59%
Are you able to differentiate easily between what is more important from what is less important?	62%	38%	36%	64%
Do you refer constantly to any illustration present while reading your text?	65%	35%	39%	61%
Do you read your text on an aspect before it is taught in class?	23%	77%	5%	95%

TABLE 3 : Students' use of the text-book

According to TABLE 3, more of the expert problem-solvers (69%) found the content in the text-book interesting than did the novices (43%). Sometimes the level of interest that a text-book is able to generate could influence the extent to which a student is motivated to use it meaningfully.

77% of the experts stated that they found it easy to apply the content to answering questions in assignments and tests, whilst only 41% of the novices responded positively in this regard. The trend observed for the novices could be linked to their perception of the text-book content as being uninteresting, and hence also to their heavy reliance on memorisation of textual information.

The majority of the experts (62%) stated that they were able to differentiate easily between what is more important from what is less important, whereas the majority of the novices (64%) said they could not. This shortcoming of the novices could probably be attributed to their inability to make use of relevant cues present in the text to facilitate the construction of meaning. This was also evidenced in the interview session, where some students were not able to use the relevant cues present in the question statement, which would have led to a greater understanding of the problem.

A majority of the experts (65%) claimed that they referred constantly to any illustration present while reading a text, whereas a majority (61%) of the novices did not make efficient use of illustrations present. The experts therefore seem to have a greater ability to use information from more than one source. In the interview session, the successful problem-solvers also showed an ability to use information present in the question statement as well as in any diagrams/graphs that were provided. They seemed to be more adept at integrating information from a variety of sources, with the information stored in their memories.

An alarmingly low percentage of both experts and novices admitted to reading the text on an aspect before it is taught in class. This shortcoming is an avenue worth exploring since it was found that pre-reading encourages students to raise their own questions, statements or hypotheses which can later be clarified, accepted or rejected during the lesson. This fosters a more critical approach to reading and problem-solving (Numi, 1994, p135/6).

In response to an invitation for any other comment related to the text-book, the following comments were received :-

- Text-books should be summarised by teachers as students find it difficult to pick out key points

- I find the text-book understanding more difficult than the class notes

- There are some things that the teacher teaches but it may not be in the text-book

○ Text-books have very bulky notes and very long statements - I prefer summarised notes - it is easier to grasp the ideas.

Firstly, the above comments seem to re-inforce the findings in TABLE 2 which showed that 35% of the novices and as much as 77% of the novices found the content in the text-book either difficult or very difficult. The comments of the students are sending out two signals for help :-

○ To the teacher: to develop in students the ability to identify key ideas and summarise textual information. It is not intended that the teacher simply provide the summarised notes, as the student would not develop the ability to critically analyse textual or other information to identify the explanatory and evaluative arguments that support a particular idea or concept - a feature that tends to become marginalised when information is summarised.

○ To text-book authors: to more carefully evaluate their use of language, length of sentences, and other features that could enhance the user-friendliness of the text.

4.2.5. Question Five : When solving the problems presented, did you make use of other ways of representing the problem ?

38% of the experts and 23% of the novices used other ways of representing the problem/s presented to them. When comment was invited on what form their alternate representation took, most students cited that they had used diagrams, flow diagrams, and mind maps. A few students stated that they visualised "the chromosomes in a cell" whilst interpreting the graph, or created a mental picture of the problem.

The percentage of experts that used alternative representations may seem surprisingly low, but being more adept at problem-solving, they are probably more capable of abstract thought and hence found little need for concrete alternative representations. In contrast, novices ought to be encouraged to use alternate ways of representing a problem as different representations helps one to see the same problem from a different situation and hence enhance the possibility of a solution.

In the interview session, some students altered the representation of problem 1.1. from graphical to diagrammatic, and this seems to have facilitated their search for a solution.

4.2.6. Question Six : How many times did you read each of the questions before or while answering it?

Question	Average number of times question was read	
	Expert (n=26)	Novice (n=44)
1.1	2.9	2.7
1.2	2.8	3.0
2.1	3.0	3.2
3.1	1.96	1.95
3.2	2.3	2.45

TABLE 4 : Average number of times students read each question

Studies show that when good readers are working with text books or other complicated material, they frequently re-read sentences and paragraphs to get the full meaning (Whimbey and Lochhead, 1982, p139).

The results in TABLE 4, however, indicate that the average number of times each question was read is more or less the same for both the experts and the novices. Despite this, the problem-solving ability of the two groups were found to be remarkably different from each other. Does this indicate that re-reading has no influence on problem-solving ability? Not necessarily - one has to distinguish between mechanical reading and reading with understanding.

4.2.7. Question Seven : On working the problems ...

The responses to questions relating to the procedure adopted in solving the problems presented is reflected in TABLE 5.

ON WORKING THE PROBLEMS	EXPERT (n=26)		NOVICE (n=44)	
	YES	NO	YES	NO
7.1 Did you underline key terms/ phrases?	42%	58%	28%	72%
7.2 Did you stop at certain points in reading the question to think further?	96%	4%	59%	41%
7.3 Did you understand fully what the problem required before attempting a solution?	75%	25%	50%	50%
7.4 Did you make wild guesses at any answers?	31%	69%	68%	32%
7.5 Did you assess your progress during the search for a solution?	54%	46%	26%	74%
7.6 Did you review your solution to each problem?	69%	31%	45%	55%

TABLE 5 : Aspects of problem-solving behaviour displayed by the students

Question 7.1. : Underlining

Only 28% of the novices used the underlining technique. One would expect a very large percentage of experts to have done so, but only 42% did. Although not reported on during the interview analysis, the successful problem-solvers did not use the underlining technique, and yet were still able to perceive and use the key words or phrases as cues in obtaining a solution. With familiarity most of the processes involved become routine and automatic and therefore not shown visibly any more. Nevertheless the large percentage of experts that used the technique in comparison with that of the novices, indicates the relative contribution of underlining to aiding comprehension and hence, problem-solving.

Question 7.2. : Stopping to think

Almost all the experts (96%) indicated that they stopped at certain points in reading the question to think further, whereas only 59% of the novices claimed to have done this. This behaviour reflects a further distinction between expert and novice problem-solvers. This trend was also detected during the interview session. The successful problem-solvers had stopped at certain words/phrases of the question either to try and relate the structure or process to function, origin, chromosome number, or to a larger structure or process. This is evidence of relational thinking, the efficiency of which depends upon well established prior knowledge, as well as the means to link the information being read to one's prior knowledge.

Question 7.3. : Did you fully understand what the problem required before attempting a solution?

The majority of the experts (75%) stated that they understood the problem fully before attempting a solution. In contrast only 50% of the novices stated that they did. This probably explains according to TABLE 5 why as much as 68% of the novices resorted to wild guessing. Providing an answer without first understanding the problem points to impulsivity as a common characteristic among novice problem-solvers. This corresponds with findings that emerged from the interviews with students.

Question 7.4. : Guessing

As much as 68% of the novices admitted to making wild guesses at some answers, whereas only 31% of the experts responded positively in the same regard. This indicates that novices are more prone to making wild guesses than are expert problem-solvers. The high incidence of guessing amongst novices probably stems from the absence of well-developed schemata relating to the problems at hand. Since they were not able to either understand the problem or devise a plan to search for a solution, they may have resorted to guessing. This was evidenced during the interview session where students gave answers impulsively. On further questioning it turned out that they did not even understand all the terms referred to in the question, or in extreme cases, did not understand the problem at all.

The incidence of guessing amongst the experts, although lower than that of novices, is admittedly quite high. It is possible that they possessed the relevant schemata but were unable to use the given content and contextual clues to activate the appropriate schemata. This is also supported by findings in the interview session. When even some of the more successful problem-solvers reached a block in the search for a solution, probing questions helped to elicit retrieval of the relevant prior knowledge that they had to bring to bear upon the problem. This confirms that the problem was not one of possession but rather activation of the appropriate schemata.

Question 7.5. : Did you assess your progress during the search for a solution?

Only a small majority (54%) of the experts assessed their progress during the search for a solution, whereas a much lower percentage (26%) of the novices engaged in such reflective behaviour. The actual percentages obtained could have been higher than those recorded if the students were allowed more time to solve the problems, which unfortunately could not happen because of various constraints. Nevertheless, the large difference between the percentages obtained for the experts as opposed to the novices points to a significant difference in the problem-solving behaviour of these two groups.

Question 7.6. : Did you review your solution to each problem?

A review of one's solution also represents a form of reflective behaviour and which can also be regarded as a heuristic which Polya referred to as "looking back" (Mayer, 1983, p45). Here again the majority of the experts (69%) but only 45% of the novices engaged in "looking back". The appreciably higher percentages obtained here as opposed to question 7.5 in TABLE 5 indicates that in general both the experts and novice problem-solvers spent more time in assessing the end product of, rather than the process involved in problem-solving.

No further comment was received in response to an invitation to provide further information on any of the questions 7.1 to 7.6 of the questionnaire.

4.2.8. Question Eight : Which question would you regard as most difficult?

Question	Percentage of students that found each question difficult		
	Expert (n=26)	Novice (n=44)	Total (n=70)
1.1	11.25%	4.5%	7.1%
1.2	23 %	25 %	24.4%
2.1	54 %	64 %	60 %
3.1	0 %	2 %	1.4%
3.2	11.5 %	4.5%	7.1%

TABLE 6 : Students' perception of the most difficult question

It was found that a ranking of the questions from difficult to easy according to the results in TABLE 6 is the same for both the experts and novices. Since each question corresponded with a different representation type (graph, table, diagram, flow diagram, non-illustration), it can be deduced that the representation type seemed not to have influenced the experts perception of the difficulty of each problem in any different way from that of the novices.

Lack of procedural knowledge

"Not too familiar with graphs"

"Could not interpret the graph"

"I could not understand the graph"

"I did not know how to work it out"

"It is difficult to work with graphs"

"With graphs it is difficult to picture what is happening"

"I forgot how to do the table"

All of the above responses reflect an inability to carry out the procedures that were required of the various questions.

"First time I worked with a graph in this particular section"

"Couldn't apply my knowledge of graphs to Biology"

These statements do not indicate a lack of procedural knowledge so much as an ability to transfer the appropriate procedural knowledge to a new situation.

"Lack of practice"

The problem of transfer mentioned above is attributable to what some students identified as a reason for their difficulty - a lack of practice but more especially it is a lack of practice in a variety of contexts.

Attitude

"I hate questions about meiosis"

"I dislike graphs"

"Do not like genetics problems"

"I don't like problems with calculations"

All of the above comments are reflective of the role that a negative attitude and a lack of interest could play in decreasing the motivational level of the problem-solver. These students have come to the problem situation with these pre-conceived ideas that would obviously dampen their problem-solving enthusiasm. Research has shown that the nature of the task, or how learners perceive a task, influences their style or approach to the tasks (Numi, 1994, p118/9).

Comprehension difficulties

"Did not know what was required"

This comprehension difficulty may be attributed to a variety of causes, the absence of the relevant prior knowledge and a lack of motivation being amongst them.

CORRECT SOLUTIONS OBTAINED	EXPERT	NOVICE	TOTAL
QUESTION NO. / TYPE	(n=26)	(n=44)	(n=70)
1.1 Diagram	69%	14%	34%
1.2 Graph	77%	27%	46%
2.1 Non-illustration	96%	36%	59%
3.1 Flow Diagram	96%	66%	77%
3.2 Table	100%	43%	64%

TABLE 7 : Percentage of students that obtained correct solutions

The number of problems to which correct solutions were obtained was used as a means of separating the problem-solvers as experts or novices. The results in TABLE 7 confirms and justifies such a separation.

4.2.11. Question Eleven : In solving the 3 problems did you know each of the following ...?

The respondents were asked to comment on their knowledge of various terms or concepts that related to the problems presented. According to TABLE 8, a higher percentage of the experts, and in all cases the majority of them claimed to have knowledge of each of the terms or concepts provided to them, whereas the percentage of novices in the same regard was always lower in each case. It is therefore evident that prior knowledge of these terms or concepts is a contributory factor towards successful problem-solving, just as it had emerged during the interview analysis.

KNOWLEDGE OF CONCEPTS RELATED TO GIVEN PROBLEMS	EXPERT (n=26)		NOVICE (n=44)	
	YES	NO	YES	NO
Definition of mitosis	100%	0%	77%	23%
Definition of meiosis	100%	0%	86%	14%
Reduction division halves the chromosome number	85%	15%	50%	50%
Significance of meiosis	65%	35%	59%	41%
Events of Anaphase II	58%	42%	36%	64%
Number of cells formed at end of meiosis	73%	27%	61%	39%
Difference between chromatid and chromosome	85%	15%	61%	39%
Difference between haploid and diploid	100%	0%	82%	8%
Significance of fusion	77%	23%	73%	27%
Difference between dominant and recessive	85%	15%	73%	27%
Definition of hybrid	77%	23%	52%	48%
Calculation of ratio	73%	27%	34%	66%
Significance of P1/G1/F1	73%	27%	48%	52%
Difference between genotype and phenotype	100%	0%	77%	23%
Result of fusion	85%	15%	77%	23%
Difference between sporophyte and gametophyte	88%	12%	75%	25%

TABLE 8 : Students' knowledge of concepts related to given problems

An interesting observation is that according to TABLE 7, only 36% of the novices obtained correct solutions to problem 2.1., the genetics problem, despite approximately

50% or more of them, according to TABLE 8, claiming to know the terms or concepts related to the problem. This brings to the fore the notion that having the relevant conceptual knowledge does not automatically guarantee success in problem-solving. There are other factors such as the effective use of ones conceptual knowledge in inference making, the level of motivation, or the level of procedural knowledge possessed by the problem-solver.

4.2.12. Question Twelve : Rank the questions according to their representation type

PREFERENCE FOR REPRESENTATION TYPES	PREFERENCE INDEX
GRAPHS	0.3
NON-ILLUSTRATION	0.38
DRAWINGS	0.26
FLOW DIAGRAMS	0.41
TABLES	0.33

TABLE 9 : Students preference for various representation types

TABLE 9 reflects the extent to which the problem-solvers preferred each problem representation type. To do this a "preference index was calculated" using the 1-5 ranking that the student allocated to each representation type, as follows : -

$$\text{Preference index of a representation} = 1 \;/\; \frac{\text{sum of all the rankings of all the pupils}}{\text{number of pupils}}$$

Below in TABLE 10 are two rankings that have been done adjacent to each other using the results of TABLE 9 and TABLE 7.

Ranking of representation type according to increased preference	Ranking of representation type according to increased success in that problem
Flow diagram Non-illustration Table Graph Diagram	Flow diagram Table Non-illustration Graph Diagram

TABLE 10 : Comparison of representation type preferred and success involving that representation type

The two rankings match each other very closely. This observation supports the presence of some influence of representation type on success in problem-solving. It thus follows that if students can be encouraged to gain confidence in working with a variety of representation types, or in changing the given representation to a more favoured one, more efficient problem-solving can be attained.

5. INTERVENTION

From the research analysis it was found that there was a marked difference in the procedural and conceptual knowledge possessed by the novices and experts, which contributed to the level of success achieved by each group in problem-solving. Inherent in this finding is that attempts to strengthen a student's procedural and conceptual knowledge, as well as when and how to use each of it, should lead to greater success in problem-solving ability.

The intervention procedure was based on the above finding and developed around three learning outcomes of genetics problem-solving expounded by Stewart (1988, p238). These are :-

- Conceptual knowledge gains
- Problem-solving heuristics
- Content-specific problem-solving procedures

As much as these are learning outcomes of problem-solving, they can also be regarded as pre-requisites for problem-solving in genetics, and have therefore been made the focus of the intervention procedure. A group of thirty standard nine students who perform poorly in genetics problem-solving, volunteered for direct instruction in each of the three aspects which will be described more fully.

This attempt at intervention was not meant to be the focus of this study, and hence only lasted two weeks. For effective results of any such intervention programme, students can only gain confidence and competence through extensive practice. They also need to be given the opportunity to use the strategies they learn in a variety of learning environments and to receive informative, corrective feedback concerning their use. The purpose of the instruction was to explore in a very limited way, the potential of direct instruction in improving problem-solving ability. The results must be viewed within this context.

5.1. Conceptual knowledge

In solving problems, students can either discover new concepts or new relationships among concepts, or they can use their existing conceptual knowledge to solve problems, thereby understanding it at a deeper level. From the research analysis we can deduce that a basic understanding of the conceptual structure of genetics is necessary to solve even a simple problem. Students are expected to think about the meaning of "heterozygous" and its relationship to the alleles identified for each trait, thereby considering "genotype" and "phenotype" relationships along with the concepts of "dominance" and "recessiveness". All of this is required even in just the first step of genetics problem-solving - to determine each parent's genotype. This is only part of the conceptual knowledge involved in solving a problem on genetics, but it is sufficient to illustrate the need for the student to have well developed and organised conceptual schemata that will allow him to work with a network of meanings, as required in genetics problem-solving.

The conceptual knowledge that is required to meaningfully solve monohybrid problems on genetics involving complete dominance, has been presented in the form of semantic networks in FIGURE 4 and FIGURE 5. The thirty students were asked to work in groups of five, and each group was asked to establish some relationship amongst the various terms in the semantic network. Although arrows were provided linking related terms, students had to provide the rationale for their inter-relatedness. eg. in FIGURE 4, between the term "gene" and "genotype" one would expect an explanation such as "the genotype of an individual is an indication of the two forms of the gene that the individual possesses for a particular characteristic."

Limited assistance was provided to each group wherever necessary. Members of each group were found to confront the genetics terms in a more active manner, trying to establish relationships amongst them very consciously.

After this exercise the students were given a short post-test intended to establish the extent to which the various conceptual relationships had been made. The results of the post-test was compared to that of a pre-test that tested for the same objective. The average performance of the 30 students in the pre-test was 32%, but this had increased to 48% in the post-test. These test results show that the students were able to forge links amongst the various genetics-related terms more successfully after this intervention, than they had done before.

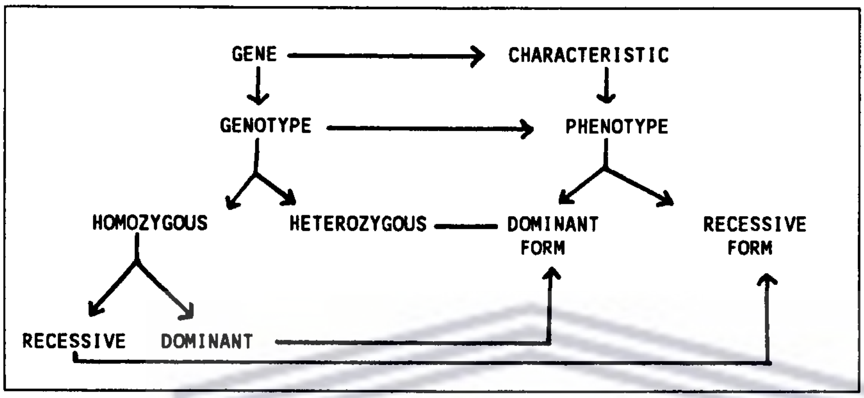


FIGURE 4 : Semantic network of genotypic and phenotypic expression

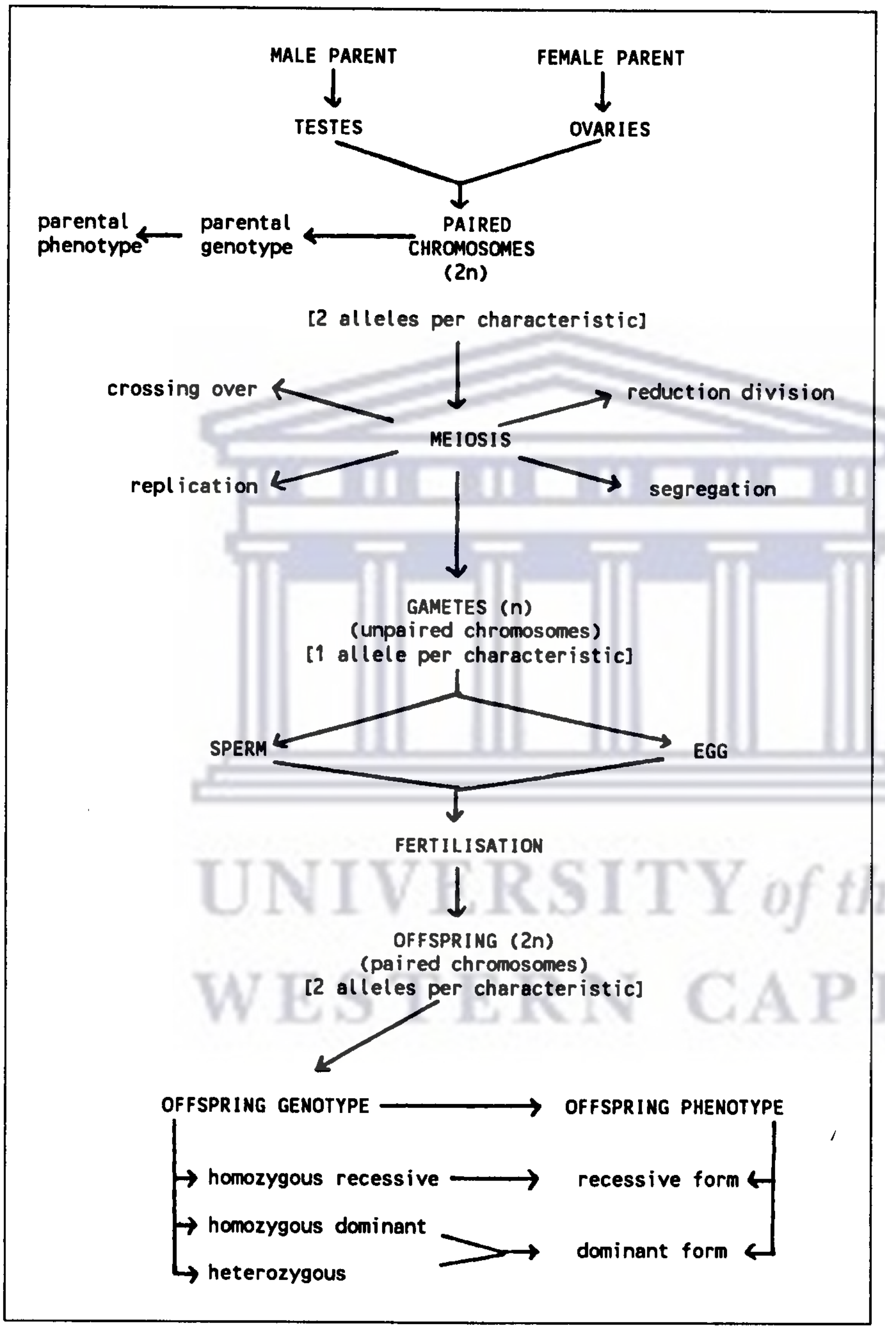


FIGURE 5 : Semantic network of conceptual relationships in a monohybrid cross

5.2. General problem-solving heuristics

Since heuristics help a problem-solver make decisions, they are of greatest value when solving difficult or novel problems. There are some general heuristics which have demonstrated a potential for transfer to specific disciplines. Reif (1983) for example describes a procedure called "problem redescription" which helps organise the data in a way that facilitates the generation of hypotheses about inheritance patterns. This is similar to Polya's (1956) heuristic on understanding a problem : "What is the unknown? What are the data? What is the condition?"

If students are made aware of these general procedures, so that they develop an abstraction of the procedure separated from the specific genetics content, then the possibility for transfer is increased. TABLE 11 contains a list of general heuristics that can be abstracted from a list of genetics-specific ones. These heuristics represent a modification of that presented by Stewart (1988, p241). They have also been regrouped to reflect the 4 stages of problem-solving for which Polya (1957) developed heuristics.

5.3. Genetics-specific procedures

5.3.1. Genetics-specific heuristics

In TABLE 11, each general heuristic presented has been instantiated as a genetics-specific heuristic. The general heuristic of "re-describe the data statement" for example is interpreted now as "re-describe in terms of the number of traits and the number of variations per trait".

Each genetics-specific heuristic is not too general as to be of limited value, whilst at the same time it is linked to a more general heuristic that could help promote it's transferability.

The students involved in the intervention program were explicitly taught how to use both the general and genetics specific heuristics listed in TABLE 11 when solving a genetics problem. While a few problems were solved on the chalkboard, students were asked to identify the general and genetics-specific heuristics that were being used. After further practice at using these heuristics, students were asked in groups of five to solve a problem on genetics. Each group was visited on a rotation basis to assess the extent to which they were achieving success. The students were then engaged in a post-test on which they obtained an average performance of 56%, compared to an average of 42% on a similar pre-test before the heuristics were taught. There was a marked but not drastic improvement in the student's success rate. This was not totally unexpected since heuristics, as helpful as they are, cannot guarantee success. That these heuristics were at least able to systematise the student's approach to problem-solving so as to effect some improvement was, in fact, encouraging.

1. Understand the problem	
General heuristics	Genetics heuristics
Understand the unknown, the data and conditions that relate to the data	Make a note of all genotypes or and phenotypes that are known, and that which needs to be determined
Draw a graph or diagram and introduce suitable notation	Symbols can be used to represent the alleles that influence a trait and hence reflect any dominance or recessiveness
Re-describe the data in the problem statement	Re-describe in terms of the number of traits and the number of variations per trait
Make inferences about initial and goal state and add them to your problem representation	Inferences can be made about genotypes of parents based on information about their offspring and vice versa

2. Devise a plan	
General heuristics	Genetics heuristics
Think of a related problem	If you suspect complete dominance, think of how you solved the last complete dominance cross
Break the problem into sub-problems	In a dihybrid cross, solve for one trait at a time
Use external memory aids	Keep records of individuals with "known" genotypes or any inferences made about an individuals genotype
Use prior knowledge to construct hypotheses	Upon seeing the phenotype of an individual think about all the genotypes that could result in that phenotype
Work backwards from the goal state to the initial state	If cross results show about 50% of each of two variations, use genetics specific procedures to work backwards to construct parental genotypes

TABLE 11 : General and genetics-specific heuristics (parts 1 and 2)

3. Execute the plan	
General heuristics	Genetics heuristics
Be systematic	In crossing gametes during fusion, systematically consider the possible combination of gametes
Check each step	Check that the determination of parental genotypes or gametes or filial genotypes and phenotypes are correct
Monitor your solution	Keep track of genotypes/phenotypes already worked out, what you are currently doing, and what genotypes/phenotypes still need to be determined

4. Look back	
General heuristics	Genetics heuristics
Read and compare problem statement with solution	Check that you have determined the genotypes/phenotypes that were required by the problem
Solve problem in a different way	Work backwards from the filial to the parental generation as a means of checking results

TABLE 11 : General and genetics-specific heuristics (parts 3 and 4)

5.3.2. Genetics-specific algorithms

Stewart, J. (1982) and Thomson and Stewart (1985) have written in detail about many genetics algorithms. They believe that it has the potential to develop in the students a better conceptual understanding of genetics and general problem-solving procedures.

The algorithm used in the intervention was modified specifically for use in monohybrid problems from that of Stewart, J. (1982).

In the algorithm represented in FIGURE 6 to FIGURE 11, the procedure for solving a genetics problem is considered as 6 sub-goals. If all the steps of the algorithm are correctly executed, then a correct solution is guaranteed. Algorithms have been criticised for the meaningless way in which it can be followed to obtain a solution. This may not necessarily indicate that the student has an appropriate conceptual understanding of the topic. This criticism is justified if algorithms are used as the only procedure in solving a problem. The intervention procedure thus makes use of other procedures as well, such as establishing relationships amongst concepts, general heuristics and genetics-specific heuristics.

The use of the algorithm was demonstrated to the thirty students using a sample problem. The students were then allowed to practice the use of the algorithm on other related problems. Finally, three groups of 3 students each were interviewed as they worked to solve a final problem on genetics. Although the interviews were not tape-recorded a number of observations were noted during the interview. It was found that the students used general and genetics-specific heuristics effectively in obtaining and using the relevant data from the problem statement. This facilitated their efficient and speedy use of the algorithm. When prompted to justify the procedures they were using, they demonstrated a sound conceptual knowledge background.

The students were then engaged in a post-test in which they obtained an average performance of 67%, compared to the same pre-test that was used prior to heuristics being taught, where they obtained an average performance of 42%. These results show that knowledge and use of appropriate algorithms makes a direct contribution to increased performance, and that these algorithms can be taught to students, allowing for their meaningful use. Furthermore the improvement made by using heuristics and algorithms together was greater than when students used heuristics alone.

It is encouraging to note that, if such a brief intervention could produce marked changes in problem-solving behaviour, a more organised program allowing for greater practice, so as to routinise certain procedures, should be considerably more successful in improving problem-solving behaviour. It was also revealed that any attempts at intervention should include a strengthening of the students conceptual knowledge, and explicit teaching of the relevant heuristics and algorithms.

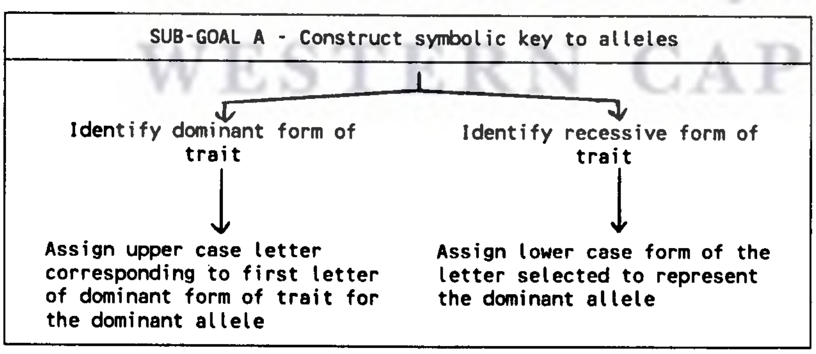


FIGURE 6 : Subgoal A : Construction of a symbolic key to alleles

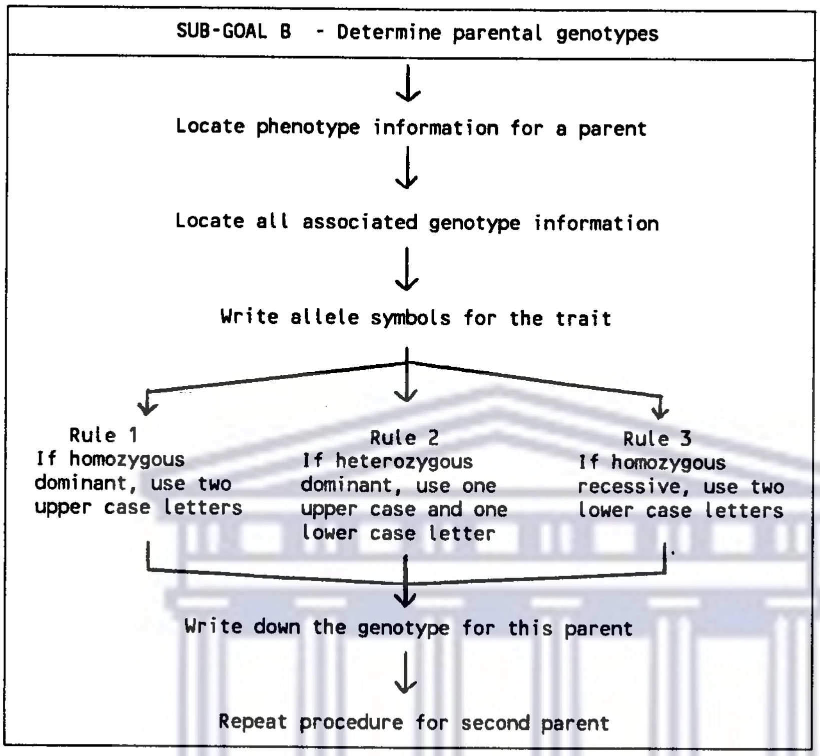


FIGURE 7 : Subgoal B : Determination of parental genotypes

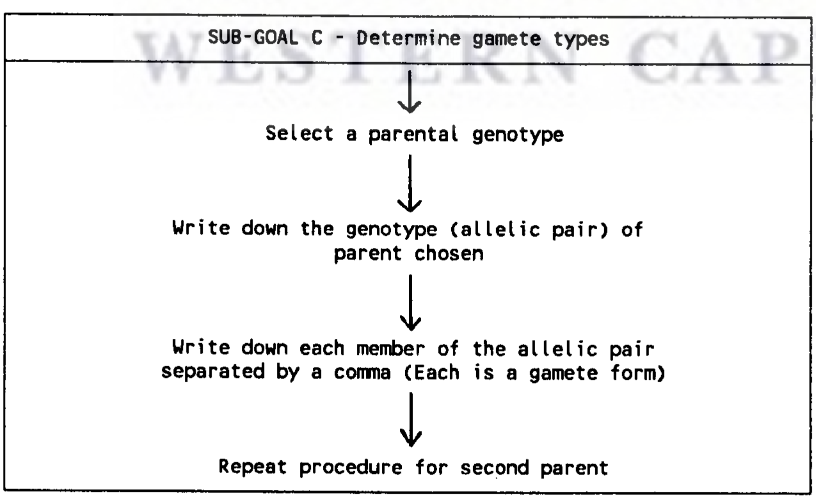


FIGURE 8 : Subgoal C : Determination of gamete types

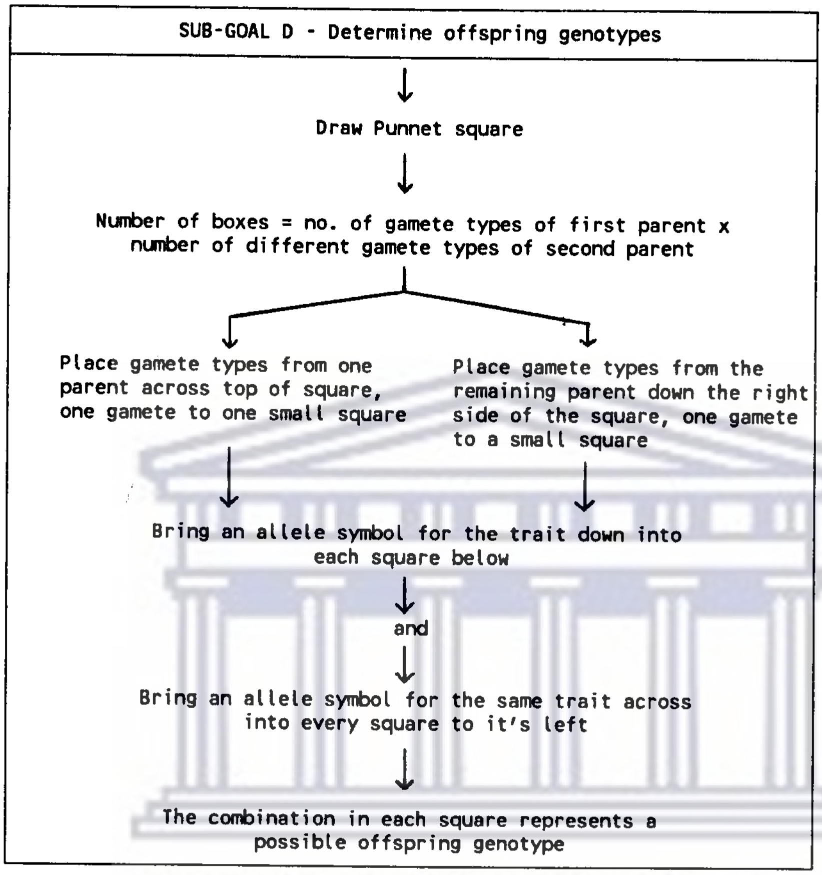


FIGURE 9 : Subgoal D : Determination of offspring genotypes

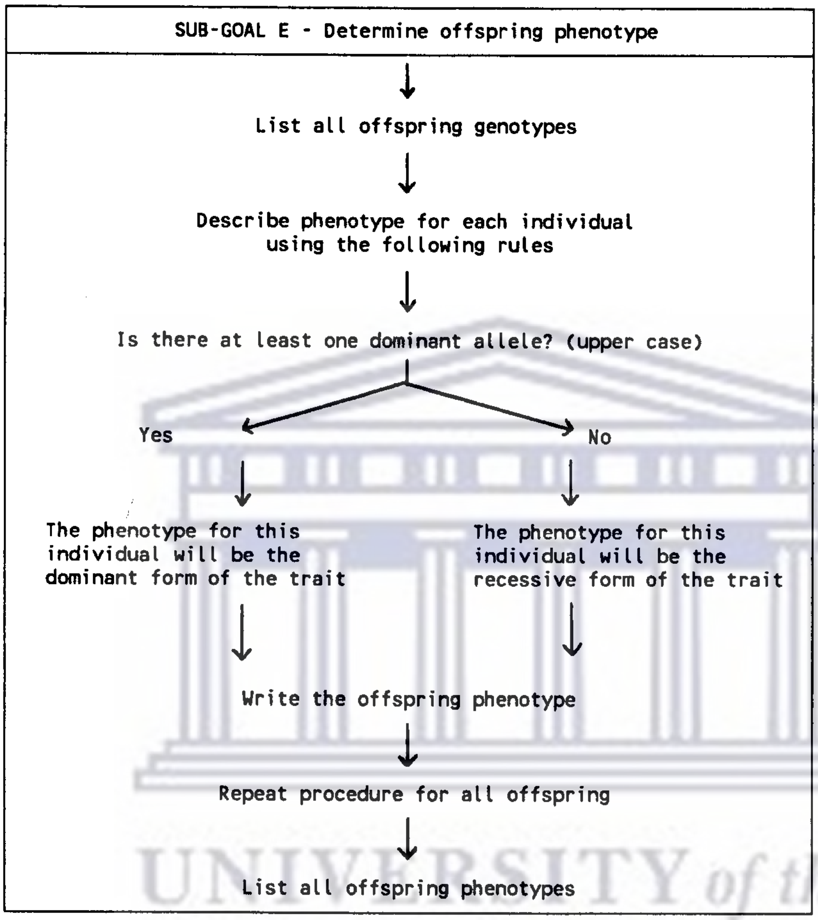


FIGURE 10 : Subgoal E : Determination of offspring phenotypes

SUB-GOAL F - Determination of phenotypic ratio

↓

Locate list of all offspring phenotypes

↓

List all different offspring phenotypes

↓

Indicate how many individuals will occur for each offspring phenotype

↓

Write as a ratio of total offspring

↓

Begin with phenotype represented by greatest number of individuals

↓

Continue for each different offspring phenotype

FIGURE 11 : Subgoal F : Determination of phenotypic ratio

6. DISCUSSION AND PEDAGOGIC IMPLICATIONS

From the interview analysis, it was found that as the level of conceptual knowledge possessed by the students increased, so too did their expertise in problem-solving. The questionnaire analysis also reflected clearly that the experts had a better understanding of the various genetics-related concepts than the novices did. The majority of the mistakes that students made during problem-solving was traced back to misunderstandings of basic genetics concepts. They lacked adequate knowledge of how meiotic division, segregation of chromosomes and genes are related to the solution of the given problems. There was also a lack of understanding of differences between genetics concepts such as genotype and phenotype, heterozygous and homozygous, and dominant and recessive.

Based on the level of conceptual knowledge possessed by the students, they can be categorised into three groups. The first group, which consisted of expert problem-solvers, had the relevant conceptual knowledge and used it in a meaningful way to obtain a solution. They were more easily able to make inferences by connecting information in the problem with information about genetics stored in long-term memory. They were therefore more adept at interactive processing, allowing for more efficient instantiation of schemata and hence speeding up the processing of information.

The second group consisted of students who had the relevant knowledge but were not able to use it during problem-solving. In this case the appropriate schemata were present, but not successfully or spontaneously activated during problem-solving. Only on prompting did many students retrieve and then use previously stored information. Also, they were able to retrieve and use certain concepts at some points in problem-solving, but failed to retrieve and use the same concepts at other times. This could be attributed to a lack of rehearsal, poor organisation of information in long-term memory, or a lack of practice in applying the information in a variety of contexts so as to increase its generalisability.

The third group, essentially novices, included those that had a very poor conceptual background in genetics. They were unable to provide appropriate justification for the various steps in solving the problems. Because of the lack of conceptual knowledge these students depended on information provided in the problem statement, thus relying more heavily on bottom-up processing. Even the reliance on bottom-up processing was hindered by an inability to recognise content and contextual clues present in the problem statement. This approach is characteristic of impulsive problem-solvers who are prone to guessing.

In the questionnaire analysis, a fairly high percentage of students claimed an adequate knowledge of genetics-related concepts. While this may be the case, the interview analysis revealed that the greater difficulty did not concern knowledge of concepts as much as in describing how the various concepts are related. This probably stems from the piecemeal way in which text books deal with them. One way of overcoming this obstacle is to consciously make links amongst various concepts, even across topics. In other words, concepts need to be learned and taught as organised networks of related information. The use of concept maps could prove beneficial in facilitating such relational thinking and learning (Novak, 1990).

A deficiency in procedural knowledge of the novices was also detected as a block to the problem-solving process. This was reflected by their inability to use appropriate algorithms and heuristics. The experts however, had a good knowledge of the procedures that were required to solve the given problems. Many of them used genetics-specific algorithms that guaranteed a solution when appropriately executed. Stewart (1988, p248) remarks that it is not a problem when algorithms are used, but that it is a problem when they are learned and applied with limited understanding of its conceptual background. This comment stems from the role of algorithms in providing a correct but not necessarily meaningful answer. It is therefore necessary to also present students with novel problems that cannot be solved just by using an algorithm. Students will then be forced to develop heuristics to guide their search for a solution. During the interview, experts used a combination of heuristics and algorithms to arrive at correct answers whilst promoting understanding.

The expert problem-solvers made use of general heuristics such as differentiating between what is given and what is required, re-describing the data in the problem statement, and working backwards. They also successfully used the heuristic of forming an alternative representation of the problem when analysing the graphs and tables. Because of the vague nature of general heuristics, the expert problem-solvers also used a repertoire of domain-specific and in many cases genetics-specifics heuristics. For example, the general heuristic of differentiating between what is given and what is required was instantiated into a genetics-specific heuristic of making a note of all genotypes and/or phenotypes that are given, and that which needs to be determined.

The genetics format used in solving genetics problems is also a genetics-specific heuristic. It is an alternative way of representing a genetics problem as a reproductive cross. Also, since particular steps are followed, it also helps to break the problem into parts. Although the majority of the students knew this format, not all were able to proceed successfully from one step to the next to eventually reach a solution. Although they possessed the necessary procedural knowledge, inadequate conceptual knowledge became a limiting factor. Even when the steps were correctly executed, some of the students were not able to justify each step conceptually. Students need to be explicitly taught the semantics of the notations used. In this way they would be able to change the problem representation from one form (eg. written) to another (eg. symbolic, as in the genetics format) with understanding, and not just mechanically. Such mediation is necessary by the teacher, as it is often lacking in text-books.

If general heuristics are being taught, they must be made explicit to students in the initial setting in which they are used, as well as with their potential to generalise to other content areas. If this is not done, the heuristics will remain too general and are unlikely to be used spontaneously by students.

All of the aforegoing, attests to the importance of conceptual and procedural knowledge in promoting problem-solving capability in biology. The presence of well elaborated schemata about a topic can more easily instantiate newly acquired information into that schema. This allows processing to occur more rapidly because inferences can be assigned to more pieces of incoming information (Sinclair, 1985, p4). It was further found that prior knowledge, both in the form of conceptual and procedural knowledge, was indispensable in problem-solving, not individually, but in combination with each other.

The difference in the novice and expert's perception of text-book content and their ability to use the text-book indicates a relation between text-book usage and problem-solving. The expert problem-solvers reported that they learnt from text-books by reading and understanding, whilst the novices simply memorised information rather than understood its significance or relevance. If memorisation is encouraged as the main method of learning, information thus learned may tend to remain inert rather than be used when it is relevant, as in problem-solving. As discussed in Chapter 2, many writers have likened purposeful reading to problem-solving, arguing that it makes the same intellectual demands. It is therefore possible that the skills developed in encouraging the proper use of text-books, could also be used successfully in problem-solving.

The clinical interview technique has allowed much of the thinking processes of the students to become "visible". It was useful for both the researcher as well as the student. During the interview, for example, students became more aware of their strengths and weaknesses as they worked through the problem, since they were prompted to clarify, explain or substantiate what they were doing while solving the problem. Students were thus engaged in self-questioning and thinking aloud, making them more aware of their thinking. These demands allowed the students to assume a more active role in problem-solving.

The same advantages could be gained from employing the peer-pair problem-solving approach. It would prove quite beneficial in making students aware of the methods they use and the relative success of their approach. In this way it would be easier to locate errors in one's own reasoning as well as to identify reasoning skills employed by problem-solvers more successful than oneself.

The intervention procedure attempted to bridge the gap between the novices and experts, such that the novices were taught procedures that the experts were found to use. The intervention focussed on the strengthening of the conceptual knowledge as well as procedures that were required in reaching a solution successfully. Conceptual knowledge was strengthened by presenting learning materials in a way that stressed conceptual relations, thus helping in the organised storage of information.

With regard to procedural knowledge, heuristics that were first taught were then translated into genetics-specific heuristics. This had a two-fold purpose - it re-inforced the internalisation of the general heuristics, as well as demonstrated the ways in which general heuristics can generalise to specific content areas. In addition, students made successful use of algorithms to increase their problem-solving performance. The encouraging results obtained using the intervention, strongly suggests that problem-solving can be taught directly.

According to students' perception of the difficulty of the problems presented, the problem representation seemed to have influenced the novices and experts choices in the same way. It was also revealed that increased preference for a particular representation type, led to increased success in a problem involving that representation type. This corresponds with similar findings by other researchers (eg. Kotovsky, Hayes and Simon, 1985), who also linked representation type to the size of the loads imposed on the memory. Problem representation is thus an additional factor that deserves attention in attempts to increase problem-solving capabilities of students.

Arising from both the interview and questionnaire analysis, the problem-solving approach of novices and experts differed markedly and corresponds very closely with those of previous researchers (eg. Chi, Glaser and Rees, 1982; Carey, 1986; Linn, 1986; Stewart and van Kirk, 1990; Smith, 1991). Although this thread was noticed in specific issues discussed so far, a few general comments can be made here. The novices, compared to the experts, were found to approach the problem very unsystematically, seldom stopping to monitor or review their solution. Their lack of appropriate knowledge and strategies were found to hamper their problem-solving capability. As a result they provided answers impulsively, not being able to justify them.

The expert problem-solvers on the other hand assumed a more planned approach to problem-solving; an approach in which they engaged actively. They were more successful in using heuristics, both general and specific, in guiding their search for a solution. They used algorithms in a meaningful manner, reflecting a clear understanding of the conceptual knowledge underlying the algorithm.

It is important to know how the problem-solving approach of experts and novices differ. In the first instance, it could help teachers differentiate likewise amongst students in their class. Furthermore, the approach employed by the experts could be taught to the novices to help them improve their ability to solve problems. Alternatively novices and experts could be matched together during a problem-solving activity so that the novice can model the behaviour of the expert.

Although the above findings, arising out of descriptive research to assess the knowledge and procedures used by students when solving problems in a particular content domain, does not contribute towards theory building, it has direct implications for science instruction.

7. CONCLUSION

If education in general, and problem-solving in particular, is to have a major influence in preparing students to solve problems later in life, then there must be a correspondence between the tasks at school with the tasks of the everyday world. Only a clear understanding of how students solve problems and how experts in particular solve problems successfully, can help in developing instructional programmes to improve the problem-solving capabilities of our charges, and hence prepare them more adequately to handle life's problems.

A major finding in this research relates to the impact of schema availability and schema activation on problem-solving capability. Two major blocks to a successful solution were attributed either to the absence of the appropriate schemata, or the inability to retrieve information from the appropriate schemata and apply it to the problem-solving situation. Students therefore need to be provided with opportunities that would develop and strengthen their schemata, allowing for increased efficiency in assimilating new information, as well as in retrieving stored information to use in problem-solving.

Stewart, J. (1982, p748) states that it is obvious that science educators know very little about what students learn from science instruction. He suggests that one way to fill this void would be for researchers to do detailed analyses of the conceptual and procedural knowledge that students are expected to learn in science courses. This would allow us to detail the knowledge that students derive from instruction, as well as the knowledge that students bring to the class, thus providing a rational basis for changing science instruction. Outcomes-based education, introduced earlier, provides an alternative to the traditional science content and instruction. It places greater emphasis on the needs and capabilities of the student, and the importance of allowing the student to develop at his/her own pace.

This research elaborated the conceptual and procedural knowledge of the problem-solvers. An analysis of the conceptual knowledge possessed by the students revealed misconceptions in the students' existing knowledge. Such misconceptions were found to interfere with the problem-solving process. This reminds us that students come to science lessons already holding ideas about natural phenomena, which they use to make sense of everyday experiences. Learning science may, therefore, not only involve learning new ideas, but also modifying or abandoning pre-existing ones. Ways must be found in effectively confronting naive conceptions so that science knowledge represented in instruction can be successfully learned, and applied to problem-solving situations.

The strong influence that conceptual knowledge was found to have on problem-solving capability has implications for future attempts at curriculum revision / development. Since successful concept development leads to development of new schemata and the re-organisation of existing schemata, we need to explicitly organise our teaching around concepts. This directs our attention to the value of a conceptually based curriculum as opposed to an informationally driven one.

Procedural knowledge deserves an equally important status as a pre-requisite for problem-solving. This research has shown that some of the students possessed the necessary conceptual knowledge, but were not able to engage in procedures that led to successful retrieval and use of that information. They lacked knowledge of the procedures needed in a problem-solving situation. Whereas conceptual knowledge refers to "knowing what", it is useless without procedural knowledge which allows one to "know how" to use what one knows. Outcomes-based education, which is to be implemented at our schools from 1998, promises to focus more strongly on the competencies developed by the individual. Unlike the present, conceptual knowledge will be used as a vehicle for the development of a repertoire of skills and attitudes.

The expert-novice distinction in this study revealed that there were differences in both the level of conceptual and procedural knowledge between the two groups. In the main, experts used general heuristics that were applicable to a wide variety of contexts, as well as genetics specific heuristics that were applicable to a specific set of genetics problems. At a more specific level, they used algorithms to direct them to a solution. This revealed that, in addition to a rich conceptual background, experts made use of strategies ranging from very general, (so as to be transferable), to very specific (so as to be useful).

For efficient problem-solving much of the strategies need to become routinised through practice. In this way more attentional capacity is freed for higher thought processes. Also, procedures that encourage chunking should be developed, as this also reduces the load on one's mental capacity. With time, therefore, much of the routine processing of experts which is initially controlled, later become automatic.

Further, it seems that experts have not just more knowledge, but have knowledge organised in such a way that reflects relationships amongst various concepts and strategies, thus facilitating their efficient retrieval and use. They were more successful at differentiating between relevant and irrelevant and in making inferences, than did the novices. Science instruction should therefore present concepts many times, in a variety of contexts, so that conceptual relationships can be drawn. The new national curriculum allows for a particular theme to appear over a number of years, at increasingly complex levels, thus allowing for easy development and strengthening of schemata as well as establishing relationships amongst schemata.

Intervention to remediate much of the schema-related problems in problem-solving was undertaken on a small scale. It involved a modification of the learning materials and the learners processes. Modification of the learning materials could involve modification of text-books, or if existing text-books have to be used, then the teacher has to assume the role of mediator between the text and the learner. Modification of the learners, processes involves the teaching of more efficient means of acquiring and retrieving knowledge, as well as effective problem-solving strategies. It was found that encouraging improvements in problem-solving were obtained when students had acquired the necessary knowledge (concepts) as well as strategies (procedures) - reflecting once again the intimate relationship between the two. A more thorough study of the influence of the intervention programme should form the object of a separate study.

Since text-books play a very prominent role in science instruction, their suitability in achieving the aims of science education, and the ability of the students to use them deserves consideration. This research has shown a correspondence between text-book use and problem-solving. Experts used the text-book in a resourceful and meaningful way since they found the content easy, whereas novices learnt information from the text-book in rote fashion since they found the content difficult. This, in turn, correlates with their ability in problem-solving. If students are expected to use the text-book as a learning device, they must be explicitly taught how to do so. Findings from many studies reveal and support growing awareness that while most students might have learned to read, they often cannot read to learn (Singer and Donlan, 1989). Subject matter information thus becomes inaccessible to these students.

On the issue of problem representation, this was found to have an influence on the success of both novices and experts in arriving at a solution. It was clear that some representations were more favoured than others. Certain problem representations make a great demand on the processing capacity of the problem-solver. This is especially a disadvantage with problem-solvers who already have limited processing resources, as with the novices. So much attention is devoted to unlocking the cues present in the representation type that very little attentional capacity is left over for further higher thought processes, leading to greater difficulty in finding a solution. It is important that students are exposed repeatedly to a variety of representation types, as well as given the practice at changing a representation from one type to another. This would allow them to see the problem from a different perspective.

The clinical interview technique was found to be a powerful diagnostic tool in exposing the influence of schema availability and schema activation in problem-solving. The prompting and probing also made students more aware of their own thinking and hence improved their metacognition. This technique was also useful in determining differences between knowledge and strategies used by novices and experts in problem-solving. The strategies used by expert problem-solvers were then taught to novices to improve their problem-solving capability.

Another advantage of the clinical interview, which is also characteristic of the peer-pair method described earlier, is the social-interaction perspective that it offers. At present school learning emphasises individual work, whereas everyday-life emphasises co-operative ventures. In the interview, both the teacher and student interact socially with each other. The teacher provides scaffolding to the student in the attempt to find a solution. As a result it is possible to determine not only what the child knows, but also what the child is capable of learning. This is what Vygotsky described as the "zone of proximal development" which contends that what children can do with the assistance of others, might be in some sense even more indicative of their mental development than what they can do alone (in Naude, 1987, p32). Knowledge and practice in the clinical interview technique should therefore be built into every pre-service and in-service teacher training course. In this way the teacher would be able to assume the task of researcher and will hence feel more empowered to improve his own teaching.

This study has shown very clearly how experts and novices approach problem-solving in different ways. It was not merely the amount of knowledge or number of skills possessed that distinguished experts from novices, but rather their ability to implement appropriate regulatory strategies, their confidence and their ability to persevere in the face of difficulty. Researchers today agree that most students do not develop learning strategies unless they receive explicit instruction in their use and hence "learning to learn cannot be left to students. It must be taught" (Gall, Gall, Jacobsen and Bullock, 1990:v). Studies such as this are therefore useful in differentiating between our initial state (the novice) and our final or goal state (the expert), as well as in ways of transforming the initial to the goal state. What would be more valuable in future research is an examination of the development of problem-solvers progressing from the novice to the expert state. From this information models of successful and unsuccessful problem-solving can be more reliably inferred.

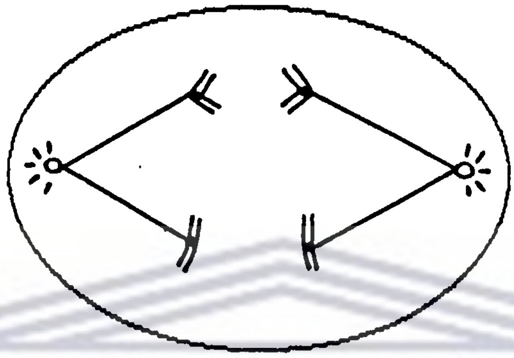
Students must be helped to find both their strengths and weaknesses; they need to develop the self-confidence to persist in the face of difficulty. Students need to realize that there are many different ways to be competent and successful. But in the words of Gragg (1940), since "wisdom can't be told", they probably can learn this only by actually being successful. We must increase the opportunities for students to achieve and experience success. Herein lies a challenge to us all.

8. APPENDICES

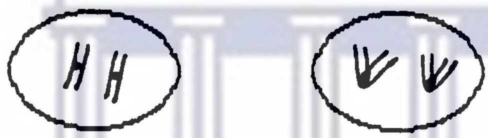
APPENDIX 8.1. - PROBLEMS USED IN INTERVIEW AND QUESTIONNAIRE

PROBLEM ONE

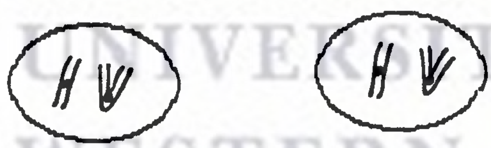
Study the diagram below of a phase in a type of cell division.

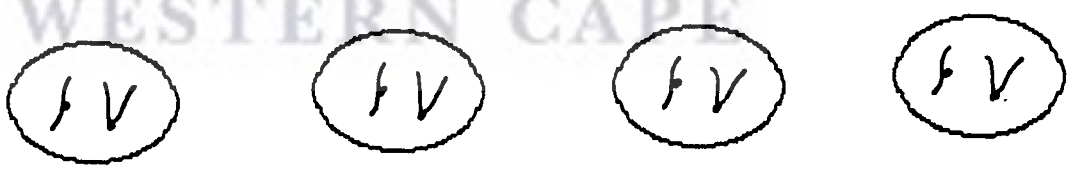


1.1 Which one of the following correctly represents the end result of cell division of the cell above ?

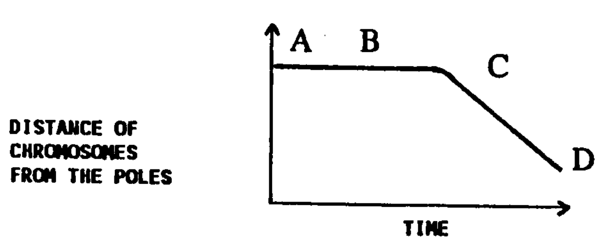
A. 

B. 

C. 

D. 

1.2 Which of the parts A,B,C or D on the graph applies most appropriately to the cell represented ?



PROBLEM TWO

2.1 **A hybrid, black male rat was crossed with a female rat of the same colour, of unknown genotype. In the F1, the following results were obtained : -**

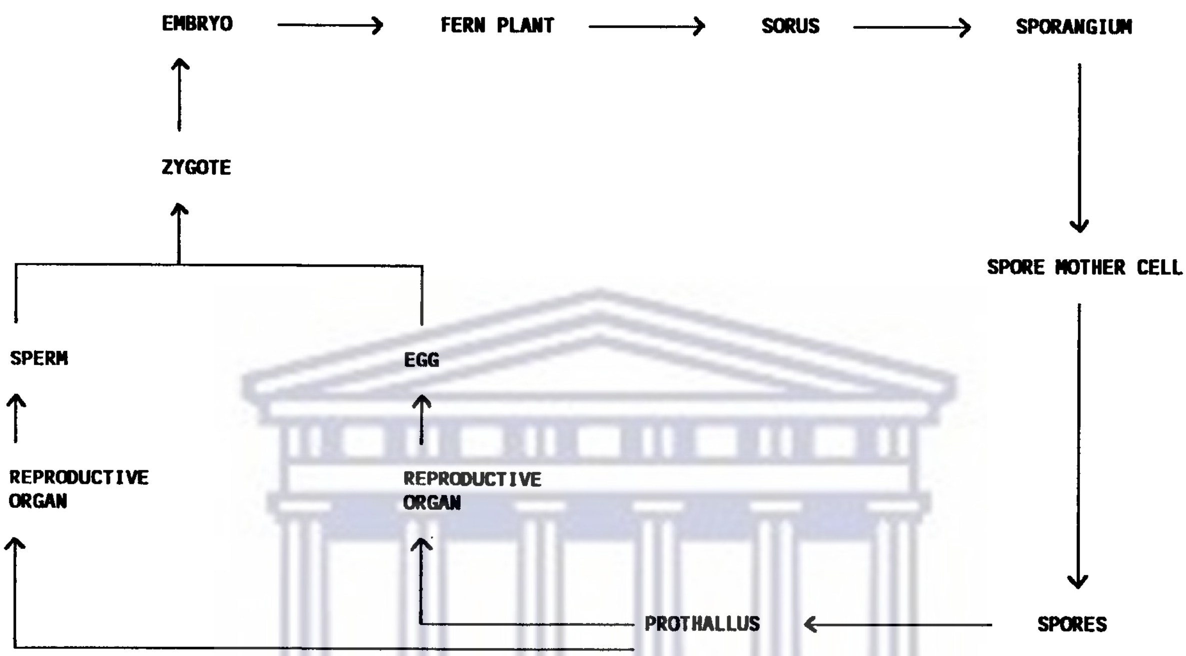
Black	**:**	**24**
White	**:**	**8**

Determine the genotype of the female rat.

(Show ALL working)

PROBLEM THREE

The flow diagram below is a schematic representation of the life cycle of a fern. Study it and answer the questions set.



3.1 On the flow diagram, write down the term "fusion" and "meiosis" to show exactly where each of these processes occur

---

3.2 If a cell in the pinna of the fern plant has 20 chromosomes, which of the following (A,B,C or D) represents the correct chromosome number for each of the parts indicated.
(Circle the letter chosen)

	EMBRYO	PROTHALLUS	SORUS	EGG
A.	10	10	20	10
B.	10	20	10	20
C.	20	10	10	20
D.	20	10	20	10

APPENDIX 8.2. : QUESTIONNAIRE ADMINISTERED TO STANDARD NINE PUPILS

1. How do you learn from your textbook?

Place a tick in the appropriate block		
	Mainly by memorising information	
	Mainly by making notes from it	
	Mainly by identifying key ideas	
	Mainly by constructing flow diagram	
	Mainly by reading and understanding	
	Mainly by another method	

2. If answer in (1) was "by another method", please describe method

   briefly : ______________________________

   ____

3. How do you find the content in your text book?

Very Difficult	
Difficult	
Reasonably easy	
Very Easy	

4. With regard to your text book:-

	YES	NO
4.1 Do you find the content interesting		
4.2 Do you find it easy to apply the content to answering questions in assignments/tests		
4.3 Are you able to differentiate easily between what is more important from what is less important		
4.4 Do you refer constantly to any illustration present while reading your text.		
4.5 Do you read your text on an aspect before it is taught in class		

ANY OTHER COMMENT :

____

____

5. When solving the problems presented, did you make use of other ways of representing the problem? (diagrams,flow charts,mind maps etc.)

YES	NO

If yes, describe how you did so. ______________________________

____

6. How many times did you read each of the following questions before or while answering it?

1.1 -----	3.1 ----
1.2 -----	3.2 ----
2.1 -----	

7. When you worked the problems presented

	YES	NO
7.1 Did you underline key terms/phrases?		
7.2 Did you stop at certain points in reading the question to think further?		
7.3 Did you understand fully what the problem required before attempting a solution		
7.4 Did you make wild guesses at any answers		
7.5 Did you assess your progress during the search for a solution?		
7.6 Did you review your solution to each problem?		

ANY FURTHER COMMENT ON ANY ANSWER 7.1 to 7.6? ______________________________

____

8. Which question would you regard as most difficult? __________

9. Why did you find that question difficult? ______________________________

____

10. Place a tick next to the question number/s that you obtained correct solutions to.

1.1	
1.2	
2.1	
3.1	
3.2	

11. In solving the 3 problems did you know each of the following?

	YES	NO
a. Definition of mitosis		
b. Definition of meiosis		
c. Reduction division halves the chromosome number		
d. Significance of meiosis		
e. Events of Anaphase II		
f. Number of cells formed at end of meiosis		
g. Difference between chromatid and chromosome		
h. Difference between haploid and diploid		
i. Significance of fusion		
j. Difference between dominant and recessive		
k. Definition of hybrid		
l. Calculation of ratio		
m. Significance of P1/G1/F1		
n. Difference between genotype and phenotype		
o. Result of fusion		
p. Difference between sporophyte and gametophyte		

12. Use the numbers 1-5 to rank the type of questions you prefer.

NB: 1 = most preferred
5 = least preferred

Graphs	
Non-illustration	
Drawings	
Flow diagrams	
Tables	

APPENDIX 8.3. : TRANSCRIPT OF INTERVIEW WITH STUDENT ONE

1 Teacher : Rubeshan, you will be required to solve three problems based on your Std 9 Biology. As you work through them, I need you to read aloud and think aloud at all times. Are you ready to go?

2 Student : Yes

3 Teacher : Well, this is problem number 1. You may begin

4 Student : "Study the diagram below of a phase in a type of cell division.
1.1. Which one of the following correctly represents the end result of cell division of the cell above" [Pupil now looks at the diagram]

5 Teacher : What are you thinking while you are looking at the diagram?

6 Student : Just trying to figure out whether it represents mitosis or meiosis. Let's see the chromosomes are being pulled apart .... it's meiosis.

7 Teacher : Why are you so certain that it is meiosis?

8 Student : Here the chromosomes are being pulled apart, but in mitosis the chromatids are pulled apart.

9 Teacher : Okay, carry on.

10 Student : [Pupil re-reads question]. "Study the diagram below of a phase in a type of cell division. 1.1. Which one of the following correctly represents the end result of cell division of the cell above, ... represents the end result of cell division "
That means end result of meiosis, which means that four cells will form.

11 Teacher : Okay, so what's next?

12 Student : Then A and C cannot be correct.

13 Teacher : Why not?

14 Student : Because both A and C show two cells which is the end result of mitosis and not meiosis

15 Teacher : Right, so are you now going to chose between B and D?

16 Student : Yes - B is the correct answer

17 Teacher : Is that your final answer then or are you still thinking about it?

18 Student : That's my final answer

19 Teacher : Before telling you whether it's right or wrong, let me ask you a question. How many chromosomes does the mother cell drawn possess?

20 Student : Four

21 Teacher : What happens to the chromosome number as a result of meiosis?

22 Student : It is halved

23 Teacher : So how many chromosomes should the cells at the end of cell division in this problem have?

24 Student : Two - oh! but in B there is only one chromosome each - so B is not the answer - it's ...... D.

25 Teacher : Why did you now change your answer to D?

26 Student : In D there are two chromosomes in each cell.

27 Teacher : What was the purpose of forming these four new cells?

28 Student : They will now function as gametes.

29 Teacher : Okay, D is in fact the correct answer.
Now try question 1.2.

30 Student : "Which of the parts A, B, C or D on the graph applies most appropriately to the cell represented" Let's see - on the Y axis we have distance of chromosomes from the poles and on the X axis, time.
Let's see again what we need to do - "Which of the parts A, B, C or D on the graph applies most appropriately to the cell represented".
Pause

31 Teacher : Please let me know what you are thinking about now?

32 Student : I'm looking at point A on the graph - the chromosomes are a great distance from the poles - that means they are at the middle of the cell. At B they are also in the middle because the graph is flat from A to B - so distance is constant.

33 Teacher : Okay - continue

34 Student : At C the distance of chromosomes from the poles decrease.

35 Teacher : How did you figure that out?

36 Student : The graph is going down at point C -.... and at D the chromosomes are a short distance from the poles, that is they are almost at the poles...

37 Teacher : So which of the points relates to the diagram given?

38 Student : Can't be A or B because the chromosomes are not right in the centre. Also it cannot be D since they have not reached the poles. C is therefore the answer.

39 Teacher : What is your reason for that choice?

40 Student : Well the diagram shows Anaphase I where the chromosomes are still in the process of moving towards the poles away from the centre.

41 Teacher : and C is in fact the correct answer.
You may now attempt question two.

42 Student : "A hybrid, black male rat was crossed with a female rat of the same colour but of unknown genotype. In the F1 the following results were obtained; black 24 and white 8. Determine the genotype of the female rat." Let me read the question one more time [student re-reads the question]. Pause....

43 Teacher : What are you going to do next?

44 Student : I will first do a key for this problem. It will be capital B for black and b for white.

45 Teacher : Why did you chose a capital B for black?

46 Student : Because black is dominant

47 Teacher : How do you know that?

48 Student : In the F1 there more black than white offspring - so black must have been dominant.

49 Teacher : If that information was not given - is there any other way of determining that black is dominant?

50 Student : Eh! ... "A hybrid black male rat...." Yes the word "hybrid" tells us that one gene was dominant and one recessive - and if male rat was black it must have been dominant.

51 Teacher : Okay, that's correct. Continue.

52 Student : In the P1 the black male rat is crossed with a black female rat

53 Teacher : How do you know that the female rat was black?

54 Student : It says that "female rat was of the same colour" as the male rat.

55 Teacher : Okay

56 Student : The P1 genotype will be Bb X Bb.

57 Teacher : Why will the male rat have the genotype Bb?

58 Student : It says here that it is a hybrid

59 Teacher : And how do you know that Bb is the genotype of the female rat?

60 Student : Well, we do not know for sure. I'm just using it as one possibility?

61 Teacher : What is the other possibility?

62 Student : Well , BB

63 Teacher : Why are you including at least one capital B in your two possibilities?

64 Student : Since the female rat is black and must therefore have one dominant gene for the black colour.

65 Teacher : What's next?

66 Student : The gametes after meiosis is B, B crossed with B, b

67 Teacher : How is it that the parents have two genes for colour, whereas the gametes have only one each for a characteristic?

68 Student : Meiosis took place to form gametes and meiosis has a halving effect.

69 Teacher : Okay, carry on

70 Student : Fusion will then take place and if we cross multiply we have BB, Bb, Bb and bb.

71 Teacher : How is it that the offspring have two genes for colour whereas the gametes had only one?

72 Student : Well, fusion occurred between two gametes and so fusion had a doubling effect.

73 Teacher : Okay, so what will the F1 phenotype be?

74 Student : These first three rats will be black and this last one will be white. We now need to see how this fits in with our question. "Determine the genotype of the female rat" Actually we not sure if this is the genotype of the female rat. We took it as a possibility. If we divide 24 by 8 because they say 24 were black and 8 were white - we get a ratio of 3:1 which is the case with the problem we just worked out.
Pause...

75 Teacher : So - what are you saying then?

76 Student : The genotype Bb we took is in fact the correct genotype.

77 Teacher : Are you confident of this answer then?

78 Student : Yes, but I need to check the answer by taking the other possibility BB. The P1 phenotype will still be black crossed with black. The genotype will be Bb crossed with BB this time.

79 Teacher : Okay.

80 Student : After meiosis the gametes will be B, b crossed with B
And then when fusion occurs we get BB and Bb. All the rats formed will be black.

81 Teacher : What do you now decide about "BB"?

82 Student : It cannot be BB and therefore Bb is correct.

83 Teacher : Why can BB not be correct?

84 Student : It does not produce white offspring, whereas we were told that 8 were white.

85 Teacher : Your answer is in fact correct.
Were you aware that the phenotypic ratio involving two hybrids in complete dominance is always 3:1?

86 Student : Yes - that is what Mendel found in his experiments.

87 Teacher : Could that not have given you more confirmation that the correct genotype was Bb, that is the female rat was also a hybrid -therefore the 3:1 ratio?

88 Student : Yes, It would have been a quicker way of checking whether the answer was correct.

89 Teacher : Okay then - that answer was correct - let's move on to question three.

90 Student : "The flow diagram below is a schematic representation of the life cycle of a fern. Study it and answer the questions set"
Okay here we have a diagram showing a life cycle of the fern - we need to know where to start - I would stay we will start with the fern plant itself. On the fern plant we have sori which contain sporangia
in which there are spore mother cells - here I would like to write that they divide by meiosis ... It may be required later

91 Teacher : Okay.

92 Student : to form spores and the spores from the prothallus which is the gametophyte and its contains reproductive organs which gives rise to the sperm and the egg and they fuse to form a zygote which forms the embryo which then gives rise to a new fern plant. The question says "on the flow diagram write down the term fusion and meiosis to show exactly where each of these processes occur" Well I already have meiosis done.

93 Teacher : Yes, I noticed that advanced planning.

94 Student : Fusion will be here where the sperm fuses with the egg to form a zygote

95 Teacher : Why is meiosis important in the place where you stated it occurs?

96 Student : The spore mother cells are said to be diploid that's (2n) and the spores are haploid that's (n) so it must have been meiosis to change diploid to haploid

97 Teacher : Why is it important for the spore to be haploid?

98 Student : It is going to give rise to a haploid prothallus.

99 Teacher : That's correct. And now finally - for 3.2.

100 Student : "If a cell in the pinna " that's a leaflet of the fern " of the fern plant has 20 chromosomes, which of the following A, B, C or D represents the correct chromosome number for each of the parts indicated" You see the pinna is a part found on the sporophyte generation and the sporophyte generation is diploid or (2n). So if this (2n) number is 20 chromosomes then the haploid (n) number will be 10 chromosomes. In the table they first say that the embryo has 10 chromosomes - but the embryo cannot have 10 since it is formed after fusion - so the answer cannot be A or B. So far it could be C or D.

101 Teacher : Okay

102 Student : We know the prothallus is haploid so it's correct 10, 10 (points to C and D) the sorus is diploid also and must have 20 chromosomes so C cannot be right because they say that it has 10. D is definitely the correct answer.

103 Teacher : That's correct
Before we round off, could you please draw a line on this diagram to separate all the haploid from the diploid parts.

104 Student : We need to see where fusion and meiosis occurs - that will give us an idea. (student draws this successfully)

105 Teacher : Right. And which would be the sporophyte and which the gametophyte?

106 Student : Above the line here would be sporophyte and this the gametophyte.

107 Teacher : Okay then that's it! - thank you so much for your time. I appreciate it.

APPENDIX 8.4. : TRANSCRIPT OF INTERVIEW WITH STUDENT TWO

1 Teacher : Nicholas, you will be asked to solve three problems now. You need to think aloud read aloud while searching for a solution. If you are ready you may begin with the first question.

2 Student : "Study the diagram below of a phase in a type of cell division." Okay - I looked at the diagram and realised it was Anaphase. "1.1. Which one of the following correctly represents the end result of cell division of the cell above? Pause ... [pupil glances at 4 alternatives provided] I think I need to figure out whether it is mitosis or meiosis ... and it is meiosis

3 Teacher : Why did you have to determine whether it was mitosis or meiosis?

4 Student : Because here there is two cells and here there is four [pupil points to cells in the various alternatives] , so we have to know whether mitosis or meiosis occurs to know which one to choose

5 Teacher : Why are you convinced that the cell represents meiosis?

6 Student : Because the cell is diploid

7 Teacher : What do you mean by that?

8 Student : The chromosomes are paired [pupil points to chromosomes in diagram]

9 Teacher : Is there a clearly observable reason in the diagram that it is meiosis?

10 Student : Well, yes - the chromosomes are moving apart

11 Teacher : Okay

12 Student : "B" is a possible answer because there are 4 cells formed since meiosis occurs Pause [looks at alternative B more closely] .... no, can't be "B".

13 Teacher : Why can it not be "B"?

14 Student : Because B does not show that crossing over occurs

15 Teacher : Crossing over may have occurred but it could not be shown in the drawing

16 Student : "B" may still be the answer

17 Teacher : Okay - you may reason through and given a definite answer when you are ready.

18 Student : "C" could be but then it cannot be because meiosis forms four cells. For the same reason A cannot be the answer - so it is either B or D. D seems like a possible answer too but there seems to be no crossing over

19 Teacher : You need to ignore crossing over in making your decision -since - as I said, only the use of different colours would have indicated whether it occurred.

20 Student : I think I will settle finally for "B"

21 Teacher : Why do you say it is "B"?

22 Student : In "B" the cells are not all identical, whereas in D they look alike

23 Teacher : Before I state whether your answer is right or wrong, let me ask you a question - How many chromosomes are there in this original cell?

24 Student : Eight

25 Teacher : And how many chromatids are there?

26 Student : No there's four chromosomes there and there will be eight chromatids

27 Teacher : If there are four in the original cell, how many will you expect to find in each cell at the end of cell division?

28 Student : Two

29 Teacher : Now look at alternative "B" which you chose as your answer -how many chromosomes does each cell have?

30 Student : Two .... No just one chromosome

31 Teacher : Could "B" therefore be your answer?

32 Student : No

33 Teacher : Why not?

34 Student : Because it was supposed to have two chromosomes after meiosis

35 Teacher : Would you like to rethink your answer in the light of that?

36 Student : Yes - the answer will have to be "D"

37 Teacher : Why do you think "D" is the answer?

38 Student : Because four cells have formed with two chromosomes each half the original number

39 Teacher : Well, "D" is in fact the correct answer - Now try question 1.2.

40 Student : "Which of the parts A, B, C or D on the graph applies most appropriately to the cell represented" [pupil looks at the cell being referred to] The distance of chromosomes from the poles .... this is the time taken
A will be quite close to the poles - the pole as in the centrosome - it can't be A because it is almost at the end -B... B could be a possible answer.

41 Teacher : Why do you think it is "B"?

42 Student : Because the chromosomes are not right at the poles

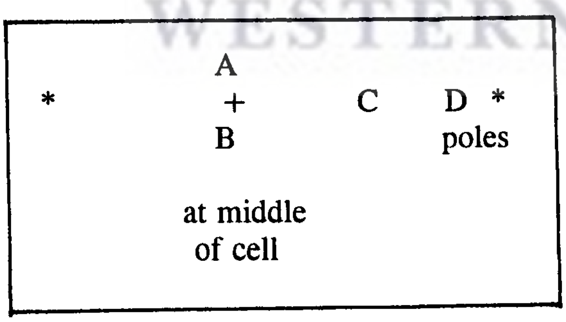
43 Teacher : Are the chromosomes at A and B at different positions in the cell?

44 Student : Yes - they are at different positions

45 Teacher : But in the graph the points A and B cuts this axis [teacher points to y axis] at the same point so what does that tell you?

46 Student : Oh yes - it means the chromosomes are the same distance from the poles - so if A is not the answer then B can't be correct also.
In C the graph is coming down here which means that the distance is decreasing - the chromosomes are moving closer to the poles. D is right down where the chromosomes are almost at the poles because the distance from the pole has decreased. The pole will be here , around here - the distance will be from there to there - so from A and B the distance is the same - so it is more toward the middle, so C will be closer to the pole - the distance will be shorter, and D will be almost at the pole.

[pupil makes the following sketch whilst reasoning the above:-



47 Teacher : Okay - now how does that help you?

48 Student : We can see from this diagram [one pupil drew) the answer is "C" because the distance is shorter - the chromosomes are moving to the poles.

49 Teacher : Why can the others not be possible?

50 Student : A and B is too far away from the poles and D is too close to the poles but in C the chromosomes are moving to the poles.

51 Teacher : Well - "C" is the correct answer
Let me now present you with problem 2. Start when you are ready. Please think and read aloud as you proceed.

52 Student : "A hybrid, black male rat was crossed with a female rat of the same colour but of unknown genotype. In the F1 the following results were obtained; black 24 and white 8. Determine the genotype of the female rat."

53 Teacher : So what will you do next?

54 Student : I will analyse the words like hybrid .... but I am not sure what hybrid means.

55 Teacher : Hybrid refers to an individual with genes that influence a characteristic in different ways. Does that help you in any way?

56 Student : Yes, but it shouldn't anyway because as shown here black was dominant over white

57 Teacher : How do you know that?

58 Student : There are more black rats than white rats in the offspring. So we have the results and we have to find the genotype of the unknown. We start with the key. Black is dominant and will be capital B and white will be small b. We know the F1 generation so we have to work backwards

59 Teacher : Okay

60 Student : Pause...

61 Teacher : What are you thinking about?

62 Student : I am trying to decide what to do but I do not know

63 Teacher : Well you developed a key - what was the reason for that?

64 Student : To work out a problem

65 Teacher : Is it possible to work out any problem here?

66 Student : But we do not known the genotype of the female rat

67 Teacher : Why don't you use what you do know and see what happens when you do get stuck

68 Student : The genotype will be black crossed with ....

69 Teacher : What is the difference between genotype and phenotype?

70 Student : Genotype is the outward appearance - how the rat really appears

71 Teacher : And what is phenotype?

72 Student : The generation that it belongs to

73 Teacher : Not quite - phenotype is the outward appearance but genotype refers to the genes the individual has. So is it correct when you say that genotype is black crossed with ... ?

74 Student : No, the phenotype will be black crossed with white.

75 Teacher : What is the colour of the male rat?

76 Student : Black

77 Teacher : What is the colour of the female rat?

78 Student : It is the same colour as the male so it is black

79 Teacher : But look at your phenotype - you have black x white

80 Student : No it will be black x black

81 Teacher : You have now completed the phenotype of which generation?

82 Student : the F1 generation

83 Teacher : But the two rats in question crossed to give rise to the F1 so can they be the F1?

84 Student : It would be the P1

85 Teacher : What is P?

86 Student : It is the parents - then meiosis occurs to form gametes (G1) and then...

87 Teacher : What process will occur to form the offspring?

88 Student : [no response]

89 Teacher : It is fusion

90 Student : Fusion, and then we have the F1 genotype and phenotype.

91 Teacher : Okay - you now have the genetics format - what next?

92 Student : The genotype of the male rat is Bb because it is a hybrid and the female rat should be recessive

93 Teacher : What is the recessive feature?

94 Student : White

95 Teacher : Is the female rat white?

96 Student : No, black ..... It could be Bb

97 Teacher : Are you sure about that?

98 Student : It could also be ... BB because it gives us black.

99 Teacher : Now you need to determine which one is correct. What will you do?

100 Student : We can try both. I will try Bb. It crosses with Bb

101 Teacher : I notice you are doing a crossing now which is related to fusion, but fusion cannot take place until gametes have been formed

102 Student : Oh - meiosis will occur to form gametes in the G1. The gametes for the male rat will be B, b.

103 Teacher : Why will each gamete have only one gene?

104 Student : Because meiosis has a halving effect. The other parent will have the same gametes B, b. When fusion occurs we get BB, Bb, Bb and bb

105 Teacher : Why do the offspring have two genes but the gametes have one?

106 Student : Fusion brought the genes from the two gametes together

107 Teacher : Okay and what will the F1 phenotype be?

108 Student : It would be three black and 1 white

109 Teacher : Well, have you answered the question?

110 Student : No we have 3 black and one white but the G1 had 24 black and 8 white. So it cannot be Bb - it must be BB

111 Teacher : So what would you now do?

112 Student : I will try the other one now

113 Teacher : Okay

114 Student : Bb crossed with BB, the gametes will be B, b crossed with B - the F1 genotype will be BB and Bb.

115 Teacher : What phenotype would you get?

116 Student : All will be black - so it cannot be BB - so it has to be Bb

117 Teacher : But you said it cannot be Bb earlier?

118 Student : With Bb we had white and black offspring, whilst with BB we only had black offspring.

119 Teacher : Look at the question again to see if there is a link between the F1 given and the F1 you worked out in the first problem

120 Student : 8 will go into 24 3 times, and into 8 one time - this is same as 3:1

121 Teacher : And what ratio did you obtain in your problem?

122 Student : also 3:1 - so Bb is definitely the correct genotype

123 Teacher : Correct - if you're happy with that then let's start problem 3.

124 Student : "The flow diagram below is a schematic representation of the life cycle of a fern. Study it and answer the questions set."
Okay - I'm looking at the flow diagram "On the flow diagram write down the term fusion and meiosis to show exactly where each of these processes occur." let's look at the flow diagram again - we start with the fern plant, the sorus, sporangium, spore mother cells and spores, then the prothallus then two different arrows going to the reproductive organs the 'n' sperm and egg going to zygote and embryo. Fusion will occur here [pupil refers to area just before "zygote"]

125 Teacher : What is the result of fusion?

126 Student : To form a zygote

127 Teacher : And where would you put meiosis in?

128 Student : I am looking at the embryo as a possibility -could be here as well - spore mother cell undergoes meiosis to form spores - yes it goes there [pupil writes meiosis after spore mother cells]

129 Teacher : That's correct - now what is important about meiosis there?

130 Student : To give rise to haploid spores as well as to bring about variation.

131 Teacher : Why is it important for the spore to be haploid?

132 Student : To form a haploid prothallus

133 Teacher : And are spore mother cells haploid or diploid?

134 Student : it is diploid

135 Teacher : Correct - now try 3.2. which is also based on the flow diagram

136 Student : "If a cell in the pinna of the fern plant has 20 chromosomes, which of the following A, B, C or D represents the correct chromosome number for each of the parts indicated.
I did not understand it so let me read it one more time. [pupil re-reads the question]
The embryo ... the pinna is 20 so the embryo... prothallus 10 - here it can't be 10 because it forms a diploid prothallus.

137 Teacher : Is the spore haploid or diploid?

138 Student : Haploid

139 Teacher : What process changes haploid to diploid?

140 Student : Fusion

141 Teacher : Did fusion occur to change the spore into a prothallus?

142 Student : No

143 Teacher : So could the prothallus be diploid?

144 Student : No - it has to be haploid also

145 Teacher : Okay - continue

146 Student : The embryo has to be like the zygote - diploid so it has to have 20 chromosomes - so it cannot be A or B -must be C or D ...
prothallus is 10 , sorus has to be 20 because meiosis only takes place later at the spore mother cell so it cannot be C but it is "D" for sure.

147 Teacher : Okay that is correct.
Just a few things more. On the flow diagram could you draw a line to separate all the haploid and diploid parts.

148 Student : [pupil does this]

149 Teacher : Which half would have 10 and which 20 chromosomes

150 Student : [student called sporophyte generation the gametophyte and vice versa]

151 Teacher : Well it is the other way around - you should look for the sporangium and gametes as clues to identifying the sporophyte and gametophyte respectively. Okay that completes all three questions.
Thank you very much for your time and effort.

APPENDIX 8.5. : TRANSCRIPT OF INTERVIEW WITH STUDENT THREE

1 Teacher : Prabashen, You will be given a series of three problems to solve. You need to think aloud and read aloud while trying to solve each problem. Okay - Let's begin with the first problem.

2 Student : "Study the diagram below of a phase in a type of cell division. [pupil looks at diagram] Which one of the following correctly represents the end result of cell division of the cell above." [pupil looks at diagram again] . Do I need to identify the phase?

3 Teacher : It is up to you

4 Student : This looks like anaphase - because the chromosomes are moving apart. "Which of the following correctly represents the end result of cell division of the cell above? ... Anaphase occurs so this is meiosis

5 Teacher : It also occurs in mitosis

6 Student : [Silence]

7 Teacher : What type of cell division is represented here?

8 Student : The chromosomes occur in pairs

9 Teacher : Show me any such pair?

10 Student : [pupil shows a homologous pair moving apart] -In one of the cell divisions the homologous chromosomes move to the poles

11 Teacher : In which cell division does that occur?

12 Student : In meiosis

13 Teacher : That's correct - continue

14 Student : "Which of the following correctly represents the end result of cell division of the cell above?" In meiosis there is a halving effect
Pause...

15 Teacher : What are you thinking about at the moment?

16 Student : I'm just trying to think what will be the end result. I think it will be C

17 Teacher : Why have you chosen C?

18 Student : This cell here [points to original cell and draws a line a vertical line that separates the cell into two parts] divides into two daughter cells , there will be like two different chromosomes in each. The chromosome number is halved

19 Teacher : Then why not "A" as an answer because there are also two chromosomes each?

20 Student : In A the homologous pair are together, but in the diagram we can see that they move apart

21 Teacher : Okay - Is that your final answer?

22 Student : Yes

23a Teacher : Why did you not consider B and D as possible answers?

23b Student : Because from the cell drawn, two cells will form

24 Teacher : How many cells form at the end of meiosis?

25 Student : Pause ... I'm not sure

26 Teacher : At the end of meiosis four new cells form - So how many cells should you expect to find in the correct answer?

27 Student : Four - so A and C cannot be correct - it must be B or D

28 Teacher : For which type of cell division would you have considered A and C?

29 Student : For mitosis

30 Teacher : Which one of B and D would you chose?

31 Student : D

32 Teacher : Why?

33 Student : They have different chromosomes in each cell -one maternal and one paternal

34 Teacher : How many chromosomes are there in each cell in D?

35 Student : Two

36 Teacher : So what has happened to the chromosome number?

37 Student : It has been halved

38 Teacher : Is that true of meiosis?

39 Student : Yes ... the halving effect

40 Teacher : Why would B be incorrect?

41 Student : Because there is only one chromosome in each cell

42 Teacher : Okay "D" is in fact the correct answer.
Let us now attempt the next question in problem one.

43 Student : "Which one of the parts A, B, C or D applies most appropriately to the cell represented? ...... Distance of chromosomes from the poles ... and .... time "[pupil reads off from graph] [pupil reads question again] [pupil looks at the cell represented]
Pause.....

44 Teacher : What are you thinking at the moment?

45 Student : I do not know what the question wants, so I will read the question again. [pupil reads question again] [pupil looks at graph]
Pause ....

46 Teacher : Do you know what information the graph is conveying?

47 Student : The distance of chromosomes form the poles at different times
Pause...

48 Teacher : Which one of these four [a, b, c or d] applies to the cell represented?

49 Student : Pause...

50 Teacher : You need to determine what is happening at point A, B, C and D on the graph

51 Student : In A the distance of chromosomes from the poles is .... [looks at graph] is great at B it is the same as A. In C the chromosomes are getting closer to the poles

52 Teacher : How do you know that?

53 Student : The graph is coming down - In D it is even closer to the poles

54 Teacher : Which one of the four that you've described is the best description of the cell given?

55 Student : [pupil reads question again] I think the answer is C

56 Teacher : Your reason for that?

57 Student : The chromosomes are close to the poles but not at the poles -
it is just getting there ... and the time taken - it is like towards the end of meiosis

58 Teacher : The answer is correct - it is "C". You can now start problem number two.

59 Student : "A hybrid, black male rat was crossed with a female rat of the same colour but of unknown genotype. In the F1 the following results were obtained; black 24 and white 8. Determine the genotype of the female rat." We must know what we mean by hybrid

60 Teacher : And do you?

61 Student : It is pure breeding

62 Teacher : It is in fact the opposite of pure breeding
Pause
Hybrid is the same as heterozygous
Pause
Hybrid means that two genes affect a particular characteristic in different ways - does that help you?

63 Student : Yes. "In the F1 the following results were obtained, Black 24 and White 8. We will draw a key. Since black is dominant over white black will be capital B and white will be small letter B

64 Teacher : How do you know that black is in fact dominant?

65 Student : Because more of the offspring were black

66 Teacher : Okay - is there any other way in which you could have figured that black was dominant?

67 Student : [pupil reads question again] the word hybrid : black must have been dominant for the male rat to be black

68 Teacher : Okay - what will you do next?
Pause

69 Student : It's been long since we did this work .... Pause

70 Teacher : What are you going to do next?

71 Student : I need to determine the genotype of the female rat - but now - "in F1 the following results were obtained " so we need to work out F2

72 Teacher : We do not need F2 since we want to know about the female parent that gave rise to the F1

73 Student : We need to work backwards then ....

74 Teacher : How are you going to do that?

75 Student : the genotype.... Pause

76 Teacher : You have drawn up a key - did you intend working out a genetics cross?

77 Student : Yes

78 Teacher : Okay then, start it

79 Student : [pupil writes down the genetics format] The phenotype of the male rat is B

80 Teacher : What is the difference between phenotype and genotype?

81 Student : Phenotype is the way it looks on the outside and genotype is the genes of the organism

82 Teacher : Now look at the way you wrote the phenotype

83 Student : I used "B" which is the gene - I supposed to write black crossed with black. The genotype would be Bb because it is hybrid "crossed with a female rat of the same colour but of unknown genotype" - we do not know the genotype of the female rat

84 Teacher : How are you going to overcome the problem there?
Pause
Do you know at least one of the two genes it will have?

85 Student : It is the same colour, black, so one of them will have to be "B"

86 Teacher : What other possibilities is there for the second gene?

87 Student : It could be another B or it could be a small "b"

88 Teacher : Which one is correct?

89 Student : I have to work out a separate one for each and see whether the answer is the same as the result given

90 Teacher : Okay, continue

91 Student : The genotype I will try first is BB... the gametes will be BB

92 Teacher : How did you get BB?

93 Student : I took the capital B from each parent

94 Teacher : Does that represent meiosis or fusion?

95 Student : Oh - that's fusion - the gametes will be B, b and for the female rat it would be "B".

96 Teacher : Why does each gamete only have one gene and the parents two?

97 Student : meiosis took place and it has a halving effect.

98 Teacher : Okay

99 Student : Fusion will occur and we get genotypes BB, Bb and all the offspring will be black .... [looks at question] so BB cannot be the correct genotype because none of the offspring turned out white. So therefore it will be Bb.

100 Teacher : How sure are you?

101 Student : I would work it out

102 Teacher : Okay, do that.

103 Student : It will be B, b crossed with B, b , the gametes will be B, b crossed with B, b .... after fusion the genotype will be BB, Bb, Bb and bb..... the phenotype will be ..... 3 black and one white.

104 Teacher : Did you get the same result as in the question?

105 Student : No, but 8 is a multiple of 24 - 8 can go into 24 three times -and 8 goes into 8 one time - that's same as 3:1 - we get the same ratio - so Bb is correct

106 Teacher : That's right. Let us now consider the last problem.

107 Student : "The flow diagram below is a schematic representation of the life cycle of a fern. Study it and answer the questions set." [pupil looks at flow diagram] embryo fern plant - sorus - sporangium -spore mother cell -spores- prothallus - reproductive organs - sperm and egg fuse to form a zygote "On the flow diagram, write down the term "fusion" and "meiosis" to how exactly where each of these processes occur." Fusion occurs here between sperm/egg and zygote. [pupil writes fusion]

108 Teacher : Why are you so sure it goes there?

109 Student : Because when a sperm and egg fuse a zygote forms
And meiosis has a halving effect - embryo develops from the zygote .... sporangium contains spore mother cells which undergoes meiosis- so it goes there [writes meiosis after spore mother cells]

110 Teacher : Why have you chosen to write it there?

111 Student : the spore mother cells undergoes meiosis to form spores.

112 Teacher : Correct - now why should meiosis specifically be the process to occur there?

113 Student : It allows the spores to develop into a prothallus
It can increase the number of chromosomes

114 Teacher : But you said before that meiosis halves the chromosome number?

115 Student : Oh - it allows haploid spores to form from diploid spore mother cells

116 Teacher : Okay - let's now move on to question 3.2.

117 Student : "If a cell in the pinna of the fern plant has 20 chromosomes, which of the following a , b, c or d represents the correct chromosome number for each of the parts indicated" [pupil re-reads question] [pupil then reads options given in A, B, C and D] It says that "the pinna of the fern has 20 chromosomes, which of the following is correct" ,.... there's 20 chromosomes in the pinna [pupil points to flow diagram] where the sorus and the sporangium is - after meiosis there should be ten, prothallus will be 10, zygote has 20 because of fusion.

118 Teacher : Why is fusion so important there?

119 Student : When fusion occurs the chromosome number is doubled

120 Teacher : Okay

121 Student : [pupil looks at alternatives] - so C and D looks like possible answers because there is 20 in the embryo and 10 in the prothallus.
The sorus ... after the embryo ... the sorus will still be 20, the egg cell will be 10 .... The answer will be D.

122 Teacher : Okay - and the answer is correct.
Thank you very much for giving up your time. You've been a great help.

APPENDIX 8.6. : TRANSCRIPT OF INTERVIEW WITH STUDENT FOUR

1 Teacher : Reginah, you will be required to solve a series of three problems. I need you to read and think aloud while you are working. You can start with the first problem.

2 Student : "Study the diagram below of a phase in a type of cell division. Which one of the following correctly represents the end result of cell division of the cell above" [pupil did not stop to look at diagram]
Pause...

3 Teacher : What are you thinking at the moment?

4 Student : I'm looking at the diagram - I'm thinking about this phase -the chromosomes are moving apart in the diagram -and the phase is prophase

5 Teacher : I'm not going to confirm that answer at the moment -continue -and you will find out if it is correct shortly

6 Student : [pupil re-reads question] - we need to choose the correct answer

7 Teacher : What are you thinking while looking at the alternatives?

8 Student : [pupil looking at alternatives] I'm looking at the chromosomes - in "C" they are in pairs

9 Teacher : So?

10 Student : So "C" is the answer

11 Teacher : Before I say whether your answer is correct -let me ask you a question - Does the cell drawn represent mitosis or meiosis?

12 Student : Meiosis

13 Teacher : Why do you feel it is meiosis?

14 Student : Because in meiosis the cells divide

15 Teacher : In mitosis the cells also divide - is there anything in the diagram that tells you it is meiosis?

16 Student : Yes, in meiosis, in prophase 1 the cells divide and ....
Pause...

17 Teacher : You remember earlier when you looked at the diagram, you told me that the chromosomes are moving apart -that is the reason why it is meiosis - in mitosis the chromatids move apart. Are you still confident that "C" is the answer?

18 Student : Yes

19 Teacher : Let me ask you another question. How many cells will form at the end of meiosis from one cell?

20 Student : Two cells

21 Teacher : And how many do you get in mitosis?

22 Student : Four

23 Teacher : It is the other way around - four cells form at the end of meiosis. You told me meiosis is occurring here, so how many cells should the correct answer have?

24 Student : Four

25 Teacher : So would you like to look at your answer again?

26 Student : C can't be right because they have two cells -in meiosis there must be 4 - so the answer is "B".

27 Teacher : But aren't there also 4 cells in "D"?

28 Student : Yes, they have four cells but in D they have chromatids but in B they have chromosomes

29 Teacher : In D they were chromatids but they are now called chromosomes. In B how many chromosomes are there in each cell?

30 Student : One

31 Teacher : And in D?

32 Student : Two

33 Teacher : So which answer will be correct - B or D?

34 Student : B with one chromosome

35 Teacher : Let me ask you this. How many chromosomes can you see in the original cell represented?

36 Student : Four

37 Teacher : What happens to the chromosome number in meiosis?

38 Student : It becomes halved

39 Teacher : So from 4 how many would you expect in the daughter cells?

40 Student : Two

41 Teacher : Which answer then reflects what you have just said?

42 Student : "D"

43 Teacher : Okay that is the correct answer.
You can now start the next question.

44 Student : "Which of the parts A, B, C or D applies most appropriately to the cell represented" .. "Distance of chromosome from the poles ... and the time" [pupil reads off from graph]

45 Teacher : And what are you thinking at the moment?

46 Student : Trying to see which one represents the cell drawn above [pupil looks at the diagram]

47a Teacher : What are you looking for?

47b Student : The chromosomes

48 Teacher : And what did you find?

49 Student : They are moving apart [pupil looks at graph again] I think it is point "D"

50 Teacher : Let us look at D - are the chromosomes far away from the poles, near the poles or at the poles?

51 Student : Far away from the poles

52 Teacher : Now look where point D falls on the Y axis -what does that tell you about the distance of chromosomes from the poles - is it small or large?

53 Student : Small distance

54 Teacher : So where are the chromosomes?

55 Student : They are near the poles because of small distance.

56 Teacher : In the cell drawn, are the chromosomes almost at the poles?

57 Student : No

58 Teacher : So could D be the answer?

59 Student : No ... B is not at the poles - the chromosomes are far from the poles - the correct answer is B

60 Teacher : In the diagram where are the poles [pupil points] and where would B be if it is a big distance from the poles?

61 Student : In the middle

62 Teacher : But are the chromosomes in the middle?

63 Student : No they are moving apart

64 Teacher : So could point B be correct?

65 Student : No - point C

66 Teacher : Why?

67 Student : Because the chromosomes are away from the poles but also away from the middle

68 Teacher : Correct - the answer is C. Can we move on to the next question now?

69 Student : "A hybrid, black male rat was crossed with a female rat of the same colour but of unknown genotype. In the F1 the following results were obtained; black 24 and white 8. Determine the genotype of the female rat."
That's P1 phenotype and meiosis and gametes, fusion, phenotype and genotype [pupil writes down genetics format]. We will now draw a key.
We have black male, and female is black because they say of the same color - that's the key , capital B and small b.

70 Teacher : I noticed you used both B and b for black - how come - is black the only colour involved?

71 Student : No white as well

72 Teacher : How will you then change your key?

73 Student : I will change the female to be white because female is recessive

74 Teacher : But you said the female was black. Do you draw the key based on the two colours in the problem or on the colour of the male and female involved?

75 Student : On the two colours

76 Teacher : Okay - do the key based on the two colours

77 Student : For black we have B and for white we have b

78 Teacher : Why did you chose capital B for black?

79 Student : Because black is dominant

80 Teacher : How do we know that?

81 Student : The problem says black male

82 Teacher : That does not mean that black is dominant. Is there any clue that led you to believe black is dominant?

83 Student : Yes, there are more black rats than white rats formed

84 Teacher : Okay that's correct. What next?

85 Student : We work the genotype and phenotype of the parents They are the same colour so black is the genotype of the male

86 Teacher : What is genotype?

87 Student : It is the outward appearance of the individual

88 Teacher : That is phenotype - genotype refers to the genes the individual has.

89 Student : Okay - then the phenotype is black crossed with black for the female rat. Then black male rat is BB - they are the same

90 Teacher : Why do you say that?

91 Student : It is hybrid

92 Teacher : Does hybrid mean the same? - hybrid is same as heterozygous

93 Student : Oh! then the two genes are different therefore it is Bb crossed with the female rat Bb

94 Teacher : Why Bb as well for the female?

95 Student : They say "of the same colour"

96 Teacher : Same colour means same phenotype not necessarily same genotype - it says of unknown genotype

97 Student : the genotype is unknown

98 Teacher : What possible genotype could there be?

99 Student : BB or Bb could give us black

100 Teacher : You have to decide which one is correct- How will you do that?

101 Student : I will use BB for the female rat. The gametes will be B, b crossed with B

102 Teacher : How is it that the gametes have one gene each but the parents two?

103 Student : Because in meiosis the cells divide

104 Teacher : Okay - carry on

105 Student : we multiply this by that, we have Bb, BB and the phenotype - all black.

106 Teacher : Which generation did you work out?

107 Student : The F1

108 Teacher : The results of the F1 is given . How does it compare with your results and can you accept BB as the answer?

109 Student : No because we got all black - we didn't get white - so the answer is Bb

110 Teacher : How do we know for sure?

111 Student : I will work another problem [pupil writes format] Bb crossed with Bb in the genotype. Then gametes are B,b crossed with B,b. The result is BB, Bb, bb.

112 Teacher : One is missing

113 Student : Oh! another Bb. We have 3 black and 1 white so this is correct - Bb

114 Teacher : But we did not get 24 black and 8 white

115 Student : But if we divide 24 by 8 we get 3 and if we divide 8 by 8 we get 1 - so it is the same - 3:1

116 Teacher : Okay that was good. Let us do problem three now.

117 Student : "The flow diagram below is a schematic representation of the life cycle of a fern. Study it and answer the questions set." [pupil looks at diagram] That's embryo, zygote, sperm, egg, reproductive organs, prothallus, spores, spore mother cells, sporangium, sorus, fern plant. "On the flow diagram write down the term 'fusion' and 'meiosis' to show exactly where each of these processes occur" Pause...

118 Teacher : What are you doing now?

119 Student : I'm looking at the diagram given - and eh...

120 Teacher : Are you looking for a place for meiosis or fusion at the moment?

121 Student : Meiosis ...... In the spore mother cell meiosis occurs [pupil writes meiosis before spore mother cell]

122 Teacher : Does meiosis occur before or after spore mother cells are formed?

123 Student : Before

124 Teacher : Are the spore mother cells haploid or diploid?

125 Student : Haploid

126 Teacher : And the spores?

127 Student : Diploid

128 Teacher : Why are the cells called "spore mother cells"?

129 Student : They divide to form daughter cells

130 Teacher : Okay - these daughter cells are called spores so where does meiosis occur then?

131 Student : It occurs after spore mother cells to form spores

132 Teacher : So which is haploid and which is diploid?

133 Student : The spore mother cell is diploid and the spores are haploid

134 Teacher : Why are they different?

135 Student : Meiosis occurs - it halves the chromosome number

136 Teacher : Right - 'meiosis' is at the right place - Where would 'fusion' go?

137 Student : Fusion would take place in the sporangium

138 Teacher : What structures fuse with each other?

139 Student : Sperm and egg - so fusion takes place here [points to sperm and egg in diagram - student writes fusion below sperm and egg]

140 Teacher : What is the result of fusion?

141 Student : The zygote - so fusion goes here [pupil now writes fusion between sperm/egg and zygote]

142 Teacher : Tell me - which way did you read the flow diagram - this way (teacher indicates clockwise) or that way (anti-clockwise)?

143 Student : This way (referring to anti-clockwise -against the direction of the arrows)

144 Teacher : And tell me will the zygote be haploid or diploid?

145 Student : Diploid

146 Teacher : And the egg and sperm ?

147 Student : Haploid

148 Teacher : Then how come the zygote becomes diploid?

149 Student : Because haploid fuse with haploid and become diploid

150 Teacher : Okay that's correct. Let's now look at the last problem.

151 Student : "If a cell in the pinna of the fern plant has 20 chromosomes, which of the following A, B, C or D represents the correct chromosome number for each of the parts indicated."
Pause ...

152 Teacher : What are you now doing?

153 Student : Looking at the flow diagram [pupil then looks at the table

154 Teacher : Do you know what the question requires of you?

155 Student : No

156 Teacher : You see one of these four is correct A, B, C, D. To choose the correct answer all the chromosome numbers of these 4 parts must be correct. How are you going to do that?

157 Student : I'll look at the question again [pupil reads question again] [pupil looks at table] I think the answer is "B".

158 Teacher : Why "B"?

159 Student : Because in B we got in the embryo 10, the prothallus is diploid so 20, the sorus 10 and the egg we got 20.

160 Teacher : That is not the correct answer - but wait - let me ask you another question. In the flow diagram put a line across the diagram to separate all the haploid parts from the diploid parts. [pupil does this by evaluating which parts were diploid] That's correct - now indicate which of the parts are haploid and which diploid. [pupil does this]. Also indicate the gametophyte and sporophyte.

161 Student : Gametophyte above the line.

162 Teacher : But the part above the line contains the sporangium

163 Student : Then it is the sporophyte, and gametophyte below the line

164 Teacher : Where are there 20 chromosomes?

165 Student : In the diploid fern plant

166 Teacher : Indicate all the parts that will have 20 chromosomes and those with 10 [pupil does this]. Now try to find the correct answer

167 Student : In the embryo 20 so it could be C or D ; the prothallus has 10 so C and D could be right; the sorus has 20 so it can't be C -it must be "D"

168 Teacher : How can you confirm that?

169 Student : The last one, the egg has 10 - so it has to be "D"

170 Teacher : That is right - very good. Thank you Reginah for your time. It is appreciated.

APPENDIX 8.7. : TRANSCRIPT OF INTERVIEW WITH STUDENT FIVE

1 Teacher : I have three problems that I would like you to work on. Please read and think aloud as you work them out.

2 Student : "Study the diagram below of a phase in a type of cell division. Which of the following correctly represents the end result of cell division of the cell above" [pupil looks at diagram]. This is meiosis because the homologous chromosomes are separating and moving apart

3 Teacher : Okay.

4 Student : and "Which of the following correctly represents the end result of cell division" - that's at the end of the whole process

5 Teacher : What are you doing or thinking at the moment?

6 Student : I'm just looking at the diagram and trying to see if I was correct about meiosis - I'm going through the phases in my mind ... Actually it is meiosis because it will divide to form two when the chromosomes separate, and then it will divide again to form four when the chromatids separate.

7 Teacher : Are you sure then that it is meiosis?

8 Student : Yes I'm certain

9 Teacher : Okay, continue

10 Student : "Which correctly represents the end result" -The answer is "D"

11 Teacher : Before confirming your answer, tell me , why can "C" not be correct?

12 Student : Because in meiosis the chromosome number is halved

13 Teacher : The cells do have half the number of chromosomes - don't they?

14 Student : Yes, but you want the end result, because this is meiosis and the cells in "C" will result after the reduction division of meiosis -not at the end of meiosis because then there would be four cells

15 Teacher : Okay, then why did you not choose "B" where there are four cells as well?

16 Student : Because once this cell divided, there will be two different cells. Then in each cell the centromere splits and the chromatids separate - so they will not appear double stranded.

17 Teacher : Is there any other visible reason why you would not accept "C"?

18 Student : The number of chromosomes - After halving one would expect 2 chromosomes, not one

19 Teacher : So why is "D" definitely the answer?

20 Student : Because there are 4 cells each with half the number of chromosomes as the original cell.

21 Teacher : Okay - good, that answer is correct
Now try the next question.

22 Student : "Which of the parts A, B, C or D on the graph applies most appropriately to the cell represented" [pupil looks at graph] Distance of chromosome from the poles .... Time .... [pupil re-reads question] [pupil looks at diagram of cell]. These are the poles of the cell -where the centrosome is [pupil points to two ends of cell] [pupil looks at graph again]

23 Teacher : What are you thinking?

24 Student : I'm confused - I can't picture it in a graph form

25 Teacher : Then why don't you picture it in another form?
Pause ....
Why don't you picture it in terms of the cell and see how the information in the graph fits into the cell

26 Student : At point A the chromosomes are not that close to the poles

27 Teacher : How do you know that?

28 Student : This is the pole [pupil points to the Y axis] and this point A is a short distance away from the pole

29 Teacher : The Y axis is not the pole - the graph is not showing the poles but it is showing the distance of the chromosome from the poles. The cell shows the poles. What is happening to the distance as you go up the Y axis?

30 Student : The distance is increasing

31 Teacher : And where is point A - low down or high up in the graph?

32 Student : It is high up which means the distance from the poles is great

33 Teacher : In the diagram which spot is furthest from the poles?

34 Student : The middle

35 Teacher : So what point can you label it as?

36 Student : Point A - then point B will also be there because it is the same distance away from the poles.

37 Teacher : How do you know that?

38 Student : It is on the same line as A

39 Teacher : Where in the cell will the chromosomes be at point "D"?

40 Student : It is closest to the poles

41 Teacher : And where did you get that information?

42 Student : On the graph - by reading off from the Y axis -it is a short distance from the pole

43 Teacher : Show me where that is on the diagram [pupil does this]. And where would point "C" be?

44 Student : "C" is the answer because it is between the middle and the poles - it is at about the same position where the chromosomes are moving apart towards the poles.

45 Teacher : Okay - "C" is in fact correct. What would you say gave you trouble with this question?

46 Student : I was not able to fit the graph and diagram together.

47 Teacher : Do you normally have a problem with interpretation of graph?

48 Student : Not really - I think I isolate my subjects -because in Physics I can deal with it but in Biology - I just don't relate graphs to Biology.

49 Teacher : Okay - let us start problem 2.

50 Student : "A hybrid, black male rat was crossed with a female rat of the same colour but of unknown genotype. In the F1 the following results were obtained; black 24 and white 8. Determine the genotype of the female rat." "Hybrid male rat" - the genes are different which affect the characteristic - "crossed with a female rat of the same colour" - so I think black - we will make it dominant - it will be capital B and white small b.

51 Teacher : How did you know that white was the second colour?

52 Student : It was stated in the results of the F1

53 Teacher : And how did you deduce that black was dominant?

54 Student : Because the male rat was hybrid black - For it to be black the dominant gene must have been for the black colour

55 Teacher : Is there any other way that you could have figured that out?

56 Student : Yes - in the F1 there were more black offspring than white

57 Teacher : What next?

58 Student : "In the F1 the following results were obtained Black 24 and White 8. Determine the genotype of the female rat." Pause ...

59 Teacher : What are you going to do now?

60 Student : I can assume the female rats genotype - work out a problem and see - If so many offspring are black - maybe both the genes in the female are for black that is BB. Lets us check.
The phenotype of the male is black crossed with black for the female. The genotype of the male is Bb crossed with the female, BB -this is trial and error so we will use BB first.

61 Teacher : Okay

62 Student : Then they undergo meiosis

63 Teacher : What is the significance of meiosis here?

64 Student : They help form the gametes

65 Teacher : Okay.

66 Student : The gametes are B, b crossed with B

67 Teacher : Why is it that the gametes only have one gene whilst the parents have two?

68 Student : Meiosis halves the chromosome number

69 Teacher : Right, continue

70 Student : In the F1 genotype we get Bb and BB and for the phenotype, all will be black so BB can't be correct

71 Teacher : Why not?

72 Student : Because in the F1 results given there were white offspring in addition to black offspring.

73 Teacher : That's correct - but now we have a problem -what then is the genotype of the female rat?

74 Student : The other possibility is Bb, the same as the male

75 Teacher : Why can't it be bb?

76 Student : It would be white, not black. Let's try out Bb. The gametes will be B, b crossed with B, b - this after fusion leads to the following F1 genotypes - BB, BB, Bb and bb -and the phenotype is 3 black and 1 white

77 Teacher : So where does that take you because we do not have 3 black and 1 white in the F1 given?

78 Student : This is a ratio thing where with 24 : 8 the ratio is also 3 : 1 same as our answer - for every 1 white there will be three black-so the unknown genotype is Bb

79 Teacher : And - that is entirely correct. Now try out problem 3.

80 Student : "The flow diagram below is a schematic representation of the life cycle of a fern. Study it and answer the questions set. On the flow diagram, write down the term "fusion" and "meiosis" to show exactly where each of these processes occur". [pupil looks at flow diagram] From the embryo we get the fern plant which has the sorus that have sporangia that contains spore mother cells where meiosis occurs to form haploid spores ...

81 Teacher : Why do you think that is the appropriate place for meiosis?

82 Student : Because the spore mother cells are diploid

83 Teacher : And are the spores haploid or diploid?

84 Student : They are haploid

85 Teacher : How is it the spores are haploid yet they formed from something that was diploid?

86 Student : Because of meiosis

87 Teacher : What about meiosis?

88 Student : Meiosis halves the chromosome number

89a Teacher : Okay carry on

89b Student : The prothallus - we have reproductive organs, and sperm and egg fuse to form a zygote - so fusion goes there [pupil writes "fusion" between sperm/egg and zygote"]

90 Teacher : Is the zygote haploid or diploid?

91 Student : Diploid

92 Teacher : How did it come to be diploid?

93 Student : When the sperm and egg come together - they are both haploid -so they form a zygote that is diploid.

94 Teacher : Okay - both your answers are correct. Let us move on to the last question. You may begin.

95 Student : "If a cell in the pinna of the fern plant has 20 chromosomes, which of the following, A, B, C or D represents the correct chromosome number for each of the parts indicated." ... The embryo will be diploid, the prothallus will be haploid, the sorus will be diploid and the egg will be haploid [pupil writes 2n, n, 2n, n on top of table]

96 Teacher : How did you figure all that out - because such information was not given?

97 Student : In the flow diagram - after fusion everything is diploid, but after meiosis everything is haploid

98 Teacher : Okay - continue

99 Student : "The pinna of the fern plant has 20 chromosomes"- The pinna is part of the leaf so it is sporophyte and will be diploid." 20 chromosomes is diploid , haploid number is 10. We then need 20, 10, 20 and 10 since we have diploid, haploid, diploid and haploid. So the answer is "D".

100 Teacher : That is correct. Thank you for your time Sabashinee.

APPENDIX 8.8. : TRANSCRIPT OF INTERVIEW WITH STUDENT SIX

1 Teacher : Anand, you will be given a series of three problems to work out. I need you to read aloud and think aloud as you are working. You may start with the first question.

2 Student : "Study the diagram below of a phase in a type of cell division. [pupil studies the diagram] Which one of the following correctly represents the end result of cell division of the cell above?" [pupil looks at alternatives] [pupil reads question again]

3 Teacher : When you looked at the diagram - what occurred to you -what caught your attention?

4 Student : I noticed the breaking up here of the chromosomes.

5 Teacher : Fine!

6 Student : The answer will be "C"

7 Teacher : Before I confirm your answer let me ask a question. What type of cell division does the diagram show?

8 Student : Meiosis

9 Teacher : Why do you say that?

10 Student : The moving apart to the poles

11 Teacher : But in mitosis there is also a moving apart. So what is different about the moving apart here?

12 Student : In pairs

13 Teacher : Okay - that is true of meiosis. In the light of that -would you still say that "C" is the answer?

14 Student : Yes

15 Teacher : How many cells are formed at the end of meiosis?

16 Student : Two

17 Teacher : And how many cells are formed at the end of mitosis?

18 Student : Also two ... no four

19 Teacher : It is the other way around - so how many would you expect in meiosis?

20 Student : Four

21 Teacher : Do you still think "C" is the answer?

22 Student : No

23 Teacher : Why do you think "C" is now wrong?

24 Student : In "C" there are two cells instead of four.

25 Teacher : Could "A" be an answer?

26 Student : No - because there are two cells only

27 Teacher : So what are you going to do now?

28 Student : I have to choose between "B" and "D"

29 Teacher : How are you going to do that now?

30 Student : [pupil looks at chromosomes in diagram] I think when they separate and combine they will be two different shapes so the answer will be "D"

31 Teacher : Since "B" also has four cells why can't it be the answer?

32 Student : The cell separates here [pupil draws vertical line down diagram] so these two chromosomes end up in one cell and these two in the other cell. In B we cannot see those two chromosomes together.

33 Teacher : But in "D" do those two chromosomes there [referring to original diagram] resemble the two in each of these cells?

34 Student : No

35 Teacher : How are they different?

36 Student : In the diagram - they are double but in the answer they are single

37 Teacher : How did they come to appear differently?
Pause...
Okay the cell will divide once first to get two cells, but we need four cells , so what must happen. ?

39 Student : Each cell must divide again

40 Teacher : How will that happen?

41 Student : The chromosomes will separate - the centromere breaks

42 Teacher : Will the chromosomes in the end result therefore be double or single?

43 Student : They will now be single

44 Teacher : How many chromosomes are there in the original cell?

45 Student : Eight

46 Teacher : And how many chromatids are there?

47 Student : Eh! No - there are four chromosomes and eight chromatids

48 Teacher : How many would you expect in the end result of meiosis?

49 Student : Two

50 Teacher : Why do you expect two in each cell?

51 Student : Meiosis halves chromosome number.

52 Teacher : So what is your final answer - B or D?

53 Student : D - because there are two chromosomes, whereas in B there is only one chromosome.

54 Teacher : Okay that is correct. Let's move on to the next question.

55 Student : "Which of the parts A, B, C or D on the graph applies most appropriately to the cell represented. Distance of chromosomes from the poles .... time [pupil looks at graph]" [Pupil re-reads the question]

56 Teacher : What are you thinking?

57 Student : This is meiosis.... breaking up - so...
Pause...

58 Teacher : Do you have an idea of what the question requires of you?

59 Student : No

60 Teacher : You see this graph has four points - Each point represents what is happening to the chromosomes during meiosis. You need to see which one (A, B, C or D) is true for the chromosomes in the cell given. So you need to know what the graph tells you about the four points. What is the graph giving you information about?

61 Student : The cell

62 Teacher : Is it the whole cell or something about the cell?

63 Student : Chromosome number

64 Teacher : Show me where on the graph you get that information

65 Student : "Distance of chromosome from the poles"

66 Teacher : Is that chromosome number?

67 Student : No - it's how far the chromosomes are from the poles

68 Teacher : So what does "A" tell you about the distance of chromosomes from the poles?

69 Student : It is close

70 Teacher : According to the Y axis what happens to the distance as one moves up?

71 Student : It is increasing

72 Teacher : Point A - is the distance small or great?

73 Student : The distance is great

74 Teacher : Show me on the diagram where the chromosomes will be for point A

75 Student : It will be here [pupil points to middle]

76 Teacher : In the same way try to figure where B, C and D will be.

77 Student : B will be at the same place - in the middle

78 Teacher : Why?

79 Student : It is at the same level "C" will be here between the middle and the poles

80 Teacher : Why do you say that?

81 Student : The chromosomes are moving apart

82 Teacher : And where will "D" be?

83 Student : It will be a small distance from the poles -near the centrosomes.

84 Teacher : So what is the answer?

85 Student : [pupil reads question again] It will be "C"

86 Teacher : Why?

87 Student : It is not a great distance from the poles like A and D but also it is not too near the poles like D.

88 Teacher : That's correct - good. You can start problem two.

89 Student : "A hybrid, black male rat was crossed with a female rat of the same colour, but of unknown genotype. In the F1, the following results were obtained , Black 24 and white 8 . Determine the genotype of the female rat"
[student re-reads the question] Pause ...

90 Teacher : What are you going to do now?

91 Student : This is a genetics problem - so I have to start of with the format

92 Teacher : Okay

93 Student : Key, F1 generation

94 Teacher : Do you start with the F1?

95 Student : Oh no -it's the parents - the P1, then the genotype and phenotype, then meiosis

96 Teacher : What does meiosis give rise to?

97 Student : To the gametes

98 Teacher : So would F1 come next then?

99 Student : No , no it will be G1 , then it will be fusion leading to the F1.

100 Teacher : Okay what will you do next?

101 Student : I'll do the key. Capital B for black -both are black rats so both will be B

102 Teacher : Do you draw a key according to the male and female or according to the two colours involved?

103 Student : The colours

104 Teacher : You have been concentrating on the male and female involved. Try drawing a key based on the two colours involved

105 Student : Capital B for black because we don't know what is dominant

106 Teacher : What colours are involved in this question?

107 Student : Black

108 Teacher : Any other colour?

109 Student : No

110 Teacher : Look at the question again [pupil reads question]

111 Student : There are two colours, black and white.

112 Teacher : Now draw up a key for black and white.

113 Student : For black it will be capital B and for white it will be a small b.

114 Teacher : Why did you choose a capital for black and a small letter for white?

115 Student : In the F1 there were more black and less white, so black is dominant over white.

116 Teacher : What do you do next?

117 Student : The phenotype of the parents is black [pupil writes B instead of black]

118 Teacher : You have written just "B" - is that B the outward appearance or is it the gene that makes the rat black?

119 Student : Silence

120 Teacher : What is phenotype?

121 Student : It's what the appearance will be

122 Teacher : So can we say that the rat is "B" in colour?

where each of these processes occur". Fusion goes here [pupil writes fusion between sperm/egg and zygote]

184 Teacher : And what forms when fusion occurs?

185 Student : A zygote

186 Teacher : Is it diploid or haploid?

187 Student : It will be haploid

188 Teacher : Is the sperm and egg haploid or diploid?

189 Student : ...... it will be ... haploid

190 Teacher : If a haploid sperm fuses with a haploid egg what will the zygote be ?

191 Student : Diploid

192 Teacher : That's correct. - Where will meiosis occur?

193 Student : Here [pupil writes meiosis after spore mother cells]

194 Teacher : What role does meiosis play there?

195 Student : It breaks up the spore mother cells into spores

196 Teacher : Is the spore mother cell haploid or diploid?

197 Student : It will be diploid

198 Teacher : Is the spore haploid or diploid?

199 Student : Haploid

200 Teacher : How did the spore turn out haploid?

201 Student : Meiosis took place - halving effect

202 Teacher : Correct. Both answers are right. Let's try the last question now.

203 Student : "If a cell in the pinna of the fern plant has 20 chromosomes, which of the following A, B, C or D represents the correct chromosome number for each of the parts indicated." [pupil looks at table then diagram]

204 Teacher : What are you thinking?

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