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	SChetty
Name	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