THE USE OF A VIRTUAL WORLD TO ADDRESS MISCONCEPTIONS HELD BY STUDENTS REGARDING PHOTOSYNTHESIS AND RESPIRATION

by

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Abstract

In an effort to contribute to the improvement of Matric Biology education, a survey was conducted in 1996 and 1997 of Matric pupils and first year students at several tertiary institutions, in order to identify those topics which learners found most difficult. Photosynthesis and respiration were among the topics with which Matric Biology learners experienced many conceptual difficulties. The aim of this project was twofold: firstly to identify specific misconceptions students had regarding these topics, and secondly, to develop and evaluate a learning tool that would address these misconceptions.

In order to identify the most common specific misconceptions, a quantitative research approach was taken. A three-tiered multiple choice questionnaire was developed, and administered to first year students in the 1998 intakes at ML Sultan Technikon and the Biology Department of the University of Natal, Durban. It was also administered to students at the end of their first, second and third years of Cell Biology (University of Natal). Analysis of the questionnaires revealed that students did not understand the complementary relationship between photosynthesis and respiration.

Computer-based virtual worlds provide constructivist learning environments, in which visualisation and problem solving in a complex system is possible. It was proposed that use of a virtual world would be an effective means of addressing the misconceptions we identified. A game was developed that presented students with authentic tasks of filling an oxygen cylinder (as an air supply) and a carbon dioxide cylinder (which would later be used to extinguish a fire). In order to do this students were required to solve a series of three puzzles, all of which related to the processes of photosynthesis and respiration. To account for different learning styles, the puzzles were based on three of Gardner's multiple forms of intelligence.

Evaluation of the virtual world made use of a combination of quantitative and qualitative research methods. Students' understanding of the processes was measured with the use of the questionnaire. A deeper evaluation of their understanding and affective response to the game was obtained through interviews.

It was found that students who had played the game had a clearer understanding of the complementary relationship between photosynthesis and respiration, and understood that respiration in plant cells is a continuous process. Students also showed greater confidence in their grasp of the processes, and reported that playing the game had been an enjoyable way of complementing their traditional lecture material in order to master these concepts. The virtual world was an effective learning tool for addressing the misconceptions students held regarding photosynthesis and respiration.

Preface

The work described in this thesis was carried out in the department of Biology, University of Natal, Durban, under the supervision of Professor Alan Amory and Mr. Costa Criticos.

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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"Sometimes, it is not your own faith that sustains you, but the faith of those around you."

\- Tracey Way, 1997

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1. Introduction

The research presented in this thesis was conducted under the auspices of the Biological Pedagogy Research Unit (Bioped), part of the Department of Biology at the University of Natal, Durban. The unit is headed by Professor Alan Amory, and offers courses at both graduate and postgraduate levels in the use of multimedia for Biology education. The department also offers research-based Master of Science degrees directed by Bioped.

In 1997, Amory proposed the hypothesis that the introduction of computer technology into the South African education system could help initiate a change from a didactic to a constructivist approach to education. A number of research projects were born out of that hypothesis. This project is one of three that investigate the effectiveness of computer-based learning at the Matric level. It is an attempt to enhance the teaching and learning of one aspect of the Matric Biology syllabus – the relationship between the processes of photosynthesis and respiration in plants.

Through the use of a questionnaire, Matric pupils and first year students at several tertiary education institutions identified these processes as two of the most difficult topics in the Matric biology syllabus (Amory, unpublished). We proposed that part of the conceptual difficulty experienced by students was due to the traditionally didactic, or instructivist, approach taken to teaching Matric biology. It was proposed that adopting a more constructivist approach would lead students to a deeper, more meaningful understanding of these processes. The use of computer technology could mediate this change.

My research comprised two phases. The first phase involved identifying the specific misconceptions held by South African students regarding photosynthesis and respiration. In order to identify the most prolific misconceptions, a quantitative research approach was required. To this end, a questionnaire was constructed based on the contents of the sections on the two processes in the Matric Biology syllabus. This was administered to students in different years of study at two tertiary education institutions.

The results of this survey exposed the most common misconceptions held by students. These related to the relationship between photosynthesis and respiration. It was proposed that an effective means of addressing these misconceptions would be a virtual world in which students were required to solve problems using an integrated understanding of the processes. The second phase of this research involved the design and evaluation of this learning tool. To test the hypothesis that the virtual world was an effective means of addressing the misconceptions we identified, a combination of quantitative and qualitative research methods was used.

Chapter one of this thesis provides a literature review of the development of modern learning theories, how they have influenced curriculum design, teaching practice and the use of computer technology in the classroom. Aspects of science education research regarding learners' misconceptions regarding photosynthesis and respiration will also be discussed.

The second chapter of this thesis describes the first phase of the research: the identification of the most common misconceptions held by South African students regarding photosynthesis and respiration. The choice of methodology is discussed and the findings are presented.

Chapter three describes the manner in which misconceptions were addressed. The design of the virtual world is described in section 3.1.1. Its effectiveness as a learning tool was evaluated using a combination of quantitative and qualitative research methods. The choice of methodology is discussed in 3.1.2 and a discussion of the results is presented in section 3.2.

Chapter four comprises a conclusion of the study.

1.1 Literature review

1.1.1 A history of modern learning theories

Learning theory was developed as part of the science of psychology. One of the first formulators of psychological theory, Wilhelm Wundt stated that consciousness could be broken down into its smallest elements or atoms through the process of introspection, and that associations link these elements. This statement formed the point of departure of two major schools of psychology: Behaviourism and Gestaltism (Sprinthall and Sprinthall, 1990).

The Gestaltists, lead by Max Wertheimer, criticised Wundt on the basis of their belief that breaking down experience (perception or consciousness) into its smallest pieces destroys the overall experience. To the Gestaltists, changing a single part of the whole changes the whole, while the whole may remain even when all the parts have changed. In essence, the whole (or the overall relationship) is greater than the sum of its parts (Sprinthall and Sprinthall, 1990).

The Behaviourists, on the other hand, criticised Wundt for his use of introspection as a method of study (Sprinthall and Sprinthall, 1990). Behaviourists held a highly mechanistic view of humankind. People were seen as elaborate machines whose behaviour is determined largely by their environment and no distinction was made between humans and other animals. The Behaviourists denied the existence of introspection, cognition and volition and considered these irrelevant, as only observable behaviour could be measured (Kolesnik, 1970). In fact, James Watson, the father of behaviourism, suggested that psychology be redefined as the 'study of behaviour' rather than 'the study of phenomena of the consciousness' (Spencer, 1988).

These two major schools of psychology spawned related learning theories. Within the Behaviourist school developed the Associationist Theory of learning (Sprinthall and Sprinthall, 1990). Gestalt psychology, on the other hand, influenced the development of

Field Theory (Kolesnik, 1970) or Cognitive Learning Theory (Sprinthall and Sprinthall, 1990).

1.1.1.1 The Associationists

During the eighteenth and nineteenth centuries, early psychologists such as Locke, Hobbe, Humes and Hartley believed that learning occurred on the basis of an association of ideas (Kolesnik, 1970). Contemporary Associationists, however, base their theory, called Connectionism, on an association of stimuli and responses (Kolesnik, 1970). The first of the early Connectionists was Edward Thorndike (1874 - 1949). His work initially dealt with a mechanistic account of animal learning and intelligence and was heavily influenced by Darwinian theory. To Thorndike, the starting point for the formation of associations was the set of instinctive activities aroused by environmental stimuli. Gradually, through trial-and-error, stamping in or out of correct or incorrect stimulus-response (S-R) associations occurred. This formed the basis of his Law of Connectionism (Spencer, 1988).

Three major laws governed this form of learning: the laws of readiness, effect and exercise (Sprinthall and Sprinthall, 1990). The law of readiness indicated a neurological state of the animal in which an unimpeded connection between stimulus and response could be made. The law of effect stated that rewards (successes or failures) formed the mechanism for the selection of more adaptive responses. (Reward or punishment, or success or failure, would either strengthen or weaken an S-R connection). The law of exercise stated that the more often an S-R connection was made the stronger it would become (Kolesnik, 1970; Spencer, 1988). This law of exercise was later amended to include the fact that exercise would only strengthen an S-R bond if accompanied by feedback (Sprinthall and Sprinthall, 1990).

The second of the early Connectionists was Ivan Pavlov (1849 - 1936) (Spencer, 1988). Pavlov was a physiologist initially concerned with the digestive processes of dogs. He observed that dogs not only salivate while eating food, but even at the sight or smell of it.

In fact he found that everything associated with the environment of receiving food elicited the same response. Pavlov held the view that there was a relationship between physiology and psychic activity. He believed that the nervous system and brain could account for all psychical phenomena through the mechanism of reflex arcs. Proof of this, he believed, came with the discovery of the conditioned reflex (CR) (Spencer, 1988). According to Pavlov, any stimuli could be linked (Spencer, 1988). A natural or unconditioned stimulus (US) (e.g. the food) would elicit an unconditioned reflex (UR) (salivation by the dog). Should the US be paired with a neutral stimulus (e.g. the sound of a bell ringing), this neutral stimulus alone could eventually produce the same response. The sound of the bell would now be called the conditioned stimulus (CS) and would result in the dog salivating. This became known as classical conditioning (Sprinthall and Sprinthall, 1990). In Pavlov's opinion, all complex learned behaviour is simply an orchestration of conditioned reflexes which are physiological, rather than mental (Spencer, 1988).

James Watson's (1878 - 1958) work followed that of these early Connectionists. Watson was the founder of Behaviourism. His view was that all organisms adjust to their environment either through hereditary means or through habit formation (Spencer, 1988). He also claimed that certain stimuli always lead to particular responses. Given a response, the stimulus could be predicted, and vice versa. By applying this knowledge he believed that behaviour could be controlled (Spencer, 1988). Part of his contribution to classical conditioning theory was that stimulus generalisation can occur, where a wide range of similar stimuli can be unintentionally linked by the learner, and lead to the same response. He also found that extinction of a response can occur when the CS is repeatedly presented alone, and never reinforced by the US (Sprinthall and Sprinthall, 1990).

The champion of modern association theory is E.B. Skinner. He applied his theories to classroom teaching more than any other Association Theorist (Kolesnik, 1970). Skinner defined two types of response: A respondent is a reflex triggered by a spontaneous, unlearned stimulus (the type of response operational in classical conditioning). An operant is a response for which the stimulus is either unidentified or nonexistent. An operant is purely voluntary, and when followed by a reinforcing stimulus, the probability of the operant being repeated is increased. This forms the basis of operant conditioning and is more closely related to the type of learning that takes place in the classroom. For example, if the teacher asks the class a question and pupils raise their hands to answer it, the teacher may praise them for a correct answer, or even an answer that partially answers the question. The teacher's praise, or reward, is the reinforcing stimulus that will increase the probability of the pupil attempting to answer questions in the future (the operant). The pupils' response cannot be forced, but the probability of it occurring can be increased (Sprinthall and Sprinthall, 1990).

Operant conditioning formed the basis of Skinner's Reinforcement Theory. In his opinion, learning is simply operant conditioning, and teaching is an arrangement of contingencies of reinforcement (Kolesnik, 1970). Reinforcement is necessary as soon as possible after the desired response has occurred (Sprinthall and Sprinthall, 1990). Skinner believed that learning is inadequate in most classrooms because there is not enough reinforcement, or it is not delivered at the right time (Kolesnik, 1970).

While Behaviourism and Association theories have contributed much to the understanding of certain forms of learning, they do not account for all forms of learning. These theories have been criticised for being too much of a robot model with little emphasis on growth and development. The process of learning is attributed to the influence of the environment on the senses, with no mention of intellect or purpose. Another criticism is that most behavioural studies have been carried out on animals and the findings simply extrapolated to humans. It seems likely that there are some differences between animal and human learning (Sprinthall and Sprinthall, 1990). Most modern educators believe that learning is more than conditioning, that it involves mental processes, purpose and motivation. The Cognitive Theories of learning place more emphasis on these factors.

1.1.1.2 The Cognitive Theorists

Although there are different schools of thought within Cognitive or Field Theory, most Cognitive Theorists agree that our purposes, perceptions, and the concept of relativism all influence behaviour and learning. They do not view learning as a simple reaction to the environment, but as a discovery of meaning in a relationship with one's personal environment. Influenced by Gestaltism, Cognitive Theory maintains that stimuli and experiences are organised and structured together, and that reactions do not occur to individual stimuli, but to these organised patterns as a whole (Kolesnik, 1970). Things have no inherent meaning of their own, but in their relationship to other things and to the knower (Kolesnik, 1970).

To Cognitive Theorists, learning is far more complex and abstract than it is to Association Theorists. This is due to the role of perception. Perception is the process by which an individual derives meaning from sensory experience (Kolesnik, 1970). It is the mental process between the sensing of a stimulus and the making of a response. Perception is abstract in that it not only changes as the environment changes, but it is also selective. To the Cognitive Theorists, learning involves reorganisation or restructuring of previous experiences, so that one comes to perceive things in a new way. Early cognitive theorists, such as Max Wertheimer and Wolfgang Kohler, maintained that learning (even in certain animals) was not by trial-and-error, but occurred as a sudden realisation or insight (Kolesnik, 1970).

The foremost modern cognitive theorist was Jerome Bruner (Sprinthall and Sprinthall, 1990). He believed that the aim of teaching, or learning, is that the student understands the overall structure of the subject matter. Bruner claimed four benefits to understanding the structure of the whole in relation to other subject matter. By learning the fundamentals, the subject is more comprehensible; details are retained because they have been learned within an organised structure; vertical transfer of knowledge is facilitated (i.e. simpler concepts can be built upon to understand more complex concepts); lateral transfer is facilitated (i.e. knowledge from one subject can be used in another subject or context) (Kolesnik, 1970).

Bruner upheld four principles of learning and teaching (Sprinthall and Sprinthall, 1990):

1) Motivation

Children have a natural curiosity and desire to learn, as well as a drive to achieve competence. The teacher should activate this intrinsic motivation and direct the student's exploration with safety and guidance.

2) Structure

Bruner believed that a lesson could be structured in such a way that any student could understand it. This could be achieved through the mode of presentation (either enactive, iconic or symbolic, depending on the age of the learner), supplying the appropriate amount of information for the learner to continue learning, and the power of the presentation (i.e. the use of simple, easy connections).

3) Sequence

The learner should be lead sequentially. The subject should be taught first enactively, then iconically, and lastly, symbolically.

4) Reinforcement

The learner should be given feedback at the appropriate time and in a form the learner understands (enactive, iconic or symbolic).

Much like Dewey, Bruner also advocated discovery learning, in which children discover facts and relationships for themselves through exploration (Kolesnik, 1970; Ornstein and Levine, 1993; Sprinthall and Sprinthall, 1990). The philosophical basis for this approach to learning is based on the following three premises: Understanding lies in our interaction with the environment; cognitive conflict (or puzzlement) is the stimulus for learning and determines the nature and organisation of what is learned; knowledge evolves through social negotiation and through the evaluation of the viability of individual understanding

(Savery and Duffy, 1995).

Bruner believed that through discovery, children are taught how to go about the task of learning through practising discovery, thus making learning meaningful to them. The act of discovery facilitates further discovery, and learners are not only less dependent on extrinsic motivation, but also retain and retrieve material more efficiently (Kolesnik, 1970).

As a final comparison of modern Associationist and Cognitive Theories, Skinner's and Bruner's views on teaching and learning can be summarised as follows. To Skinner, good teaching consists of the arrangement of the appropriate sequence of reinforcements for the student to emit the right response. Bruner's view is that the learner should be guided to an overall understanding of the meaning of a subject, rather than conditioning of facts and details.

1.1.1.3 The theory of multiple intelligences

Gardner (1983; 1993) advocates the existence of at least seven forms of intelligence. These include linguistic intelligence, spatial intelligence, musical intelligence, mathematical-logical intelligence, bodily kinesthetic intelligence, interpersonal intelligence and intrapersonal intelligence. Each of these intelligences has its own symbol system (for example, symbols of linguistic intelligence include sentences and stories, symbols of musical intelligence include tunes, the symbol system of spatial intelligence includes drawings, and that of bodily-kinesthetic intelligence includes gestures and dance). Traditional schooling has emphasised linguistic and mathematical-logical intelligences, in fact the medium of presentation is usually the linguistic symbol system (Gardner, 1993), effectively disadvantaging learners whose intelligence lies in other areas.

Like Bruner, who suggested that information should be structured so that the learner can understand it, Gardner believes that an intelligence can serve as both the content of instruction and the medium of instruction. This theory of intelligence and learning has a lot to offer in terms of our understanding of learning styles.

1.1.2 The influence of modern learning theories on teaching

These schools of learning theory are related to two views on teaching: instructivism and constructivism. Skinner's view that learning is the acquisition of a repertoire of conditioned responses to certain stimuli suggests that it is very teacher-centered. The teacher sets very specific aims, and controls as opposed to guides, the learning process. This is in line with the instructivist mode of teaching. From an instructivist point of view, teaching and learning are seen as a transmission of knowledge intact from the teacher's mind to the pupils' minds (Bodner, 1986). This is an active process on the part of the teacher and the learner is seen as an intellectually passive vessel to whom the knowledge is imparted (Scott, 1987).

Constructivism relates more to the Cognitive Theory of learning. Piaget, regarded as one of the early constructivists, maintained that learners construct knowledge as they attempt to organise their own experiences in terms of their pre-existing mental structures or schemes. New knowledge may be assimilated into existing cognitive structures, or these structures may be modified to accommodate new knowledge (Bodner, 1986). Thus, the experiences and understanding that learners bring to the learning situation are important, and their role is an active one, adopting new ideas, modifying or discarding pre-existing ideas, and thus constructing their own meaning (Scott, 1987). This is reminiscent of the Gestaltist view of learning as a reorganisation of one's experiences so that one comes to perceive things in a new way. It also suggests that learning is based on personal discovery by the student, while the teacher's role is one of guidance, much like Bruner's view on teaching and learning.

Because a personal construction of knowledge is relative, it seems unclear how groups of people share common knowledge. Von Glaserfeld, quoted by Bodner (1986), believed that knowledge fits, rather than matches, reality and is good only if it works, or is viable for achieving our goals. This gives a common basis for knowledge, since, to some extent, we all inhabit a common reality.

In many instructivist classrooms, children's minds have been held to be blank slates until they are filled with knowledge by their teacher. However, it seems clear now, that children always come to the classroom with their own experiences and ideas. When it comes to the teaching of science, many of these informal, "common sense" ideas that children have about the natural world may differ from or even contradict the ideas formally presented to them at school, and inhibit their learning. This needs to be taken into account by teachers and curriculum planners (Driver, 1991).

It is important for pupils also to be aware of their initial ideas at the start of the learning process (Scott, 1987) and how their learning progresses. This metacognitive aspect of reviewing their own ideas encourages involvement and should provide learning motivation (Needham, 1987). Teachers need to be aware of their pupils' initial ideas and perceptions so that they can plan their teaching strategy, as well as for assessment purposes. The learning process involves a change in ideas over time, and credit should be given for progress (Scott, 1987).

A constructivist teaching strategy should encourage involvement by the students in their own learning experience. This may take the form of group and individual projects, presentations, and group discussions of initial ideas and how these ideas have changed after the lesson(s). Particularly in science education, group discussion and reporting back of findings provides a forum for clarifying pupils learning and the change in their ideas, as well as exposure to their classmates opinions. Besides the presentation of scientific fact, an understanding of scientific inquiry and knowledge is encouraged also, i.e. that scientific findings are not a fixed body of knowledge simply to be learned (Needham, 1987), but that the scientific process is about discovery, and that scientific knowledge changes.

In schools where science is taught in an instructivist manner, this approach can be traced to curriculum planning and extends to the individual classroom, influencing teaching at ground level. Changing to a constructivist approach is initially demanding for both teachers and pupils. Development and teaching of the curriculum may be more time consuming, and assessment procedures must be adapted (Scott, 1987).

1.1.3 Views on learning and curriculum development

Curriculum planning is complex, especially in a multicultural country, like South Africa. Because learning occurs in a social context, there exists a tension between establishing a degree of cohesion in society and allowing for cultural diversity. Different authors argue for varying degrees of either an individualist or communitarian emphasis (Burtonwood, 1996). Within a multicultural society, who determines the nature of the school curriculum? Who decides what is important enough to be taught, and often, how it is to be taught? In many countries the stakeholders in education do not share this control. In England a number of educational institutions, like the Further Education Unit (FEU) and Business and Technology Education Unit (BTEC) have tried to compose a definitive list of "core skills" that pupils should be provided with (Tribe, 1996). These educational aims are to be met by the school curriculum, which in England, New Zealand and Australia, is imposed nationally by a central Education Department. Teachers, however, while pressured with increased professional requirements, have no professional voice at a national level when it comes to curriculum policy (Chitty and Lawn, 1995).

In the United States and Scotland, the curriculum is multilaterally controlled by its stakeholders. While the degree of decision making power sharing varies from state to state, teachers retain considerable curricular discretion, and parents are also consulted on policy changes (Cornbleth, 1995).

1.1.3.1 Curriculum development in South Africa

Recently, there have been changes in the South African education system with regard to the structure of the national and provincial Departments of Education. There also have been curriculum changes in the form of syllabus revision in 1994 and 1995, and in 1995 and 1996, the proposed introduction of continuous assessment (Jansen, 1997). The overhaul of South African schooling was planned through the initiation of Curriculum 2005, an outcomes based approach to education (National Department of Education, 1998). This new curriculum was to be phased in at both junior primary and junior secondary level in 1998, and finally implemented at Matric level by 2005. Despite criticism of the old curriculum under apartheid, Curriculum 2005 has already met with resistance. Development of the new curriculum has not involved teachers at ground level, and many teachers feel they are under-trained and under-resourced to implement the change so rapidly (Jansen, 1997). Thus far, these obstacles have resulted in the implementation of Curriculum 2005 at a junior primary level only. Despite policy changes, educational practice has changed little in the average classroom. Many subjects, including Matric level Biology, are still taught according to the old syllabus.

Tema (1995) scrutinised the Matric Biology syllabus as a literary document. He found that the syllabus was constructed by a committee of experts outside of the schools where it is taught. None of the stakeholders were included in its construction. It was grown by accretion with topics interesting to the committee on an *ad hoc* basis, and was not evaluated, and changed, on the basis of its effects in schools (Tema, 1995).

He found that while the educational aims and recommended approaches were stated, there was no attempt to justify them, and the relationship between the two was not clear. In many cases, the subject content of the syllabus and the recommended approaches did not relate to the stated aims. Often imprecise language and contradictions gave unclear guidance to teachers. One example of contradiction is the "cook book" approach to practical work recommended on the one hand, and then the inquiry-related approach recommended on the other.

The tone was very authoritarian, being one of instruction to the teacher, rather than recommendation. Tema's view is that this disempowers the teacher. The instructivist approach was leveled all the way through to the pupil: the underlying view of the document was that learning has been successful when pupils have mastered concepts and principles; they were not expected or encouraged to critique the knowledge offered to them.

While the aims of the old Matric Biology syllabus were stated but not justified by the Departments of Education, teachers also seldom referred to these aims. Even where teaching support aids have been developed (as in the case of science kits developed by the Natal Primary Science Project (PSP)) they are often simply not used, even when teachers have been trained to use them. Raubenheimer (1993) suggests that this may be due to a lack of a sense of ownership by teachers, even though they had been consulted in the design and later improvements to the kits. There was far greater success in a project **initiated by teachers** to produce their own set of support materials. They identified their own needs and designed a set of materials to aid them in teaching ecology (Raubenheimer, 1993).

A sense of ownership is missing with regard to the school curriculum, and may contribute to teachers not fully exploiting what recommendations and resources are available through the education department. A democratic approach to curriculum development is needed, where all stakeholders are allowed a voice, so that a sense of ownership is encouraged. A sense of security and creativity within the boundaries of the curriculum need to be established.

An instructivist, authoritarian approach has been used by most provincial Departments of Education and by the National Department of Education in teacher training and curriculum design. Hence, teachers are constrained to use the same approach in the classroom. Only when the Departments of Education adopt a more democratic, constructivist approach to the curriculum will this philosophy impact teaching in the classroom. The empowerment of students will not take place without the empowerment of teachers. With the restructuring of the South African school syllabus, it seems hopeful that the instructivist tradition will give way to a more inclusive, constructivist approach.

1.1.4 The changing role of computers in education

The early role of computers in teaching was seen as a Skinnerian 'teaching machine'. Skinner felt that the greatest hindrance to classroom learning was lack of appropriate and well-timed feedback. This problem could be overcome by the introduction of 'teaching machines' (Kolesnik, 1970; Spencer, 1988).

Teaching machines include books, machines or electronic devices that provide programmed learning in the form of automatic guidance and reinforcement. These include many of the computer aided learning programs available today and consist of two main types: linear and branching programs (Kolesnik, 1970). The linear programs are based on Skinner's theory of operant conditioning and consist of a single sequence of frames, each containing a specific piece of information and requiring a specific response from the learner. (Thus, the programmer determines the outcome of the learning and the learning style).

The typical branching program allows the learner to select a multiple-choice response. The alternative chosen determines the next frame. If the correct response is made, the next frame comprises the next step of the lesson. If the wrong response is made, a remedial frame is shown and the learner is allowed to make the choice again. Thus, faster and slower learners are accommodated (Kolesnik, 1970). This individualistic approach is even more pronounced with the advent of hypermedia and the Internet.

With the linear method, frames cannot be skipped. The purpose of questions within the frames is not to test, but to teach, and to Skinner, a mistake made by the student is an indication of the program's inadequacy. Skinnerian linear teaching machines are based on the premise that there should be lots of repetition and reinforcement and too much guidance is better than too little (Kolesnik, 1970). Skinner objected to multiple choice frameworks because the student failed to get immediate reinforcement, and erroneous answers may be remembered. He also believed that mere selection of an answer is not enough, but that an active response is necessary, e.g. the student writing out an answer

(Kolesnik, 1970). Branching programs are more compatible with the view of learning held by Cognitive Theorists.

As educational trends are changing toward a constructivist philosophy, the role of computers in education is being evaluated. The understanding of their role has changed over the years from computer aided instruction (CAI) where the computer was seen as the tireless tutor, replacing the human teacher, presenting information in a traditional, linear, book-like manner, in the model of a Skinnerian teaching machine (Hansen, 1990). Here the learner followed the author's organisation of the text which reflected the author's knowledge structure (Jonassen, 1988). There were advantages in that students could study at their own pace, however, this form of education was essentially still instuctivist in nature. Computer based education (CBE) has changed, and with the development of multimedia, hypertext, computer games and simulations, and the Internet, the computer is seen as a learning tool more convergent with the cognitive view of learning held by constructivists.

The learner controls more of the learning experience - not just pace of instruction, but order of presentation, choice of subject access, and inquiry into linked topics. Information can also be presented in more than one mode. All of this accommodates a wider range of learning styles, interests and aptitudes. When used properly, such a tool can encourage co-operative learning and development of cognitive skills. Because the computer gives students access to the information content, the teacher can now relinquish the role of subject expert and become a learning facilitator. In this role the teacher now has time to teach learning skills, how to access information and give individual attention when problems arise (Carey, 1993; Bostow, Kritch and Tompkins, 1995; Alonso and Norman, 1996).

1.1.4.1. Cognitive psychology and hypermedia as a learning tool

Cognitive strategies are processes whereby new information is gained from the environment or long term memory, rehearsed, manipulated, organised and structured so that it (re)enters the long term memory (LTM) in retrievable form (Kozma, 1987). These processes are carried out in the short-term memory (STM), however the STM can only hold a limited amount of information (approximately seven pieces of information) (Kozma, 1987). This can be increased by "chunking", or grouping pieces of information into larger units (Wade and Tavris, 1990). New information competes for space in the STM with rehearsed information, information retrieved from the LTM and decisions about how to process the information (cognitive strategies) (Kozma, 1987).

Once in the LTM, information may be stored permanently in either a verbal or pictorial form. Forgetting is based on retrieval problems. However, each connecting idea in a knowledge schema acts as a point of retrieval, and retrieval is enhanced if the information is stored both verbally and pictorially (Kozma, 1987).

Thus, inhibiting factors in the learning process include limited STM capacity, inefficient use of cognitive strategies and difficulty in retrieval from LTM. Efficient learners have automatized cognitive strategies that take up less space in STM. Inefficient learners' cognitive strategies take up STM space so that there is less space for new information and information retrieved from LTM, which need to be transformed and interconnected. Consequently less information passes into LTM and it is often poorly connected so that less is available for subsequent learning (Kozma, 1987).

Kozma (1987) says that computer based learning tools or cognitive tools amplify or enhance human cognition. They do not actively engage in instruction, but short circuit task-relevant cognitive processes and decrease the cognitive load, thus freeing cognitive resources that may be used for other higher level cognitive processing. Such tools model cognitive processes and overtly display these processes, making it easier for the learner to internalise them, (as opposed to tools such as calculators, which do not overtly display their processes and do not allow learners to internalise these processes).

A tool for learning will not perform cognitive strategies for the learner, (as a calculator does), but will prompt and model the process to evoke the right response. The basic requirements of such a tool are that it should supplement the STM with large amounts of information for the learner's use and make previously learned information simultaneously available. It enables the learner to present information both verbally and pictorially and prompts the learner to structure and integrate ideas. It should provide self-testing and practice to enhance information retrieval, and should provide easy movement, consolidation and restructuring of information as the learner's knowledge grows (Kozma, 1987).

Hypermedia has the potential to provide software packages that fulfil these requirements. Grabowski and Aggen (1984) state that computer based interactive video provides cognitive processing experiences such as sensory processing, chunking, rehearsal, paraphrasing, mnemonics, imaging, assimilation and analogical reasoning. Knowledge transfer is also facilitated by hypermedia packages by providing a non-linear problem solving environment (Kumar, 1994).

Hypermedia based learning environments take a number of forms.

a) Hypertext and CD-ROM learning materials

The concept of hypertext was discussed as long ago as the late 1940s (Marchionini, 1988), but it was only in 1974 that Theodor Nelson formally developed the concept of hypertext to describe non-linear writing (Jonassen, 1988). Hypermedia, the system used to create or display hypertext documents (Marchionini, 1988), bridges related information by forming omni-dimensional associations often using a multimedia environment of computer-computer interactions, computer-audio/video interactions and interactions among screens on the same computer (Kumar, 1994). Knowledge is represented and organised as proposed by the Cognitive Theories of learning: related ideas are associated in a knowledge schema and an integrated framework of these schema forms a semantic network (Jonassen, 1988). Within a hyperdocument a 'node' may represent a concept and 'links' form the semantic relationship between the nodes (Kumar, 1994). Because it resembles the human knowledge structure, hypermedia is a learning tool, not a teaching machine. It organises learning behaviour without regimenting it (Hansen, 1990). It is enabling rather than directive, thus allowing greater learner control over the learning process and enhancing metacognition (Marchionini, 1988).

Studies of hypertext learning materials include children's use of CD-ROM learning materials (Salomon, 1984; Jaspers, 1994; Oliver and Perzylo; 1994), use of interactive courseware in tertiary Chemistry and Biology courses (Waddick, 1994; Hall, Hall and Kasperek, 1995); use of a hypermedia based art history course at tertiary level (Dorricot and Wilson, 1997); hypermedia used in a third year Marine Botany course (Keats, 1998); and the use of hypermedia in teacher and midwifery education (van der Westhuizen, Nolte and Fourie,1998).

b) The Internet

The advent of the Internet has allowed greater opportunity for faster communication over great distance. The use of the World Wide Web allows access to hypermedia based education from all over the globe, allowing students learning facilities in 'virtual classrooms' at any time and in any place where they can log on to the internet. This allows students flexibility in terms of when they study, giving them the benefit of access to their coursework after hours. Programs using hypermedia delivered over the Internet include those by Dorricot and Wilson (1997), Clarke and Cronje (1998), Keats (1998) and van der Westhuizen et al. (1998) mentioned above. Some of the better General Biology learning materials on the Web include the MIT Biology Hypertextbook (http://esg-www.mit.edu) and Dr. Farabee's Online Biology Book (http://www.dist.maricopa.edu). One need only conduct a cursory search of the Worldwide Web to discover a host of online learning materials supplied by numerous academic institutions.

A number of these Web-based programs have been used in conjunction with Email to facilitate student evaluation and discussion groups (Clarke and Cronje, 1998; Galloway, 1998).

c) Games: microworlds and simulations

Play has long been considered the domain of children and has earned little respectability in the adult world (Rieber, 1996). Computer games particularly, have been perceived to erode cognitive function, motivation and contact with the 'real world' (Thomas and Macredie, 1994). However, research has shown that play is an important mediator in learning and socialisation. Play is difficult to define, but it generally has the following characteristics: It is voluntary; it is intrinsically motivating; it involves active engagement (physical and mental); it has a 'make believe quality'. Game playing can provide an authentic task or problem to solve, anchoring learning in authentic situations. Play also often requires critical thinking and problem solving skills (Rieber, 1996) making it a powerful tool for organising cognition. The multimedia computer environment with its capacity for rich sensory stimulation and feedback allows game technology to engage the learner even further.

Computer games can be described as microworlds or simulations. Rieber (1996) describes a microworld (or virtual world) as a small, but complete version of some domain of interest. Whereas a simulation is determined by the content it models, and the fidelity with which this is modeled, a microworld presents the learner with a simple case of the domain, with the means to reshape it and make it more sophisticated. Furthermore, a microworld should match the learners cognitive and affective state to the point where little or no training is necessary (Rieber, 1992; 1996).

Betz (1996) believes that computer games can enhance learning in the following ways. They can integrate curriculum knowledge by simulating whole systems instead of parts, and they allow students to visualise these systems, thus allowing students to solve complex problems. They provide challenge, fantasy, novelty, complexity, the illusion of control, goal formulation, competition, active participation and feedback (Thomas and Macredie, 1994), all of which enhance the learning process. Rieber (1992) also believes they provide a bridge between constructivist and instructivist approaches to learning: The boundaries of a virtual world are limited, allowing the instructor to predetermine a range of learning outcomes, while at the same time, allowing the learner freedom to explore and discover concepts through experience.

In the early 1980's, very few tertiary educators used games and simulations in their teaching programs (Birnbaum, 1982), but their availability and use has increased over recent years. Simulations have been used successfully in teacher training in New Zealand and Australia. Student teachers were exposed to typical classroom situations on interactive video, and were asked to manage these situations and then compare how an expert teacher (on video) handled the problem (Chen, 1993; O'Neill and Pitney, 1993). One of the main advantages of these programs was that they not only allowed demonstrations by experts, but also access by student teachers to the expert's reasoning. They also provided modeling and simulation of classroom interactions that appeared to be as effective as real classroom experience. O'Neill and Pitney (1993) praised this approach because it encouraged inquiry skills and reflective learning. Similar benefits were found in simulations of laboratory experiments in engineering courses (Betz, 1996; Edward, 1997).

It is important to note that such technology is simply a tool. Morariu (1988) warns that the introduction of a new tool does not automatically mean better learning. He suggests that educators should first question the premise of using hypermedia in education, and use it cautiously. Jih and Reeves (1992) state that multiple factors affect learning outcomes, not just interactive learning systems (ILS) or the abilities of the students themselves. These include personal differences such as prior knowledge and experience (including computer experience), learning styles, affective factors and physiological factors like hand-eye co-ordination and visual acuity.

Where CBE programs have failed this often is due to inappropriate use. Educators may have unrealistic expectations of the learning outcomes that such programs should achieve. External influences, such as the hardware and software available, as well as the cost of equipment, influence the use to which such tools are put (Waddick, 1994). When it comes to assessment of learning success, a measurable learning course may not be charted out and hypermedia education tools may be inappropriately used (Morariu, 1988). This may include factors such as fairness, generalizability and cognitive demand of hypermedia based assessment tools, which often are not considered (Kumar, 1994).

In large systems, students may experience navigational problems and become disoriented (Jonassen, 1988; Kumar, 1994). Too little structuring and navigational guidance increases the cognitive load of the learner, hampering the learning process.

The role of the teacher in CBE is also a complicating factor (Kumar, 1994). Katz (1992) believes that one of the reasons computers have not yet become the educational force we expected, is that many teachers do not have the necessary attitudes and personality to use them effectively. A number of personality tests have shown similar personality traits in teachers who are more likely to accept computers in the schoolroom and use them successfully. These include willingness to accept innovation and change, a degree of risk taking both professionally and personally, lower levels of neuroticism (i.e. displaying traits such as calmness, flexibility, social adjustment and self-confidence) and a higher degree of psychotism (impulsiveness, craving of change and stimulus and sensation seeking) (Katz, 1992).

1.1.5. Considerations for the design and implementation of computer-based learning tools

In 1988, Jonassen stated that many of Theodor Nelson's assumptions about hypermedia had not been supported empirically. Almost a decade on, much research into hypermedia as an educational tool has been done. Studies include an investigation of the effects of structural freedom and navigational aids in hypermedia-based educational programs, content structure (inductive, deductive or serialist) (Stanton, 1994), preference for perceptional modalities (Jaspers, 1994), effect of the interface (Kearsley, 1988; Waddick, 1994) and assessment procedures (Morariu, 1988; Kumar, 1994; Waddick, 1994).

What is the basis for the design of hypermedia based educational tools? Hoffman (1997) feels that for hypermedia to be an effective tool it needs to be paired with a macro-level instructional design theory. He believes that the Elaboration Theory (ET) is appropriate for hypermedia based education. This is a partial theory of instructional design that deals with macrostrategies of organising instruction (i.e. the inter-relationship of topics, as opposed to strategies for teaching a single topic (microstrategies)). It deals with selection of subject matter to achieve learning goals / lesson objectives; the sequence of instruction (simple to complex and general to specific); synthesis (the relation of ideas); and summarizing (both reviewing and previewing).

The cognitive load associated with CBE includes the content, the structure of the program and response strategies (Jih and Reeves, 1992). As a result, novice users often feel overwhelmed. These authors believe that such factors should be taken into account in the mental or conceptual model that the designer develops. Ideally, the user's and designer's mental models should be consistent. Learners may battle when this is not the case.

Many hyperdocuments take a glossary approach with an overview of all major concepts (Kearsley, 1988). This approach had been shown to increase reading speed and learning (Murray and McGlone, 1997). Other hypertext programs take a top-down or hierarchical approach, or a menu approach with a list or table of contents that learners can access randomly. The tutorial approach is also used, much like a tour through a database (Kearsley, 1988)

From the basis of a macro-level instructional design theory, other factors need to be considered in designing CBE tools. These may fall under microstrategies. Computer based education tools should be relevant to the envisaged learning objectives and compatible with external syllabus requirements. Appropriate hardware and software should be selected. They should provide benefits that other methods do not provide, in other words they should not be simply "expensive page turners or typewriters" (Waddick, 1994).

In any computer-based learning tool, the interface between learner and computer should be invisible: access to and navigation through the program should be simple (Kearsley, 1988; Waddick, 1994). Screen design should be conceptually easy to grasp. The design should facilitate "chunking" of information by establishing a topic or idea as a node. The more relevant links to this node, the better for association, and processing into and retrieval from the LTM. At the same time, the learner should not have to remember previous screens in order to understand new information. All of this should serve to reduce the cognitive load in the learner's working memory (Kearsley, 1988).

Research into presentation of hypertext information, has shown that there appears to be a difference between visualizing and verbalizing students (pictures vs. speech). However, there is no substantial proof that there exists a subjective preference to information presented visually or aurally, or that such a preference is effective for instruction (Jaspers, 1994). Evaluation of this research must take into account that many experiments on modal preference have concerned memory tasks or measures of reaction time, and results may not be readily transferable to instructional materials. Also, knowledge of the target group is usually intuitive and factors such as intelligence, reading capabilities and familiarity with certain visual representations are not empirically tested. Furthermore, noisy test environments may inhibit audio message components (Jaspers, 1994).

When given a choice of information to select for project work, many learners, especially younger students, tend to prefer textual information as opposed to images (television or pictures). In one study (Salomon, 1984) children considered printed information more difficult than pictorially presented information, thus the amount of invested mental effort was far higher when information was presented textually than on television or video.

In another study (Oliver and Perzylo, 1994) children using hypermedia (Mammals CD-ROM by National Geographic) as an information-seeking tool for a school project tended to choose topics for which they felt confident they would find print based information. They presented lots of quantitative information and much less qualitative or descriptive data. Any use of images in their projects was more aesthetic than to provide information to the reader. However information-seeking skills may change with age. Jaspers (1994) concludes that theory does not provide effective rules for design in this area. He also questions the pedagogical implications of capitalizing on specific learning strengths (should modal preferences exist) at the cost of neglecting the development of other faculties. Finally, he advocates a bimodal approach (i.e. both audio and visual presentation of material) without too much redundancy (Jaspers, 1994).

Rieber (1992) gives the following considerations for the design of virtual worlds. They should provide a meaningful context, intrinsic motivation and self-regulation on the part of the learner. The pattern of learning should be from the known to the unknown and there should be a balance between inductive and deductive reasoning required. The usefulness of errors should be emphasised. This is only possible where the goal is clearly known and feedback is unambiguous. Incidental learning should be anticipated and nurtured.

What of the environment and atmosphere in which CBL tools are optimally used? The physical classroom environment should be conducive to ease of movement and eye contact (Waddick, 1994) as well as being appropriately lit and well ventilated. As previously mentioned the attitude of the teacher plays an important role in the successful implementation of CBE, one aspect of this being flexibility and the development of a relaxed atmosphere in the classroom. Social interaction between students should be encouraged (Waddick, 1994).

In a case study of the creation of a computer learning environment for a university chemistry course, Waddick (1994) found that grouping of students who shared computers encouraged co-operative learning, with even weak students volunteering help at times. The social aspect was also incorporated into the assessment stage of this course. The software generated questions of which each student had to answer twenty-five correctly. This test could be taken at any time, but had to be witnessed and signed by another student. Thus, this course not only was enhanced by social interaction, but also produced some beneficial social development, such as teamwork, co-operation and accountability.

Another case study (Dorricot and Wilson, 1997) also shows the benefits of co-operative learning in which hypermedia was used in an art history course. Semnet (a semantic networking package) was used to establish relevant links to the topic of the painting "The Red Tower". The initial links were established by the lecturer but were added to by the students themselves. This allowed the students to learn from their peers, conceptualise, create and articulate their own ideas, and continually refine their ideas by researching, verifying and seeking feedback (Dorricot and Wilson, 1997). Co-operation and group support among geographically distant Education students were found to be a possible reason for the success of an Internet based course at the Masters level (Clarke and Cronje, 1998).

A further example of CBE being used to stimulate co-operative learning, this time in the context of a virtual world, is the development and use of "Bubble Dialogue" (Language Development and Hypermedia Research Group, 1992). This provided a cartoon strip setting with both an editing and viewing mode, that allowed children to write their own short dialogues and practise public and private speech. The children worked in pairs and sometimes groups of three. This sort of education tool also gives insight into the children's understanding of certain social situations as well as their language development.

While CBE can provide opportunities for reflective learning, it is important to remember that this is not inherent in CBE. Some extrinsic motivation by the teacher is often needed for reflective learning to occur (Hansen, 1990). This is especially true of below average students and unmotivated learners. Thus, the optimal amount of learner control in a CBE environment may vary (Hoffman, 1997).

Waddick (1994) found that some older students who may have lacked formal training in self-directed learning skills in their traditional classrooms preferred the more structured, teacher-centered learning environment. Jones and Kember (1993) found that self-directed learning is often less welcomed by students who have a superficial approach to studying. Again, these students did not have an intrinsic interest in their studies and relied on lecturers to set tasks and boundaries. However, there was a possible indication in this study that the more self-study packages students completed, the more likely they were to develop a deeper approach to learning (Jones and Kember, 1993).

Computer based education tools show great potential, not only for a more effective, constructivist approach to learning subject content, but also for developing learning skills. Chen (1993) believes that despite the large capital outlay (in terms of money and time) in initiating CBE programs, the benefits far outweigh the costs, not only in terms of transferring competence to students, but also as a possible solution to increased student:teacher ratios. Much is to be gained by linking CBE to a constructivist approach in transforming education, especially in South African Science education.

1.1.6 Learner misconceptions regarding photosynthesis and respiration

Teachers have rated photosynthesis as one of the most important and difficult topics for pupils to understand (Waheed and Lucas, 1992; Chacko, 1996). This was confirmed by surveys conducted by Bioped in 1996 and 1997. Here, Matric pupils and first year University and Technikon students completed questionnaires in which they ranked photosynthesis and respiration as two of the most difficult topics in the Matric biology syllabus.

Part of the complexity of this topic lies in the fact that it incorporates aspects of ecology, anatomy and physiology, biochemistry and energy exchange (Waheed and Lucas, 1992). Moreover, many Science and Biology syllabi, including the South African Matric Biology syllabus (Tema, 1995), are structured and taught in a very linear, compartmentalized fashion (Waheed and Lucas, 1992; Lucas, 1995; Bunce, 1996; Mayoh and Knutton, 1997). As a result, students are unable to link photosynthesis with other physical and chemical processes of plant physiology and ecology (Hazel and Prosser, 1994).

Much research has been done on students' misconceptions of photosynthesis (Haslam and Treagust, 1987; Amir and Tamir, 1994; Waheed and Lucas, 1992; Ross, 1993; Hazel and Prosser, 1994; Lumpe, 1995). However, none of this has explored students understanding of the relationships between the anatomical, physiological, biochemical and ecological aspects of the process (Waheed and Lucas, 1992). These authors suggest that further research should question whether relationships between these facets are mentioned in the curriculum, teachers guide and textbooks. They also question whether examination papers even require students to make such connections.

Certain research instruments probe the relationship between photosynthesis and at least one other process, e.g. the two tiered multiple choice instrument by Haslam and Treagust (1987) and the multiple choice and open-ended question instrument by Amir and Tamir (1994). Both of these test students' understanding of photosynthesis and respiration and the relationship between these two processes.

The majority of such studies on learners' misconceptions, however, are themselves compartmentalised, focusing on individual topics or processes (Lucas, 1995). This author states that the findings of these studies influence curriculum designers, suggesting that Science teaching should consist of a series of unconnected topics, which when learned are left unreinforced as a new theme is addressed. Lucas' suggestion is that good research programs should map out schemes of sequential or parallel studies, instead of merely accumulating data on isolated topics. It is hoped that this project will form part of an ongoing and integrated approach to improving South African Biology education.

2. Identifying misconceptions regarding photosynthesis and respiration

2.1 Method

Quantitative research methodology allows the measurement, comparison and statistical analysis of general characteristics of a population (Jones, 1997). For this reason, it was an appropriate research approach for identifying the most prolific misconceptions students held regarding the processes of photosynthesis and respiration. To this end, an instrument was designed to measure students understanding of these topics at the level of the South African Matric Biology syllabus.

2.1.1 Construction of the questionnaire

A questionnaire was constructed based on similar instruments developed by Haslam and Treagust (1987) and Amir and Tamir (1994). These workers compiled their questionnaires with the use of propositional statements and concept maps. Items in the questionnaires were further developed based on common misconceptions discovered through the literature, interviews with students and open-ended pencil - and - paper tests. Subject experts verified the content accuracy of the questionnaires. To construct the instrument used in this study, sections on photosynthesis and respiration from the Matric Biology syllabus were analysed by reducing the topics to the form of propositional statements. All of these propositional statements were addressed in the questionnaire, which consisted of thirteen three-tiered multiple-choice questions. A subject expert within the Biology Department of the University of Natal verified the accuracy of these questions.

The first tier of each question was a factual MC question, probing a concept within one of the topics, or the relationship between the two topics. Tier two was also in MC format, and probed the students' understanding by asking them to supply a reason for their answer in tier one. The third tier, which other researchers had not used, required that the students rate the confidence they had in their answer. Confidence ratings ranged from one to four, representing the choices 'not at all confident', 'somewhat confident', 'confident' and 'very confident'. Wherever possible, more than one question was used to probe a particular concept, to allow for cross checking that responses were not merely artifacts of the wording of a particular question, or of students guessing. The questionnaire may be referred to in Appendix 1.

2.1.2 Use of the questionnaire

The instrument was administered in a pilot study to first, second and third year Cell Biology students during one of their practical periods at the University of Natal, Durban. These data were analysed, as described below, and allowed us to make minor clarifications to three of the questions. The corrections were as follows:

1. Question 10: The label on the light compensation point in figure 1 was changed from an 'A' to an 'I'.
2. Question 11: The labeled point on the light response curve in figure 2 was changed from an 'A' to an 'I'.
3. Question 13: The wording in option 'd' of tier two was changed from:
   "During respiration, green plants derive energy from glucose, releasing CO_2 and water in the process" to
   "During respiration, green plants derive energy from glucose, using oxygen, and releasing CO_2 and water in the process."

The amended questionnaire was administered to the new intake of first year Cell Biology students, and also to first year students at the ML Sultan Technikon. The entry requirements to these institutions are different and sampling students from both institutions allowed us to probe the understanding of students of mixed ability and interest. Analysis of this data was the same as for the pilot study.

Since only minor changes were made to the pilot questionnaire, it was believed that data from the pilot study were comparable to that obtained from the new intake Technikon and

Cell Biology students. Data from these two studies were grouped as follows: new intake Technikon students, new intake Cell Biology students, first year Cell Biology students in the pilot study and senior Cell Biology students in the pilot study. (Senior students' responses consisted of responses from second and third year students which were pooled because of small sample size).

Tiers one and two of each question were crosstabulated using the statistical package SPSS, and the modal choice identified. This provided an indication of the most common misconceptions, and the proportions of students who exhibited complete or partial understanding of the concept being probed.

A G test (performed by hand) (Sokal and Rohlf, 1981) was used to determine any statistically significant differences in the confidence expressed by students from different institutions, and in different years of study. The G test determines only that significant differences exist between the categories. It does not identify where these differences lie, unless repeatedly carried out between different permutations of two categories at a time. Since this would result in repeated analysis of the same sample, only one G test could be carried out for each question to determine simply whether significant differences in confidence existed among the categories. To allow comparison of the confidence expressed by different groups, the average confidence expressed by each group was computed. While such a value is statistically meaningless, it provided a qualitative means of comparison that allowed easy presentation and interpretation.

2.2. Results and Discussion

The results of the crosstabulations and the mean confidence expressed by students are presented for each question in tables one to thirteen. The statistical analysis of students' confidence for each question (using the G test) is presented in Table 14.

Table 1. Percentage of students selecting two-tiered options for question one

Year of Study	No. of students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	60	A	0.0	6.7	-	1.7	-	8.3	3.31
		B	0.0	5.0	1.7	80.0*	-	86.7	
		C	1.7	-	-	-	-	1.7	
		D	-	-	3.3	-	-	3.3	
Cell Biology New intake	125	A	-	-	-	-	-	-	3.47
		B	-	-	1.6	89.6*	3.2	94.4	
		C	-	-	-	-	-	-	
		D	-	-	4.0	1.6	-	5.6	
Cell Biology First year	80	A	-	-	-	-	-	-	3.71
		B	-	-	2.5	87.5*	-	90.0	
		C	1.3	-	-	-	-	1.3	
		D	-	-	6.3	2.5	-	8.8	
Cell Biology Seniors	34	A	-	-	-	-	-	-	3.69
		B	-	-	-	100.0	-	100.0	
		C	-	-	-	-	-	-	
		D	-	-	-	-	-	-	

* indicates the correct answer

Question 1 requested that the students name the process by which plants produce 'food'. Almost all of them correctly selected photosynthesis (86.7 % of Technikon new intakes, 94.4 % of Cell Biology new intakes, 90 % of first year students, and 100 % of senior Cell Biology students). The vast majority of the students correctly identified the process as the conversion of light energy to chemical energy (80.0 % of Technikon new intakes, 89.6 % of Cell Biology new intakes, 87.5 % of first years, and 100 % of second and third years). Confidence expressed by students was high in all cases (above 3.0), although students with at least one year of tertiary study appeared more confident than school leavers (Table 1).

This is at odds with Hazel and Prosser's (1994) study of first year university students and Lumpe's (1995) study of secondary school pupils. These authors found that students' intuitive definition of plant 'food' was often incompatible with the scientific view. Because students were familiar with the concept of animals ingesting food, they often extrapolated this idea to define plant foods as water, mineral nutrients and carbon dioxide, taken in through the roots and leaves respectively (Hazel and Prosser, 1994). Likewise, in Lumpe's (1995) study, students grappled with the notion that plants manufacture their 'food', as opposed to ingesting it, and that this 'food', with which the plant meets its energy requirements, consists of the sugars and starch produced by photosynthesis. Both studies revealed a lack of understanding that the plant is able to convert light energy from the sun to chemical energy, by combining water and carbon dioxide to form these sugars (Hazel and Prosser, 1994; Lumpe, 1995). While there was some evidence of this misconception among younger students sampled in this study, it appears that the concept is clarified during the second and third years of study.

Table 2. Percentage of students selecting two-tiered options for question two

Year of Study	No. of students	Content choice	Reason choice A	b	c	d	e	Total	Mean confidence
Technikon New intake	59	A	1.7	-	-	-	-	1.7	2.88
		B	-	-	1.7	25.4	-	27.1	
		C	1.7	1.7	1.7	66.1*	-	71.2	
Cell Biology New intake	129	A	0.8	-	-	-	-	0.8	3.02
		B	-	-	9.3	28.7	0.8	38.8	
		C	5.4	0.8	1.6	52.7*	-	60.5	
Cell Biology First year	81	A	1.2	-	-	1.2	-	2.5	3.40
		B	-	-	7.4	40.7	1.2	49.4	
		C	1.2	1.2	1.2	44.4*	-	48.1	
Cell Biology Seniors	34	A	-	-	-	-	-	-	3.29
		B	-	-	5.9	35.3	-	41.2	
		C	-	2.9	-	55.9*	-	58.8	

* indicates the correct answer

Question 2 dealt directly with the relationship between photosynthesis and respiration. These results are presented in Table 2 below. Many of the students believed that these were opposite processes (27.1 % of Technikon new intakes, 38.8 % of Cell Biology new intakes, 49.4 % of the first years and 41.2 % of the seniors). The more accurate choice, that they are complementary processes, was made by 71.2 % of Technikon new intakes, 60.5 % of Cell Biology new intakes, 48.1% of the first years, and 58.8% of the seniors.

Of interest, is that far more school leavers grasped this concept than did those with at least one year of tertiary education. However, around half the students understood the concept enough to identify the products of one process as the reactants of the other (52.7 % of Cell Biology new intakes, 44.4 % of first years, and 55.9 % of seniors). The notable exception was the group of Technikon new intakes, 66.1 % of whom grasped the relationship between products and reactants of the two processes. This was not reflected in the students' confidence in their answers. Technikon students expressed the least confidence in their answers, while first year Cell Biology students expressed the most confidence in their answers.

Questions 3 to 6 dealt indirectly with the relationship between photosynthesis and respiration, probing students understanding of their products and reactants, and when these processes occurred.

Table 3. Percentage of students selecting two-tiered options for question three

Year of Study	No. of students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Technikon New intake	61	A B	1.6 13.1	- 4.9	1.6 13.1*	- 62.3	- 3.3	3.3 96.7	2.92
Cell Biology New intake	131	A B	1.5 3.1	1.5 3.8	2.3 12.2*	4.6 71.0	- -	9.9 90.1	3.13
Cell Biology First year	79	A B	- 2.5	1.3 1.3	2.5 15.2*	6.3 69.6	- 1.3	10.1 89.9	3.13
Cell Biology Seniors	34	A B	- 2.9	- 5.9	- 26.5*	2.9 61.8	- -	2.9 97.1	3.11

* indicates the correct answer

Question 3 asked which gas is released in large amounts in the presence of sunlight. Results are presented in Table 3. Most of the students correctly selected oxygen (96.7 % of Technikon new intakes, 90.1 % of Cell Biology new intakes, 89.9 % of the first years, and 97.1 % of the seniors). Their understanding of this process was somewhat naive, in that the majority said that oxygen was released simply as a by-product of photosynthesis. This comprised 62.3 % of Technikon new intakes, 71.0 % of Cell Biology new intakes, 69.6 % of first years, and 61.8 % of seniors. Very few students (13.1 % of Technikon new intakes, 12.2 % of Cell Biology new intakes, 15.2 % of first years, and 26.5 % of seniors) grasped that the oxygen produced by photosynthesis is used in respiration, and only if photosynthetic oxygen production is greater than its respiratory consumption is the excess gas released. University students showed similar levels of confidence in their answers, while Technikon students expressed less confidence in their answers

Table 4. Percentage of students selecting two-tiered options for question four

Year of Study	No. of students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	61	A	6.6	45.9*	34.4	6.6	1.6	95.1	2.63
		B	-	3.3	1.6	-	-	4.9	
Cell Biology New intake	129	A	3.9	61.2*	25.6	3.9	-	94.6	2.92
		B	2.3	1.6	0.8	0.8	-	5.4	
Cell Biology First year	79	A	1.2	67.9*	16.0	3.7	1.2	90.1	3.30
		B	1.2	6.2	1.2	1.2	-	9.9	
Cell Biology Seniors	34	A	-	70.6*	23.5	2.9	-	97.1	
		B	-	-	2.9	-	-	2.9	3.17

* indicates the correct answer

Question 4 asked which gas is absorbed in largest amounts in the presence of sunlight. The majority correctly answered that it was carbon dioxide, (95.1 % of Technikon new intakes, 94.6 % of Cell Biology new intakes, 90.1 % of first years, and 97.1 % of seniors). Less grasped that this is because photosynthesis is dependent on light (45.9 % of Technikon new intakes, 61.2 % of Cell Biology new intakes, 67.9 % of first years, and 70.6 % of seniors). The confidence expressed by school leavers was markedly lower than that expressed by students with at least one year of tertiary Biology education (Table 4).

Table 5. Percentage of students selecting two-tiered options for question five

Year of Study	No. of students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	59	A	6.8	15.3	8.5	5.1	-	35.6	2.35
		B	11.9	5.1	22.0*	22.0	3.4	64.4	
Cell Biology New intake	120	A	1.7	17.5	13.3	2.5	0.8	35.8	2.52
		B	3.3	3.3	39.2*	18.3	-	64.2	
Cell Biology First year	77	A	-	7.8	10.4	1.3	-	19.5	2.80
		B	2.6	1.3	48.1*	27.3	1.3	80.5	
Cell Biology Seniors	33	A	-	15.2	6.1	3.0	-	24.2	3.03
		B	3.0	3.0	45.5*	21.2	3.0	75.8	

* indicates the correct answer

Question 5 asked which gas is absorbed in largest amounts in the dark. The correct answer (oxygen) was correctly selected by 64.4 % of the Technikon new intakes, 64.2 % of the Cell Biology new intakes, 80.5 % of the first years, and 75.8 % of the seniors. The majority of the students were aware that the oxygen absorbed is used in respiration, but fewer understood that respiration is a continuous process (22.0 % of Technikon new intakes, 39.2 % of Cell Biology new intakes, 48.1 % of first years, and 45.5 % of seniors). The remainder (22.0 % of Technikon new intakes, 18.3 % of Cell Biology new intakes, 27.3 % of first years, and 21.2 % of senior students) believed it to occur in the dark only. School leavers' confidence in their answers was fairly low, with higher confidence expressed by first years, and senior students expressed the highest confidence (Table 5).

Question 6 asked which gas is released in largest amounts in the absence of light. Results are presented in Table 6. Most students correctly selected carbon dioxide (73.3 % of Technikon new intakes, 57.0 % of Cell Biology new intakes, 88.0 % of first years, and 76.5 % of seniors). Less recognised that respiration is a continuous process (51.7 % of Technikon new intakes, 46.3 % of Cell Biology new intakes, 68.0 % of first years, and 58.8 % of seniors). Once again, some students believed that respiration occurs in the dark only (1.7 % of Technikon new intakes, 5.8 % of Cell Biology new intakes, 17.3 % of first years, and 8.8 % of seniors). In all cases, the mean confidence expressed by students was fairly low, with Technikon students expressing the least confidence in their answers, and senior Cell Biology students the highest (Table 6).

Table 6. Percentage of students selecting two-tiered options for question six

Year of Study	No. of students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Technikon New intake	60	A	51.7*	16.7	1.7	3.3	-	73.3	2.28
		B	10.0	15.0	-	1.7	-	26.7	
Cell Biology New intake	121	A	46.3*	2.5	5.8	2.5	-	57.0	2.65
		B	25.6	8.3	5.0	4.1	-	43.0	
Cell Biology First year	75	A	68.0*	1.3	17.3	1.3	-	88.0	2.77
		B	9.3	2.7	-	-	-	12.0	
Cell Biology Seniors	34	A	58.8*	8.8	8.8	-	-	76.5	2.88
		B	11.8	8.8	2.9	-	-	23.5	

* indicates the correct answer

Responses to questions three to six indicate that students have a poor grasp of the complementary relationship between photosynthesis and respiration, and when these processes occur. The finding that students view photosynthesis and respiration as 'opposite' and unconnected processes concurs with results from similar studies by Haslam and Treagust (1987) and Hazel and Prosser (1994). These authors reported student views that photosynthesis occurred during the day, and respiration strictly occurred at night. Hazel and Prosser (1994) suggest that the use of summary equations for the two processes may have lead students to view them as alternative processes, instead of simultaneous processes. This misconception may also be due to the linear and compartmentalised nature of the Matric Biology syllabus. Like most such syllabi (Waheed and Lucas, 1992; Lucas, 1995; Bunce, 1996), it does not overtly emphasise the relationships between topics such as water uptake, mineral nutrition, photosynthesis, phloem translocation and respiration.

More of the senior students understood that photosynthesis and respiration are synchronous and complementary. This may be due to the less compartmentalised arrangement of topics in tertiary level Biology education. Once at University, students are expected to make more associations between topics learned previously, and to understand more deeply the relationships between biological processes.

Questions 7 to 9 dealt with the relationship between the light and dark phases of photosynthesis.

Table 7. Percentage of students selecting two-tiered options for question seven

Year of Study	No. of students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	60	A	58.3*	26.7	3.3	-	1.7	90.0	2.58
		B	-	-	1.7	-	-	1.7	
		C	1.7	-	1.7	5.0	-	8.3	
Cell Biology New intake	121	A	57.0*	24.0	1.7	3.3	1.7	87.6	2.62
		B	-	1.7	-	-	-	1.7	
		C	0.8	2.5	0.8	6.6	-	10.7	
Cell Biology First year	77	A	68.8*	18.2	1.3	5.2	1.3	94.8	2.73
		B	-	-	-	-	-	-	
		C	1.3	-	1.3	2.6	-	5.2	
Cell Biology Seniors	34	A	82.4*	14.7	-	-	-	97.1	2.91
		B	-	-	-	-	-	-	
		C	-	-	-	2.9	-	2.9	

* indicates the correct answer

Question 7 asked when the light phase of photosynthesis occurred. Results are presented in Table 7 above. The vast majority (90.0 % of Technikon new intakes, 87.6 % of Cell Biology new intakes, 94.8 % of first years, and 97.1 % of seniors) knew that it occurred only in the presence of light. The role of light in this process was less clearly understood. Only 58.3 % of Technikon new intakes, 57.0 % of Cell Biology new intakes, 68.8 % of first years, and 82.4 % of seniors grasped the role of light in chlorophyll excitation and electron transport. The rest believed the light phase involved the uptake of carbon dioxide. Once again, the mean confidence answers expressed by students was fairly low in all cases, with the least confidence expressed by Technikon students, and the highest by senior Cell Biology students.

Table 8. Percentage of students selecting two-tiered options for question eight

Year of Study	No. of students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Technikon New intake	61	A	6.6	4.9	31.1	8.2	-	50.8	2.25
		B	3.3	1.6	-	1.6	-	6.6	
		C	-	1.6	1.6	39.3*	-	42.6	
Cell Biology New intake	122	A	4.9	3.3	13.1	8.2	1.6	31.1	2.44
		B	-	4.1	0.8	0.8	-	5.7	
		C	3.3	0.8	3.3	55.7*	-	63.1	
Cell Biology First year	71	A	2.8	2.8	23.9	12.7	2.8	45.1	2.27
		B	-	4.2	-	1.4	-	5.6	
		C	1.4	1.4	1.4	45.1*	-	49.3	
Cell Biology Seniors	34	A	2.9	2.9	2.9	2.9	2.9	14.7	2.56
		B	-	-	2.9	2.9	2.9	8.8	
		C	-	-	-	76.5*	-	76.5	

* indicates the correct answer

Question 8 asked when the dark phase of photosynthesis occurs. The most common misconception expressed was that the dark phase takes place only in the dark (50.8 % of Technikon new intakes, 31.1 % of Cell Biology new intakes, 45.1 % of first years, and 14.7 % of seniors). Only 42.6 % of Technikon new intakes, 63.3 % of Cell Biology new intakes, 49.3 % of first years, and 76.5 % of the seniors knew that the dark phase is simply light independent, and thus takes place continuously, in the presence or absence of light. The role of the dark phase as the uptake and reduction of carbon dioxide was grasped by 39.3 % of Technikon new intakes, 55.7 % of Cell Biology new intakes, 45.1 % of first years, and 76.5 % of seniors. Mean confidence in their answers was generally low. It was lowest for Technikon students and first year Cell Biology students and somewhat higher for new Cell Biology intakes and senior Cell Biology students (Table 8).

Table 9. Percentage of students selecting two-tiered options for question nine

Year of Study	No. of students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	61	A	4.9	1.6	-	8.2	-	14.8	2.40
		B	3.3	6.6	3.3	3.3	-	16.4	
		C	41.0*	1.6	18.0	8.2	-	68.9	
Cell Biology New intake	120	A	-	4.2	2.5	2.5	-	9.2	2.39
		B	4.2	2.5	2.5	0.8	-	10.0	
		C	49.2*	6.7	17.5	6.7	0.8	80.8	
Cell Biology First year	73	A	2.7	1.4	-	1.4	-	5.5	2.30
		B	2.7	6.8	5.5	4.1	-	19.2	
		C	43.8*	5.5	19.2	4.1	2.7	75.3	
Cell Biology Seniors	32	A	-	-	-	-	-	-	2.44
		B	6.3	-	6.3	-	-	12.5	
		C	50.0*	9.4	25.0	3.1	-	87.5	

* indicates the correct answer

Question 9 explicitly asked about the relationship of the light phase and dark phase of photosynthesis. Most students could identify these as complementary processes (68.9 % of Technikon new intakes, 80.8 % of Cell Biology new intakes, 75.9 % of first years, and 85.3 % of seniors). Fewer could identify clearly the products and function of each phase. Those that could identify products and functions of each phase comprised 41.0 % of Technikon new intakes, 49.2 % of Cell Biology new intakes, 43.8 % of first years, and 50.0 % of seniors. The majority confused the products and functions. Students' confidence in their answers was generally low, but highest in senior Cell Biology students (Table 9).

Responses to questions seven to nine revealed that there is little clarity as to the different processes that occur in the light and dark phases of photosynthesis, and the way in which these processes relate to each other. Fewer senior students showed these misconceptions than did first years or school leavers.

Question 10 once again probed the students understanding of the relationship between photosynthesis and respiration. A figure was shown representing a light response curve and students were required to identify the light compensation point. A high percentage of the students (61.7 % of Technikon new intakes, 64.9 % of Cell Biology new intakes, 72.2 % of first years, and 94.1 % of seniors) could identify the point indicated on the curve as the light compensation point. Fewer students (26.7 % of Technikon new intakes, 31.6 % of Cell Biology new intakes, 33.3 % of first years, and 76.5 % of seniors) could interpret its significance, i.e. that at this light intensity, the rate of photosynthesis equals the rate of respiration. Students' confidence in answering question ten was lowest for school leavers. It was somewhat higher for first year Cell Biology students, and highest among senior students (Table 10).

Table 10. Percentage of students selecting two-tiered options for question ten

Year of Study	No. of students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Technikon New intake	60	A	26.7	6.7	26.7*	1.7	-	61.7	2.10
		B	15.0	11.7	10.0	1.7	-	38.3	
Cell Biology New intake	114	A	28.9	3.5	31.6*	0.9	-	64.9	2.07
		B	19.3	10.5	5.3	-	-	35.1	
Cell Biology First year	72	A	34.7	1.4	33.3*	2.8	-	72.2	2.20
		B	11.1	11.1	4.2	1.4	-	27.8	
Cell Biology Seniors	34	A	17.6	-	76.5*	-	-	94.1	2.76
		B	2.9	2.9	-	-	-	5.9	

* indicates the correct answer

In question 11, students' understanding of limiting factors was investigated. Once again, a light response curve was presented, and students were required to identify the point at which the rate of photosynthesis became constant. Most students could identify this point (67.2 % of Technikon new intakes, 72.1 % of Cell Biology new intakes, 77.3 % of first years, and 73.5 % of seniors). The second tier questioned what caused the leveling off of the curve. Only 9.8 % of Technikon new intakes, 19.8 % of Cell Biology new intakes, 30.7 % of first years, and 64.7 % of seniors, knew that something other than light was limiting photosynthesis from this point. Despite the fact that the figure shows increasing light intensity, some of these said that light was the limiting factor (14.8 % of Technikon new intakes, 22.4 % of Cell Biology new intakes, 24.0 % of first years, and 5.9 % of seniors). The mean confidence in answering this question was low for school leavers and first year Cell Biology students. It was notably higher for senior Cell Biology students (Table 11).

Table 11. Percentage of students selecting two-tiered options for question eleven

Year of Study	No. of students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Technikon New intake	61	A	8.2	3.3	4.9	-	-	16.4	2.25
		B	8.2	6.6	9.8	4.9	-	29.5	
		C	14.8	9.8*	19.7	8.2	1.6	54.1	
Cell Biology New intake	116	A	4.3	1.7	5.2	0.9	-	12.1	2.23
		B	8.6	2.6	6.9	2.6	-	20.7	
		C	22.4	19.8*	18.1	2.6	4.3	67.2	
Cell Biology First year	75	A	4.0	2.7	1.3	-	1.3	9.3	2.26
		B	4.0	5.3	1.3	1.3	1.3	13.3	
		C	24.0	30.7*	8.0	10.7	4.0	77.3	
Cell Biology Seniors	34	A	2.9	8.8	8.8	-	-	20.6	3.00
		B	2.9	2.9	-	-	-	5.9	
		C	5.9	64.7*	-	-	2.9	73.5	

*indicates the correct answer

Questions ten and eleven, requiring students to interpret a light response curve, were both answered more accurately by senior students (Table 10 and 11, respectively). Haslam and Treagust (1987) also reported the poor understanding of rate limiting factors displayed by younger students. This may be because senior students have developed a clearer understanding of photosynthesis and respiration, and the relationship between the processes. It may be also that they have developed better graphical interpretation skills.

Question 12 asked that the students identify the equation representing the net reaction of photosynthesis. A large proportion could identify the equation (67.2 % of Technikon new intakes, 72.1 % of Cell Biology new intakes, 79.2 % of first years, and 90.9 % of seniors), but fewer could fully interpret which were products and reactants (55.7 % of

Technikon new intakes, 50.8 % of Cell Biology new intakes, 59.7 % of first years, and 66.7 % of seniors). Mean confidence in answering this question was lowest for new Cell Biology intakes, followed by new intake Technikon students, then Cell Biology seniors, and was highest in Cell Biology first years (Question 12).

Table 12. Percentage of students selecting two-tiered options for question twelve

Year of Study	No. of students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	61	A	6.6	1.6	6.6	-	-	14.8	3.02
		B	9.8	55.7*	1.6	-	-	67.2	
		C	-	18.0	-	-	-	18.0	
Cell Biology New intake	122	A	2.5	-	3.3	-	-	5.7	2.82
		B	18.0	50.8*	2.5	0.8	-	72.1	
		C	4.1	16.4	0.8	0.8	-	22.1	
Cell Biology First year	77	A	1.3	-	1.3	-	-	2.6	3.35
		B	14.3	59.7*	3.9	1.3	-	79.2	
		C	-	14.3	2.6	1.3	-	18.2	
Cell Biology Seniors	33	A	-	-	-	-	-	-	3.15
		B	21.2	66.7*	3.0	-	-	90.9	
		C	-	9.1	-	-	-	9.1	

* indicates the correct answer

Question 13 required the students to identify the net reaction equation of respiration. Once again, most could identify the equation, (83.1 % of first years, 78.8 % of seniors, 63.6 % of Cell Biology new intakes, and 52.5 % of Technikon new intakes). However, fewer could fully interpret the equation and identify products and reactants (27.9 % of Technikon new intakes, 42.4 % of Cell Biology new intakes, 53.2 % of first years, and 54.5 % of seniors). Mean confidence in answering this question was highest in Cell Biology first years, and similarly lower amongst other students (Table 13).

As with questions ten and eleven, data presentation may have played a role in student responses to questions twelve and thirteen. In answering question thirteen, most school leavers selected the correct summary equation for respiration. Far fewer of these could interpret the equation correctly. A higher proportion of first year and senior Cell Biology students could interpret the equation. Once more, this may be due to a better understanding of the process, or it may be that students leaving Matric are not well equipped to interpret data in 'mathematical' form. By their second and third years of tertiary study, students may have a more developed ability to interpret equations.

Table 13. Percentage of students selecting two-tiered options for question thirteen

Year of Study	No. of Students	Content choice	Reason choice a	b	c	d	e	Total	Mean confidence
Technikon New intake	61	A	8.2	-	16.4	27.9*	-	52.5	2.55
		B	1.6	4.9	3.3	1.6	-	11.5	
		C	6.6	8.2	-	3.3	-	18.0	
		D	1.6	-	9.8	6.6	-	18.0	
Cell Biology New intake	118	A	4.2	4.2	11.9	42.4*	0.8	63.6	2.57
		B	0.8	5.1	-	0.8	-	6.8	
		C	3.4	5.1	2.5	0.8	-	11.9	
		D	-	0.8	7.6	9.3	-	17.8	
Cell Biology First year	77	A	-	2.6	23.4	53.2*	-	83.1	2.64
		B	-	3.9	-	-	3.9	3.9	
		C	3.9	1.3	1.3	-	-	6.5	
		D	-	-	1.3	5.2	-	6.5	
Cell Biology Seniors	33	A	3.0	6.1	12.1	54.5*	3.0	78.8	2.59
		B	-	-	-	-	-	-	
		C	-	3.0	-	-	-	3.0	
		D	-	-	15.2	3.0	-	18.2	

* indicates the correct answer

In summary, the concepts that students have not fully grasped include the complementary nature of the relationship between photosynthesis and respiration, and the timing of these processes. They also displayed a lack of understanding as to the role of the light and dark phases of photosynthesis and the nature of the relationship between these processes. The significance of the 'light compensation point' was also not clearly understood. Nor did students understand that the rate of photosynthesis reaches a point where it remains constant, even with increasing light intensity, because it is limited by some factor other than light (i.e. the regeneration of Ribulose-1,5-bisphosphate).

These concepts appear to have been clarified somewhat by the second or third years of tertiary Biology education. Results of the G test suggest that students' confidence in their understanding also appears to change with different levels of Biology education. For every question, the computed value for G was higher than the tabulated value, indicating that there were statistically significant differences in confidence expressed among the student groups (Table 14). Tables one to thirteen suggest that students with at least one year of tertiary study in Biology are more confident in their answers than those who had just matriculated. Senior Cell Biology students tended to be most confident of their answers.

Table 14. Results of the G test to determine whether statistically significant differences existed in the confidence expressed by different groups of students
df = 3; $\alpha = 0.05$; tabulated G= 7.815

Question	G
1	23.152
2	27.562
3	8.860
4	30.947
5	31.131
6	19.010
7	19.067
8	8.860
9	8.506
10	18.108
11	27.00
12	22.349
13	12.061

Among all categories of students, the main misconception identified, and chosen to address, was that relating to the synchronous and complementary relationship between photosynthesis and respiration. A learning tool, in the form of a virtual world, was designed with the aim of addressing this concept.

3.0 Addressing misconceptions regarding photosynthesis and respiration

3.1 Method

The first phase of this research, reported in chapter two, provided information on the specific concepts that students did not grasp. The most prolific of these misconceptions related to the relationship between photosynthesis and respiration. A description of the second phase of the project, the development and evaluation of a learning tool to address these misconceptions, follows in this chapter. The learning tool took the form of a computer game in the form of an exploratory virtual world. Here students were faced with problems related to photosynthesis and respiration. Solving the problems illustrated the individual processes and how they relate to each other. Although the game was played in a 'stand alone' context, it is to be incorporated ultimately as one level of the game Zadarh, an educational adventure game designed by Bioped to teach a number of biological concepts (Amory, Naicker, Vincent and Adams, 1998).

In order to evaluate the game's effectiveness as a learning tool, it was felt that students' understanding should be assessed using the questionnaire described earlier, as well as through the use of interviews. Although these techniques are derived from divergent theoretical approaches, there is nothing inherent in the methods themselves that precludes their combination. In fact, the particular strengths and limitations of both quantitative and qualitative research allow these methods to complement one another, when unified in the project design (Wolff, Knodel and Sittitrai, 1993; Jones, 1997). In this case, all of the students who played the game completed the questionnaire, while a subset were interviewed to probe more carefully the cognitive processes used in playing the game and answering the questionnaire. Students' affective response to the game could also be evaluated using the interview technique, as well as their opinions of technical aspects and suggested enhancements of game quality. This deeper evaluation, rather than merely a quantitative 'measurement' of the students understanding, can be gained only through a qualitative research approach (Wainwright, 1997; van der Merwe, publication forthcoming).

3.1.1. Development of the virtual world

The computer game was designed specifically to teach the concept of a simultaneous and complementary relationship between photosynthesis and respiration. It provided a problem based learning environment in which students were provided with a variable gas supply of carbon dioxide and oxygen, a variable light source, and two cuvettes, one containing mitochondria only (representing an animal cell), and the other containing mitochondria and chloroplasts (representing a plant cell) (Figure 1.). The object of the game was to fill an oxygen cylinder (to replenish the players oxygen supplies to his biohazard suit worn in the game, Zadarh), and a carbon dioxide cylinder (to extinguish a fire). Filling of the cylinders was achieved by varying the light intensity and gas flow through either the animal or plant cell, so that the processes of photosynthesis and respiration would occur in the appropriate cuvette, to produce a net yield of either oxygen or carbon dioxide.

Clues to managing the processes were provided in the form of puzzles, which were based on five of the seven forms of intelligence proposed by Gardner (1993). Initially, five puzzles were designed requiring spatial, linguistic, musical, mathematical-logical, or bodily kinesthetic ability. The solution of each puzzle allowed the students to fill each cylinder by one third, thus students were required to solve three out of the five puzzles in order to fill each cylinder completely.

However, due to the time constraints of the study year, and thus, the possibility of student volunteers being available to test the game, only three of the five puzzles were completed in time. These were a spatial puzzle, a linguistic puzzle and a musical puzzle. Students had to solve all three of these in order to fill the cylinders completely. A brief description of the game layout and the puzzles may be necessary for the reader's benefit.

As students began the game, they found themselves in a lift, which opened into a foyer. (It should be remembered that the lift will be used later as a means to access different levels of Zadarh). On the far side of the foyer is a storeroom, in which students

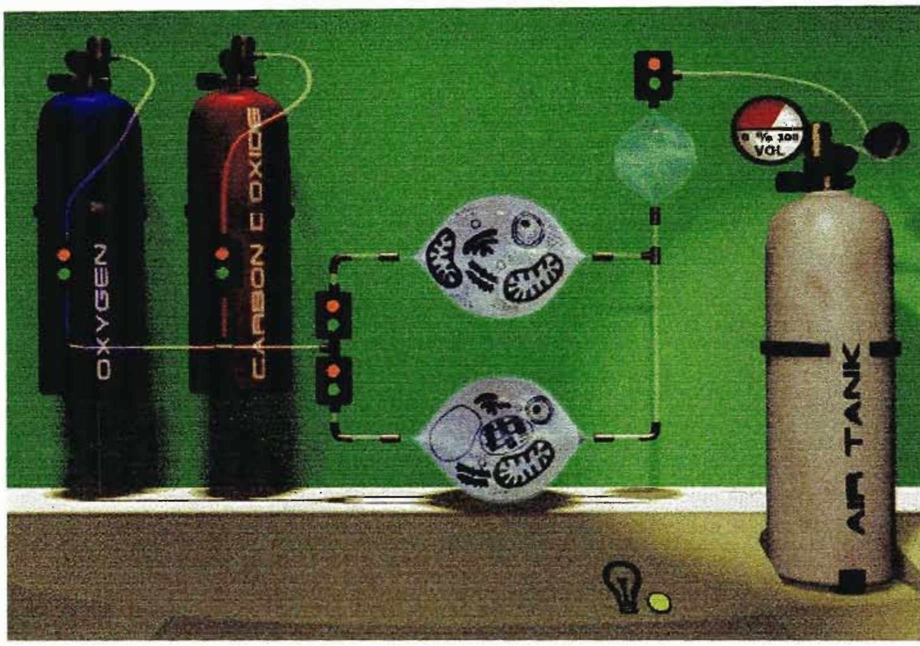

Figure 1. The gas panel. Students could alter gas and light supplies through each cuvette in order to fill the air tank with oxygen

Figure 2. The linguistic puzzle. Selecting the correct spots on the beetle and flower produced statements about photosynthesis and respiration.

are required later to extinguish a fire. On either side of the storeroom is a door marked with an entrance sign. Each entrance leads to a set of three interleading rooms. Pictures of plants and animals adorning the walls identify one set of rooms. This clue reminds the students that the puzzles in these rooms are based on the process common to plants and animals, i.e. respiration. The first in this set of three rooms contains a linguistic puzzle, the second a musical puzzle, and the third a spatial puzzle.

The rooms leading off from the other side of the foyer are hung with pictures of plants only. This indicates to players that the puzzles in these rooms are based on the processes occurring in plants, i.e. both photosynthesis and respiration. Again, the first room in this sequence houses a linguistic puzzle, the second a musical puzzle, and the third a spatial puzzle.

The linguistic puzzle consisted of a large metallic model of two flowers in the 'plant room', and a flower and a beetle in the 'plants and animals room'. On the flowers' petals and limbs of the beetle were small spots , which when clicked on, flashed a word or phrase across the face of the model. On each petal or limb, each spot represented a different word or phrase, and this representation was duplicated on all the petals and limbs (Figure 2). The words and phrases related to the processes of photosynthesis, their timing and the cells in which they occur.

In order to solve the puzzle, players had to select one spot from each petal, or limb, to make an appropriate sentence. Where the beetle and flower models were being used, the sentences to be compiled on each model were: 'Animal cells respire in the light and dark', and 'Plant cells respire in the light and dark' respectively. Where two flower models were used, the concepts they had to recognise and express as sentences were: 'Plant cells respire in the light and dark', and 'Plant cells photosynthesize and respire in the light'. All of these sentences were selected in order to emphasise the concept that respiration in plant cells, as in animal cells, occurs during the night and during the day, while photosynthesis occurs with respiration during the day.

In the room housing the musical puzzle, the dominant feature was a piano (Figure 3). The walls of this room were hung with charts showing the reactants and products of photosynthesis and respiration. Beneath each molecule was a corresponding music note (Figure 4). On the piano lay sheet music made up of the same notes that represented the processes of photosynthesis and respiration. Even for players who could not read music, the charts on the wall provided enough information to solve the musical puzzle by playing the right notes in the right order.

This puzzle emphasised the complementary relationship between photosynthesis and respiration. By playing the tunes corresponding to each process, students should notice that the notes are the same but that their order is reversed. This illustrates that the products of each process are the reactants of the other.

The dominant feature in the spatial puzzle room was a model of two organelles, one a mitochondrion and the other a chloroplast (Figure 5). If players did not recognise these, micrographs on the wall showed each organelle's structure and its function. Elsewhere in the room was a machine that generated slides showing the molecular structure of each of the reactants of photosynthesis and respiration. Players had to view the slides, select the correct reactants for each process (clues were on the wall charts), and place the reactants in the correct organelle. Above the organelle models was a light, which the students had the option of switching on or off.

In the room dealing with plants and animals, only the process of respiration was involved. Thus, only the slides of the respiration reactants had to be inserted into the mitochondrion, and since respiration occurs in the light and dark, the puzzle could be solved with the light switched either on or off.

The room that showed pictures of plants only dealt with both photosynthesis and respiration simultaneously, since both processes occur alongside each other in plants. In this case reactants of both processes had to be inserted into both organelles, and the light

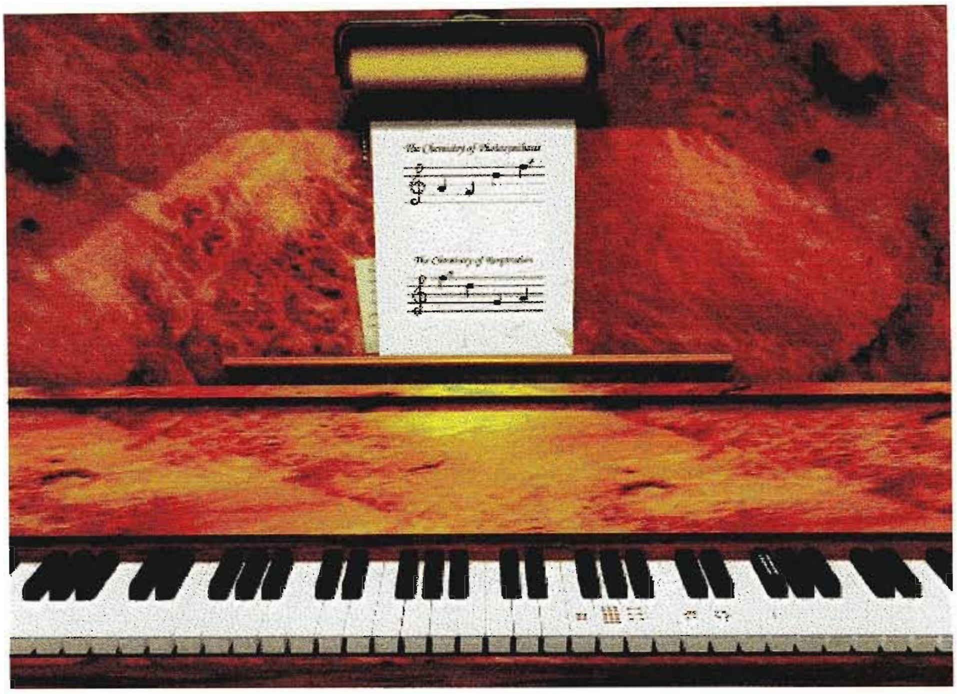

Figure 3. The musical puzzle. Piano and sheet music are shown.

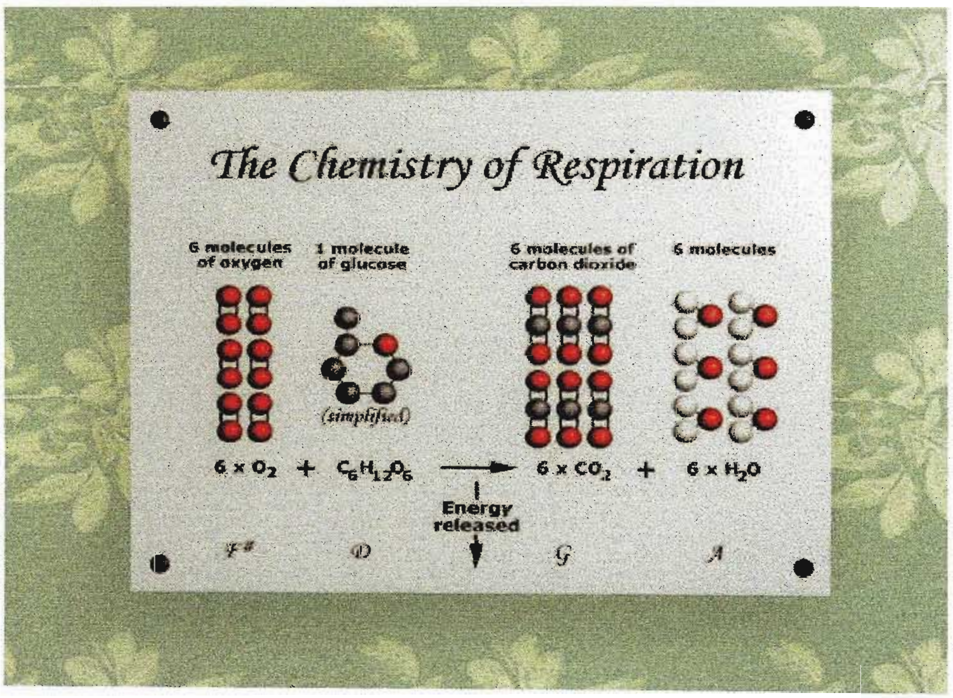

Figure 4. Chart with clues for solving the musical puzzle

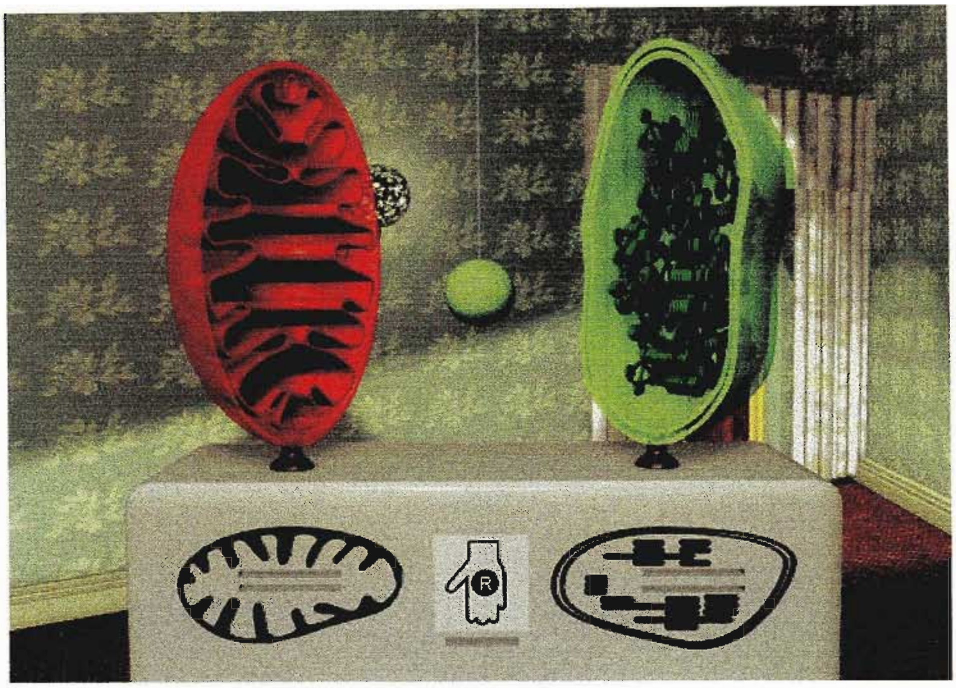

Figure 5. The spatial puzzle. Models of the chloroplast and mitochondria are shown. Students were required to insert disks representing the appropriate reactants for photosynthesis or respiration into the correct slots.

had to be switched on to solve the puzzle.

When each puzzle was solved, students were rewarded with a token to put into a slot machine. On completing this task, they were given access to the gas panel (Figure 1).

A graphic designer was employed by Bioped to design the game graphics. 3D Studio Max and Adobe Photoshop were used to do this. Programming was done using software developed in Delphi 3.0 by Professor Amory.

3.1.2. Assessment of the teaching effectiveness of the virtual world

Twenty-two students volunteered to test the game. Due to the small sample size, students from all three years of study were grouped. These students played the game for a period of two hours in the Biology computer room, where the game was loaded on to the local area network (LAN). Groups of friends tended to volunteer to play in the same time slot, and although each student played on a separate computer, collaboration between students was allowed. Since this game was designed ultimately to be incorporated into Zadarh, it was necessary to provide a briefing of the games objectives. This was done verbally with each student before they commenced playing. I remained present while students were playing in order to provide guidance, and to observe their behaviour.

3.1.2.1 Quantitative evaluation through use of the questionnaire

Immediately after playing the game, students completed the questionnaire used earlier to identify common misconceptions. The responses were analysed using the statistical package, SPSS, in the same way as mentioned previously. The responses from these students (Cell Biology undergraduates in all three years of study who had played the game) were termed ‘players’. Responses from Cell Biology undergraduates who had answered the pilot questionnaire were grouped and referred to as ‘non-players’. Although there was some overlap among those students who had taken part in the pilot study and those who had played the game, these student populations were not identical and therefore, no statistical analysis could be applied to the comparison of the two groups.

3.1.2.2 Qualitative evaluation through student interviews

Both Bell (1995) and Treagust (1995) recognise the usefulness of interviews as an assessment technique for determining students' understanding of scientific concepts. Bell (1995) recommends that interviews are conducted prior to teaching (for diagnostic assessment), during teaching (as formative assessment), and after teaching (as summative assessment). In this study, interviews were conducted in a diagnostic capacity prior to students playing the game, and after playing the game as a summative assessment. A more informal formative assessment was done while I observed and assisted students playing the game.

Students were not compelled to take part in the interviews, and only a small number volunteered to do so. I encouraged participation by suggesting that participants may improve their understanding of the processes of photosynthesis and respiration, topics that the majority of them found daunting. Another factor that encouraged participation, especially among male students, was the opportunity to take part in the testing and design of a new computer game.

The initial interview took the form of a focus group since many of the students showed reluctance to be interviewed. In certain situations a focus group can provide a more relaxed, less interrogatory setting than individual interviews (Morgan and Kreuger, 1993). These preliminary interviews were conducted one month prior to playing the game.

Interviews conducted after playing the game were conducted on an individual basis. By this time, I had established a friendly relationship with these students, and they were comfortable enough to be interviewed individually. These later interviews focused primarily on the students' experience of playing the game and an evaluation of their understanding of photosynthesis and respiration. For this reason, I felt that the interviews should be conducted individually, allowing the students complete freedom of expression without the pressure to conform to the group opinion.

The initial focus group was arranged at a time that suited the students, a feat that took some planning, since they were in different years of study and had varied timetables. A venue within the department was needed, since, many of the students did not have their own transport, and the focus group would have to be conducted during university hours. The focus groups were held in the departmental museum, a room very seldom used for teaching and with a comfortable layout, where a small table and several chairs could be casually arranged for our discussion. My dress was casual, in keeping with student attire. This, as was the choice of venue and seating arrangement, was designed to maintain the effect of equality between the students and myself (Douglas, 1985).

Seven students volunteered to participate in the interviews, although three of these arrived only after the focus group had been conducted. These students were still very keen to take part in the study, and so were interviewed as a second focus group the following day.

Students were welcomed and set at ease by an explanation of the aims of the study. I encouraged their openness by explaining that the game was being developed for students like them, and that as the end users, their input in the design of the game was of utmost importance. They were assured of anonymity, and for this reason I have changed all names in the text. In order to break the ice, I gave them all a watch shaped sweet, to say 'thank you for their time'! This produced some laughter and lightened the atmosphere. We then began the discussion.

The conversation revolved around the students' attitudes and experience regarding computer technology and computer games, their knowledge recall and enjoyment of school and University Biology courses, and their understanding of the processes of photosynthesis and respiration. In the first focus group, the participants included Tarryn, Rebecca, Alex and Paul. The participants of the second group, who arrived late, included

Kevin, Terence and Mark. The focus group participants comprised two first year students (an Indian female and a white female), three second year students (all Indian males), and two third year students (an Indian male and a white male).

At the end of the discussion I asked the students what their reasons were volunteering for this study. Since many of them expressed the desire to improve their understanding of the topics under discussion, I reassured them that I was committed to helping them in this area, and in any other area of their studies they were battling with. I made this gesture since I knew that the exams were approaching, and the time they were donating to my study was precious. By the second round of interviews, two of the students had redeemed my offer of help. This encouraged me. I felt I had managed to establish enough rapport and credibility with them, that they felt their help with my research was significant enough to ask for my help with their studies. They saw our relationship as mutually beneficial, and the expertise each of us offered as equally valid.

For the post-game interviews, the same venue was used, and once again, the time was set at the students' convenience. These individual interviews were easier to conduct since there was an established rapport between us, and all of the students were eager to talk about their experience of playing the game. The fact that they alone held the floor appeared to give them greater confidence and openness in expressing their feelings and opinions.

I opened the discussion by asking them to describe the manner in which they played the game, such as the routes they took through each section, and the ways in which they interpreted clues and solved the puzzles. Later, they were asked for their opinions on technical aspects such as graphics and sound design, and game layout, as well as any improvements they felt would improve these and other features. They were asked also what they believed the game designers were hoping for them to learn from the game. Depending on their responses, they were questioned more specifically on their understanding of the relationship between photosynthesis and respiration, using the puzzles presented in the game as cognitive aids in their description of the processes.

Since the focus groups and interviews were very unstructured, writing down responses would have been both impractical and intrusive to the flow of conversation and the building of intimacy (Douglas, 1985). Hence, all of the interviews were audiotape recorded, and transcribed. The transcripts were coded and analysed using the qualitative research package QSR NUD*IST 4.0.

3.2. Results and Discussion

3.2.1. Quantitative evaluation of the effectiveness of the virtual world: Assessment of questionnaire responses

Students' responses on tiers one and two were crosstabulated, and the mean level of confidence was calculated as described in section 2.2. The results are presented for each question, comparing undergraduate students that played the game with the undergraduate students in the pilot study.

Table 15. Percentage of players and non-players selecting two-tiered multiple choice options on question one

Student Category	No. of Students	Content Choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Players	21	A	-	9.5	-	-	-	9.5	3.68
		B	-	-	-	81.0*	-	81.0	
		C	-	-	-	-	-	-	
		D	-	-	9.5	-	-	9.5	
Non-Players	114	A	-	-	-	-	-	-	3.70
		B	-	-	1.8	91.2*	-	93.0	
		C	0.9	-	-	-	-	0.9	
		D	-	-	4.4	-	1.8	6.1	

* indicates the correct answer

Question 1 requested that the students name the process by which plants produce 'food'. Crosstabulation results appear in Table 15. Almost all of them (81.0 % of the players, compared to 93.0 % of the non-players) correctly selected photosynthesis, and all of these correctly identified the process as the conversion of light energy to chemical energy. A small portion of the players (9.5 %) selected respiration as the process whereby plants produce food. These results indicate that some players still confused the role of photosynthesis and respiration. Also, 9.5 % of the players selected mineral absorption through the roots as the process whereby plants produce food. Hazel and Prosser (1995) reported this to be a common misconception among secondary school students. It should be considered, however that the sample size was small in this case (9.5 % representing two students). Corresponding with the high percentage of students who answered this question correctly, mean confidence expressed by the students was very high for players and non-players (Table 15).

Table 16. Percentage of players and non-players selecting two-tiered multiple choice options on question two

Student Category	No. of Students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Players	22	A	-	-	-	-	-	-	3.48
		B	-	-	-	31.8	-	31.8	
		C	-	-	-	68.2*	-	68.2	
Non-Players	115	A	0.9	-	-	0.9	-	1.7	3.37
		B	-	-	7.0	39.1	0.9	47.0	
		C	0.9	1.7	0.9	47.8*	-	51.3	

* indicates the correct answer

Question 2 dealt directly with the relationship between photosynthesis and respiration. Approximately half of the non-players (47.0 %) and approximately a third of the players (31.8 %) believed that these were opposite processes (Table 16). Far more players than non-players (68.2 % compared to 51.3 %) more correctly classified the relationship as complementary. However, no matter the term assigned by the students to describe the relationship, 87.8 % of non-players and 100.0 % of players recognised that the products of each process are the reactants of the other. Once again, students expressed a very high degree of confidence in their answers (Table 16).

Questions 3 to 6 dealt indirectly with the relationship between photosynthesis and respiration, probing students understanding of their products and reactants, and when these processes occurred.

Question 3 asked which gas is released in largest amounts in the presence of sunlight. Most of the students (92.0 % of non-players and 95.5 % of players) correctly selected oxygen. Many of the non-players (67.3 %) showed a somewhat limited understanding of this process, in that they viewed oxygen simply as a by-product of photosynthesis. Fewer of the players (50.0 %) expressed this view. An overwhelmingly larger proportion of players compared to non-players grasped the complementary relationship between photosynthetic products and the reactants of respiration. Those that did understand this, realised that the oxygen produced by photosynthesis is used in respiration, and only if photosynthetic oxygen production is greater than its respiratory consumption is the excess gas released (45.5 % of players compared to 18.6 % of non-players). This shows a far clearer understanding of the complementary relationship between the two processes among players than non-players. Confidence in their answers was high for players and non-players (Table 17.).

Table 17. Percentage of players and non-players selecting two-tiered multiple choice options on question three

Student Category	No. of Students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Players	22	A	-	-	4.5	-	-	4.5	3.27
		B	-	-	45.5*	50.0	-	95.5	
Non-Players	113	A	-	0.9	1.8	5.3	-	8.0	3.13
		B	2.7	2.7	18.3*	67.3	0.9	92.0	

* indicates the correct answer

Question 4 asked which gas is absorbed in largest amounts in the presence of sunlight. The majority (92.2 % of non-players and 90.9 % of players) correctly answered that it was carbon dioxide. Of the non-players, 68.7 % grasped that this is because photosynthesis is dependent on light, compared to 77.3 % of the players. Confidence in their answers was higher for players than for non-players) (Table 18).

Table 18. Percentage of players and non-players selecting two-tiered multiple choice options on question four

Student Category	No. of Students	Content choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Players	22	A	-	77.3*	9.1	4.5	-	90.9	3.45
		B	-	4.5	4.5	-	-	9.1	
Non-Players	115	A	0.9	68.7*	18.3	3.5	0.9	92.2	3.25
		B	0.9	4.3	1.7	0.9	-	7.8	

* indicates the correct answer

Table 19. Percentage of players and non-players selecting two-tiered multiple choice options on question five

Student Category	No. of Students	Content choice	Reason Choice					Total	Mean Confidence
			a	b	c	d	e		
Players	19	A	-	-	5.3	-	-	5.3	3.53
		B	-	5.3	78.9*	10.5	-	94.7	
Non-Players	110	A	-	10.0	9.1	1.8	-	20.9	2.87
		B	2.7	1.8	47.3*	25.5	1.8	79.1	

* indicates the correct answer

Question 5 asked which gas is absorbed in largest amounts in the dark. The correct answer (oxygen) was correctly selected by 79.1 % of non-players and 94.7 % of players. A high proportion of these students knew that this gas is used in respiration. However, only 47.3 % of non-players also grasped that this process takes place continuously, compared to 78.9 % of players. Of the non-players, as many as 25.5 % believed that it occurred in the dark only. Only 10.5 % of players expressed this view, indicating that this misconception has been successfully addressed in the minds of most of the students who played the game. Furthermore, players were far more confident of their answers to this question (Table 19).

Question 6 asked which gas is released in largest amounts in the absence of light. Results of these crosstabulations appear in Table 20. Most students (84.4 % of non-players and 81.8 % of players) correctly selected carbon dioxide. Despite almost a fifth of the players selecting oxygen, 100.0 % of them gave as a reason for their answer that the gas was released during respiration, and recognised this as a process which continued during the day and the night, after photosynthesis had ceased. Only 65.1 % of the non-players understood this, while as many as 47.7 % of them believed respiration occurred only at night. None of the players chose this last option, once again suggesting that this misconception had been addressed. Their confidence in the answers was much higher than the confidence expressed by non-players).

Table 20. Percentage of players and non-players selecting two-tiered multiple choice options on question six

Student Category	No. of Students	Content Choice	Reason choice					Total	Mean confidence
			a	b	c	d	e		
Players	22	A	81.8*	-	-	-	-	81.8	3.50
		B	18.2	-	-	-	-	18.2	
Non-Players	109	A	65.1*	3.7	14.7	0.9	-	84.4	2.81
		B	10.1	4.6	0.9	-	-	15.6	

* indicates the correct answer

Question 12 asked that the students identify the equation representing the net reaction of photosynthesis. A large proportion (82.7 % of non-players and 81.8 % of players) could identify the equation, with 61.8 % of non-players and 68.2 % of players able to interpret which were products and reactants. Mean confidence in answering this question was similarly high amongst players and non-players (Table 21).

Table 21. Percentage of players and non-players selecting two-tiered multiple choice options on question twelve

Student Category	No. of Students	Content Choice	Reason Choice a	b	c	d	e	Total	Mean confidence
Players	22	A	4.5	-	4.5	-	-	9.1	3.32
		B	13.6	68.2*	-	-	-	81.8	
		C	-	9.1	-	-	-	9.1	
Non-Players	110	A	0.9	-	0.9	-	-	1.8	3.27
		B	16.4	61.8*	3.6	0.9	-	82.7	
		C	-	12.7	1.8	0.9	-	15.5	

* indicates the correct answer

Table 22. Percentage of players and non-players selecting two-tiered multiple choice options on question thirteen

Student Category	No. of Students	Content Choice	Reason Choice a	b	c	d	e	Total	Mean confidence
Players	22	A	-	-	4.5	72.7*	-	77.3	3.32
		B	4.5	-	4.5	-	-	9.1	
		C	-	4.5	-	-	-	4.5	
		D	-	-	4.5	4.5	-	9.1	
Non-Players	110	A	0.9	3.6	20.0	53.6*	3.6	81.8	2.62
		B	-	2.7	-	-	-	2.7	
		C	2.7	1.8	0.9	-	-	5.5	
		D	-	-	5.5	4.5	-	10.0	

* indicates the correct answer

Question 13 required the students to identify the net reaction equation of respiration. Once again, most (81.8 % of non-players and 77.3 % of players) could identify the equation. However, only 53.6 % of non-players compared to 72.7 % of players were able to interpret the equation and identify products and reactants. Mean confidence in answering this question was much higher for players than for non-players (Table 22).

Since questions seven to eleven dealt with concepts not presented in the game, an analysis of these responses has not been presented.

In summary, students who had played the game showed a much clearer understanding of the complementary relationship between photosynthesis and respiration, than did students who had not played the game. Also more of the non-players held the view that photosynthesis occurs during the day, and respiration occurs only at night. Those who had played the game clearly understood the concept that respiration in plant cells is a continuous process, occurring alongside photosynthesis during the day and continuing at night.

3.2.2.Qualitative evaluation of the effectiveness of the virtual world: observation of game playing behaviour and interview analysis

During the focus group sessions, all of the students participated quite freely in the conversation. The atmosphere was quite relaxed and friendly and there was a good deal of humour and camaraderie amongst the participants. In one instance, Tarryn expressed the fact that it was difficult for her to find specific information on the Worldwide Web. The conversation very naturally turned to Paul giving her some practical advice on how to solve her problem. Even when the discussion turned to the processes of photosynthesis and respiration, and many of the students felt slightly embarrassed at their vague understanding of these topics, this was always treated with empathetic laughter from all members of the group.

In the first group, consisting of Rebecca, Tarryn, Paul and Alex, the female students made fewer contributions overall. Paul, and Alex in particular, dominated the conversation slightly. However, when questions or comments were specifically directed at Tarryn and Rebecca, in order to draw them back into the conversation, they were quite open in their response. Similarly, within the second group, Mark made fewer spontaneous responses than did Terence or Kevin, but when more of the conversation was directed at him, he did not hesitate to offer his views. This slight reticence among some of the students may have been based on gender differences, or on seniority differences. In both groups, the more reticent students were more junior to their fellow participants. This sort of gender- or status-based communication dynamic is often evident in focus group situations (Morgan and Kreuger, 1993; Alexopoulou and Driver, 1997).

The focus group sessions were aimed primarily at getting background information regarding experience and attitudes towards computer technology, and students understanding of the relationship between photosynthesis and respiration. Since this information was fairly general and a friendly rapport was set up within the group, the more reticent students were easily drawn into the conversation, and the focus group technique was an adequate means of obtaining the necessary information.

During the individual interviews, all of the students appeared comfortable enough to talk very freely. Far fewer conversational nudges were required. The individual interview was a far more suitable approach for obtaining more sensitive information. Cases like this included probing students thinking without drawing attention to them and potentially embarrassing them if they felt their understanding was inadequate, or obtaining their opinions on aspects of the game that they felt could potentially offend me. The more intimate environment of an individual interview reassured them that their opinions were highly valued, and that we were in a comfortable and secluded setting where neither of us would be potentially embarrassed.

3.2.2.1. General experience and attitudes towards computer technology

Almost all of the students interviewed felt comfortable with computer technology. This, they felt, was something their generation had grown up with, and was an increasingly powerful tool that enhanced both their working and recreational lives. Many agreed enthusiastically with Tarryn's response:

> "Good, I'll say... It's modern, it's technology, it's what's going on today." (Adams, 1998a)

Besides using the computer facilities provided in the Biology department, all of the students interviewed had access to a personal computer at home. Although Tarryn reported that her parents frequently made use of their household computer, all of the other participants said that it was only them and their siblings who used the computer at home. It seemed that computer technology was seen as the domain of the younger generation. When asked if their parents used their household computer as much as they did, Mark and Kevin responded with an emphatic "No."
Terence's response:

> "Not at all!" (Adams, 1998b)

was followed by some laughter as all of them appeared to relate to this aspect of family life. They agreed with Terence's explanation that it wasn't a case of his father lacking any relevant information, but that he lacked confidence in this arena.

> "Ja... I... my... dad... isn't... really... computer literate. I mean, he's been to a couple of courses... at... he... I don't think he's comfortable around the technology."

And,

> "... It's more I, I reckon that... they're a bit intimidated... by it... than anything else" (Adams, 1998b)

When asked if they believed that using computer technology required certain skills, Paul was the only one who expressed his firm agreement with this statement.

> "No, definitely... If you only know a little bit about it, about computers, then you're, limited by what you know, and when you come up against, uh, come up difficulties... then, uh, you're gonna struggle... to find ways around them..." (Adams, 1998a)

The others seemed to feel that most software packages they used were very user-friendly, and did not require any in depth understanding to operate. Tarryn's response was:

> "I find a lot of these programs are very user-friendly,"

and

> "You just know how to get in there, and you know how to work around a mouse. You can pretty much find your way around it . You don't have to know too much like in depth how they work or anything, you just need to know how to type, and basically..." (Adams, 1998a)

Rebecca agreed with this statement and Mark voiced a similar opinion:

> "No... it's... you can pick it up easily. I mean there's a few basic commands that you need to know first. And after that... you... you get quite computer literate." (Adams, 1998b)

Terence and Kevin seemed to feel that most operating requirements were fairly intuitive. Terence said:

> "And now in Windows, you need to know nothing!"

Kevin agreed with this, followed by the statement:

> "If you do... fiddle around, you can find out what you need to know anyway." (Adams, 1998b)

While none of the participants had any programming experience, all of them reported using spreadsheet, database and word processing packages, as well as the Internet. They enjoyed the variety of information accessible on the Internet. Even Paul, whose initial response to the word 'computer' was:

> "They're a lot of trouble!" (Adams, 1998a)

seemed to use the Internet fairly adeptly for recreational as well as study purposes.

Many would agree (including most of these students' parents!) that a certain literacy is required when using computer technology, in much the same way that musical literacy is needed when playing the piano. With the exception of Paul, these students seemed to see their use of computer technology as intuitive. Perhaps, the fact that computers have been an integral part of their lives for most of their formative years has lead them to take their computer literacy for granted, in the same way that many adults of our generation take their basic reading and writing skills for granted. However, the view of computer use being completely intuitive was not extended to all forms of computer technology. When it came to playing computer games, it became evident that ease of play depended very much on previous experience and the ability to interpret the user interface.

3.2.2.2. Computer game literacy and ease of game play

Experience with computer games varied within the group. Paul, Tarryn and Rebecca had not played many games with any great frequency. The two female students had played card games and some sport simulation games, such as Golf and Grand Prix. Paul on occasion had played games such as Duke Nukem and Tomb Raider, but said that he preferred reading to playing computer games.

These students were very tentative in their responses when asked if they felt one could learn anything from computer games. Paul's initial response, which was greeted with laughter, was:

> "Hand-eye coordination - if the computer's up to your speed!" (Adams, 1998a)

When asked more directly whether one could learn any thinking skills from playing computer games, all three of them were a little uncertain, and eventually made a non-committal statement that it depended on the game.

Alex, Kevin, Terence and Mark had all played a wider range of games. These included games of the 'shoot-em-up' genre such as Doom and Duke Nukem, strategy games such as Red Alert and Warcraft (which Terence, Mark and Kevin enjoyed the most), and adventure games such as Myst, Riven and Zork Nemesis.

Alex immediately acknowledged that he had learned a lot from playing Zork Nemesis.

> "That was... no, I think that was stimulating, but at the same time, it involved every facet that you deal with in every day life as well. So that was good."

Terence echoed the aspect of mental challenge:

> "... you need to be able to use your head..." (Adams, 1998b)

All of these students felt that being able to compete against other players' strategic skills, as well as the computer heightened the challenge.

(Interestingly, none of the students interviewed enjoyed working in groups. They felt that one person usually ended up doing all the work, and that they would rather be individually accountable for their work. When it came to playing computer games, however, they professed to enjoy group play far more than individual play. This may highlight two aspects of students' attitudes towards work and play. First of all, play is very seldom associated with work (Rieber, 1996) and individual accountability is less important in a play situation. Secondly, group play is often competitive, whereas group work requires co-operation. Since the majority of these students were male, and males often prefer competitive environments more than females do (Canada and Brusca, 1996), it may be that the social component enhancing the appeal of these games was the competition they provided.)

Other factors that contributed to their enjoyment of computer games included realistic goals, fantasy, mystery and adequate feedback (Adams, 1998a; 1998b). When it came to skills used in playing computer games, Kevin believed that game-playing ability had a lot to do with attitude. Terence supported this view with his remark that:

> "I think it's more that you just want, need to... like them, and like to explore."

and:

> "You just pick it up, very easily." (Adams, 1998b)

These statements, however, hint that many games do require certain intellectual skills. What exactly is it that one "picks up"? Even the desire and ability to explore requires certain skills, such as orientation and navigation ability, or a "sense of direction in the game", as Tarryn later described it. Successful exploration also requires good observation skills, as many of the participants discovered. The ability to grasp the perceptual design of the screen is also an important requirement (Kearsley, 1988).

a) Navigational skills

While observing the students playing the game, those who showed the most frustration were Kevin and Rebecca. Paul and Tarryn also reported some minor frustration in their individual interviews. All three of the least experienced game players, Tarryn, Rebecca and Paul, gave the same reasons for their frustration - difficulty in navigating their way through the game.

Movement through the game was programmed using a north, south, east and west view from each point in the game. Although this limits the number of routes a player can take, it is a fairly standard approach to computer game programming. Those who were familiar with such a navigation system showed the least difficulty in negotiating a route through the game. Those who had played fewer computer games showed more difficulty with navigation. Rebecca and Tarryn required some assistance at first, while Paul mastered the navigation system on his own. All three of them, however, reported that their grasp of the movement became easier as they played.

b) Orientation with game objectives

Kevin's sense of frustration came from a lack of overall guidance.

> "There wasn't much guidance. It's almost like we were like thrown into it. I didn't know what the start or the finish was." (Adams, 1998d)

Despite the fact that I had verbally explained the context of the game, Kevin had been left feeling aimless. He felt that a briefing within the game would have been far more helpful. When I explained once more how we saw the game fitting in as a level of Zadarh, I also suggested to him how we might brief the players about the aim of this level.

> "...what we'll do is, at some point, um, you'll notice that your oxygen supplies are going down and there'll be something to tell you, "listen, your oxygen levels are low, you need to replenish them, go to this level to do that." Um, it might give you a clue as well, when you see the fire, that, in that same vicinity you can fill a CO_2 cylinder to extinguish the fire. If that sort of clue is given to you, in Zadarh, would that make sense?" (Adams, 1998d)

Kevin felt that this would provide enough direction.

More of Kevin's frustration stemmed from the fact that the first puzzle he attempted was not working. This was a programming fault, and although I acknowledged this and suggested several times that he move on to another puzzle, he persisted, with dogged determination, in attempting to solve that puzzle! As a result, he did not get to play the rest of the game where he could have solved the rest of the puzzles, as the others did. For this reason, Kevin's experience of the game was a little less positive than the other players.

For most of the others, the overall objective of the game was clear, and if somewhat hazy in the beginning of the game, it became clearer as they played. Alex remarked that:

> "At the beginning, ja, it was floating in the air. But that was only because, we were focused on one aspect of the game... But once you got into the first room, you knew **exactly** what you had to do..." (Adams, 1998g)

Once more, Rebecca and Tarryn, who had less experience with the adventure genre of computer games required more guidance in orientating themselves with the objectives of the game. Paul, however, expressed no difficulty in conceptualising the game objectives, and working towards them. Terence and Mark approached the game with the least assistance from me, and appeared very much at ease with what was required of them.

c) Finding and interpreting clues

Most of the students found that there were enough clues for them to negotiate the puzzles. Kevin said that the clues were quite subtle, and Tarryn would have liked more clues, whereas Mark, Terence and Alex felt that there were enough clues provided. Rebecca and Paul found the clues helpful, but acknowledged that half the battle was finding them. As Rebecca put it:

> "You just had to look for the clues. I guess mystery was the most important thing to get around." (Adams, 1998h)

Observation was an important component of clue interpretation. Tarryn said she did not notice all the clues initially.

> "Cos I missed a few things the first time going through, and then, when I had to go through a second time, I saw." (Adams, 1998e)

In a number of instances, Tarryn said she relied a lot on the assistance of a friend who was playing next to her. She did not notice many of the clues herself, and felt that if she had not had the assistance of a more experienced game player, she would have lost interest and given up.

The more experienced players, Terence, Mark and Alex, all showed a relaxed and unhurried approach to exploring the rooms generally, before concentrating on any specific puzzle. They showed an acceptance that the clues would be there, and that they would find them. Alex said:

> "Basically, I approached it as a game... I knew that there'd be clues and I'd have to look for them. So when I entered the rooms, you look around generally. Then if you see something of interest you go and have a look at that."

He also seemed to know where to look for clues.

> "Um, picture frames, diagrams, those were clues." (Adams, 1998g)

Terence showed a similar approach to exploration.

> "... you see the piano, you need the clues on the wall. You need... to look around. You notice what's on the wall." (Adams, 1998i)

d) Solving puzzles

A description of the game layout and the puzzles was provided in section 3.1.1. Students generally enjoyed solving the puzzles, and made good use of clues such as the wall paintings. These they not only used as landmarks when navigating through the game, but also as clues for which process to use in solving the puzzles. Rebecca said:

> "Um, the pictures were very helpful, because they give you an identification as to what uh, different processes occur..." (Adams, 1998h)

For each puzzle, further clues were provided in the form of charts and micrographs on the walls.

i) The musical puzzle

This was the first puzzle to be attempted by players, perhaps because the piano was a recognisable object to all of them, and playing it was an intuitive approach to solving this puzzle. Sufficient clues were provided in the form of wall charts, even for those who could not read sheet music. Mark, who does not read music, said:

> "...when I played the piano, I noticed the resemblance of the notes on the piano and the pictures on the wall. I kind of figured out if you played those notes, you would get something." (Adams, 1998f)

Alex agreed with this:

> "Cos you've got the key notes on the, on the diagrams are quite important, You've got your A, D, G, and your F sharp, you know? And then on the (photo)respiration, the same notes, reversed. And if you looked at the diagrams you'd see that. Cos they actually had the letters in front of the key..." (Adams, 1998g)

Once these clues had been found, the players found them easy to interpret, and were able to solve the music puzzle. As Alex suggested, those who took note of the tunes for each process realised that the tunes representing photosynthesis and respiration were made up of the same notes in a reversed order. When the correct tune was played, the students were given a token, which when put into the slot machine, allowed them access to the gas panel where they could fill their gas cylinders.

Those who took the time to make notes from the wall chart, found it easier to solve the puzzle without repeatedly referring to the chart. Once again, this was something, more experienced players such as Mark, Kevin, Terence and Alex did without prompting. More inexperienced players, such as Rebecca, Tarryn and Paul initially tried to rely on memory, until I suggested they write down any information they felt they may need later in the game.

ii) The spatial puzzle

The spatial puzzle was usually the second puzzle attempted. Tarryn found this puzzle the easiest to do, but due to her disorientation, she only found the room where the respiration process alone was needed to solve the puzzle. Mark, Paul, Terence, Rebecca and Alex solved both spatial puzzles.

Once more, some conceptual difficulty crept in for those who were not familiar with the adventure genre of computer games. In this case, Paul took some time to figure out that when he had picked up the disks, he could find and use them by selecting objects in his itinerary. Once this was mastered, he solved the puzzles fairly easily. Rebecca and Tarryn were familiar with the concept of an itinerary because they had played Zadarh during a practical session on human evolution.

The concept that confronted students in this puzzle was that during the day, photosynthesis and respiration occur simultaneously in plant cells. Mark, Alex and Rebecca easily grasped this. Once she had discovered the slides, Rebecca knew immediately what was required of her:

> "...it's kind of obvious to me, I don't know if it's obvious to anyone else, but, the mitochondria is used for respiration, and for photosynthesis, we have the chloroplast". (Adams, 1998h)

When asked why he used both organelles in the plant spatial puzzle, Mark answered:

> "Because all the gases were needed there..." (Adams, 1998f)

Alex, too, found this a logical solution to the puzzle. Terence, however, solved both the spatial puzzles by inserting disks into both organelles. While that would have been logical in the plant room, it was not logical in the room representing both animals and plants, since the only process common to both of them is respiration, and animal cells do not contain chloroplasts. Terence said that he had solved the puzzle this way in the 'plant room', and thought he would try the same solution in the 'animal and plant room'. In order to direct a more logical evaluation of the processes that occur in animals, the spatial puzzle should be reprogrammed to disallow use of the chloroplast in the 'animal and plant room'.

iii) The linguistic puzzle

This puzzle had the least clues provided, and all of the players who attempted it found it confusing initially. However, after a brief explanation of what was required of them, they managed to compile the relevant sentences fairly easily. Tarryn's and Rebecca's greatest difficulty lay in remembering the layout of the spots and the words they represented. All of them had to rely on drawing a map and referring to this when they selected a spot on each petal. Although this took some time and thought, the sentences they had to compile made logical sense.

Terence felt that:

> "Once you've got all the words, you could actually see you had to make two sentences with them." (Adams, 1998i)

The older students, in particular echoed this sentiment. Tarryn and Rebecca, both first year students, had a little more difficulty in selecting the appropriate sentences.

iv) The gas panel

Observing their play, it seemed that reaching the gas panel and being able to fill the cylinders was very rewarding to the players. The sight and sound of the door rolling open usually produced excitement, relief and a sense of achievement. It seemed to be a source of encouragement, especially to Rebecca and Tarryn. This feedback motivated them to continue playing the game. Those that reached this section of the game found it enjoyable and fairly simple to conceptualise. Tarryn enjoyed the options of switching on the valves and the light. Initially she did not always choose the correct combinations, but once she succeeded, her choices made logical sense.

> "I liked the switching on the light... for the photosynthesis one. It was artificial light, but it was still photosynthesis. You actually didn't think about it, until you have to switch on the light, and that's why the process wasn't working!" (Adams, 1998e)

Alex's comment was:

> "It was easy... if you got that far, it was easy..." (Adams, 1998g)

Terence remarked that:

> "It was fairly intuitive, simple." (Adams, 1998i)

Watching these students play, and listening to their narration of how they solved the puzzles, it became very obvious that previous experience with computer games, particularly with the adventure and strategy genre, equipped players with certain problem solving skills. Those who were avid players of such games found navigation more intuitive. They were more observant and found and interpreted clues more easily. Both Alex and Terence felt that their previous gaming experience helped them in solving the puzzles. When asked in what way this experience had helped him, Alex said:

> "Besides movement, just what to do.... what is expected of you." (Adams, 1998g)

Terence said:

> "I... you get used to this kind of thing and like the strategy... of the games, and things like that. So, you know, once you can actually put all the pieces together, then, it's very straightforward."

and

> "...You're more... receptive to certain things." (Adams, 1998i)

These comments suggest the development of a kind of literacy is required to play computer games successfully. The skills these students have developed are problem solving skills such as observation, logical thinking, and the ability to orientate oneself and navigate through a three dimensional virtual world, in the same manner one would in the real world. As Alex said, you have to think and behave, and look for clues in the same way you would in a real room. This also requires a non-intrusive interface, and familiarity with that interface.

It may be possible that students who are not familiar with the interface, will master less of the content the game attempts to teach. They are heavily occupied with learning basic game skills. On the other hand, the more a learner has struggled to solve a puzzle, the more likely they finally may be to remember the concept that puzzle has allowed them to work through. Tarryn is unlikely to ever forget that photosynthesis requires light. Those students who struggled through playing the correct tune for photosynthesis and respiration, are unlikely to forget that the products of one are the reactants of the other.

3.2.2.3. Students' suggestions for improving game quality

Rieber (1995) suggests that the learner should be a co-designer of instructional software. It makes sense that input from the end-users themselves is an important component in designing a learning tool. In this study, assuring the students that their help was needed, lead them to play the game on a number of levels. One of these was the casual curiosity of simply playing a new game. A second was the learning involved and the conceptual effort of solving the puzzles. A third level of involvement with the game was the critical eye of the beta-tester. Most of the players said that they found the game highly enjoyable, and all of them made useful comments for enhancing the quality of the game experience.

Kevin agreed that the briefing of their objectives once incorporated into Zadarh, would go a long way to directing his efforts. Tarryn and Rebecca also felt that they would have liked more of a definite start and conclusion to the game. This could have been partially addressed by providing the brief that Kevin felt was necessary.

Tarryn, Alex and Rebecca all felt that some kind of overall floor plan or map would have been helpful in orientating themselves, so that they would know how to get to points of interest.

Both Tarryn and Rebecca, probably the least experienced players, required more guidance while playing, and expressed a need for more feedback while solving the puzzles. Rebecca in particular felt that the reward of gaining access to the gas panel was very delayed feedback. She and Tarryn suggested a points system, as Tarryn put it:

> "...so people could know they've got this much to get, to get towards..." (Adams, 1998e)

Rebecca stated it like this:

> "...You should get a reward, make you feel good and stuff like that! You know

> what I mean? Like um, even though it's an educational game, you have a bit… not fun, but it rewards you in a sense. Like, if you're playing one of the normal games, like Packman or something, you know your score, you know if it's high, or something like that." (Adams, 1998h)

Paul and Alex expressed this role of game feedback in a different manner. Alex felt that the background sound (which many of the players found quite monotonous) could have been used more effectively as a form of clue.

> "Sound I had a problem with. It didn't have any effect, it was just there, for the sake of being there. I mean, it didn't help me. It didn't help me get anywhere. If I got something, uh, the animal room didn't have any animal sounds - it was a bit annoying, because it didn't help." (Adams, 1998g)

Tarryn too, felt that using different background music for each room would have reduced the monotony, and provided an aural clue to the processes being studied in that room.

Paul felt that sound could have played a feedback role in the linguistic puzzle. When the sentences are played back, the end of the sentence is followed by a fairly final sounding tone. Paul felt that this was the wrong tone to signify a correct sentence.

> "... I don't know, for me, a happy sound would have been easier to tell me I got it right!" (Adams, 1998c)

Although none of the others went along with this idea, Alex also felt that the role of sound could have been used more effectively in the form of verbal instruction as a spoken voice. He believed that this would provide not only clearer direction, but also change the atmosphere from time to time, and maintain interest.

All of the students found the graphics very appealing, although Alex, an experienced game player, found the rooms too sparse. He suggested that filling them with more furniture or interesting artifacts and clues would make the setting more realistic and engaging. Rebecca, however, who had never played this type of game before, said that she found the game highly engaging, and that it often felt like "you were in the computer".

Another very useful piece of advice was the possibility of installing an option to save any puzzles solved, so that if players wished to stop playing and then return later, they would not have to start from the beginning again.

3.2.2.4. Effectiveness of the game as a learning tool

Almost all of the participants said that they enjoyed playing the game and that they felt it had clarified certain concepts. Even those who were not frequent players of computer games, and initially experienced some difficulty in progressing through the game, later reported that they learned something and had fun while playing. Mark said:

> "...see, when you work on a subject, that's say, biology, you don't really get to play these games, because they just give you these notes. Carry on reading, it's like monotonous. Basic stuff. You read and you regurgitate. And when you play this game, like, it's enjoyable, you have puzzles to do. You have to complete the game. The aim of the game is to complete it. So, everything that you do, has a purpose. So, ja, it's interesting. It makes learning fun." (Adams, 1998f)

Tarryn and Rebecca echoed similar sentiments. Tarryn's statement was:

> "...So we're having some fun, with computer games, and we're... learning. It's a little bit better... If you just have to regurgitate it, you don't enjoy it." (Adams, 1998e)

Photosynthesis and respiration are topics that all of them found quite daunting during the focus groups. Most of them openly expressed confusion about the roles of the processes, and neither of the topics were among those they had particularly enjoyed at school. The fact that almost all of the students enjoyed playing the game, and felt that they had learned something, is in itself a great step toward learning success in these topics. These students had fun, and their confidence in their ability to grasp a difficult concept had grown.

During the focus groups, it was evident that all of them were very uncertain about the timing of the processes, and they were all hesitant in their answers, often relying on prompting from each other to finish a train of thought. They all agreed that photosynthesis took place primarily in the presence of light, unless the products of the light phase had accumulated sufficiently for the dark phase to continue at night. When asked when respiration took place, their initial response was that it occurred at night.

Then Paul said:

> "Wait, no, it's actually, it's all -"

Rebecca, Tarryn and Alex each echoed the shift in their opinion that respiration actually took place continually. They seemed uncertain as to what gases were required and released during each process. Amidst some embarrassed laughter, Tarryn said:

> "In photosynthesis... hhhmm... carbon dioxide..."

Rebecca continued:

> "Hhhmm... carbon... um... Oxygen is released and results in respiration."

It was only when Paul said that the processes are linked:

> "...it's a cycle." (Adams, 1998a)

that Tarryn and Rebecca started to consider the possibility of oxygen released during photosynthesis being used in respiration, and not just simply released into the atmosphere, as they were lead to believe. Tarryn ascribed this to the fact that they had been taught the processes as entirely separate topics, and were never required to integrate this knowledge. Mark also suggested this lack of integration, and the fact that the topics had never had any real relevance when he said that:

> "It was taught for us just to remember it for that period, for an exam period... and after that... basically...." (Adams, 1998b)

Non-integrated science and biology curricula, with little relevance to students daily life, are concerns raised by a number researchers, including Haslam and Treagust (1987), Waheed and Lucas (1992), Amir and Tamir (1994), Hazel and Prosser (1994), Lucas (1995), Lumpe (1995), Bunce (1996), Barak (1997) and Mayoh and Knutton (1997).

After having played the game the majority of these students expressed a far clearer understanding of the reactants and products of each process, and how these processes relate to one another. Paul described the processes as "interchangeable", Mark and Terence described them as "opposite", and Rebecca and Tarryn used the correct term: "complementary". Despite the fact that they used different terms to describe this relationship, every one of them clearly grasped the concept that the photosynthetic products are reactants in respiration, and vice versa.

The second concept, that respiration is a continuous process was much clearer for most of them. Even Kevin, who had only attempted one puzzle had seen enough of the wall paintings, to comment:

> "You said photosynthesis was for plants only, and then we had one where there was plants and animals. That was respiration. I felt that it wouldn't be right to say photosynthesis is dealing with plants, because respiration is also in plants." (Adams, 1998d)

When I explained to him that this was the very concept we trying to emphasise, and that for the other 'plant rooms' he would have had to use both processes to solve the puzzles, he was satisfied with that logic.

Tarryn realised that she could solve respiration puzzles with the light on or off, showing her that respiration occurs continuously, day and night. She also felt that the game had clarified the difference in the roles of photosynthesis and respiration, something she had always confused at school. She voiced it like this:

> "But they're actually not... different processes. They just... complement each other... the products... you can't have one without the other. Cos the one's output, and the other's input." (Adams, 1998e)

She felt that her understanding of these processes would have improved greatly, had she had the opportunity to play this game at school.

Mark felt that the game had emphasised the basic steps involved in the processes. Mark's concept of the timing of respiration, however, had not been clarified fully. He explained his thinking as follows:

> "Because in the light phase, photosynthesis is, I mean, the main process of photosynthesis is absorbing light from the sun, and through use of the electron pathway. So I think that after that, it's dark, and cellular respiration occurs. That's, that's what I think."

When I asked him when respiration occurred in animal cells, he replied without hesitation that it occurred all the time. I asked him why he did not think respiration occurred all the time in plant cells, and he responded:

> "Um... why I'm saying is, is, there's a difference is because, in, in, uh, in uh, plants there's two, there's both reactions. So, it can occur simultaneously, right, it,

it depends, I'm not too sure."

When I nodded, he continued:

"So it probably could. Ja." (Adams, 1998f)

Mark had not yet fully embraced the concept of respiration being continuous in plant cells.

Alex and Terence both felt that the puzzles presented this concept very logically, and related fully to respiration occurring day and night in plant cells, as it did in animal cells.

Rebecca expressed most clearly that her understanding of respiration had altered.

"Because at first, at school level, I did not know that, uh, respiration occurs all the time, because they told us that no, it occurred only at night."

When asked what she had learned from the game, she answered:

"Distinguishing between photosynthesis and respiration, and not to confuse them. Like everyone thinks that, uh, respiration occurs only at night, and that it well... it's a continuous process and things like that. Because a lot of people have the perception that it isn't." (Adams, 1998h)

Both the junior and senior students felt they had benefited from playing the game. When asked if he felt he had learned anything, Paul replied emphatically:

"Definitely! I think if you played it regularly you'd understand those processes backwards." (Adams, 1998c)

Alex said:

> "Oh yes! It cleared up certain things."

and,

> "...basically, it clears up misconceptions. It doesn't teach you anything new, but it just clears up the misconceptions." (Adams, 1998g)

These students felt that the game was successful in clarifying their understanding of photosynthesis and respiration. During the individual interviews, there appeared to be a significant shift in the clarity and confidence with which they expressed their understanding of these concepts. The virtual world appears to have been effective in addressing their misconceptions.

Because virtual worlds have boundaries, a limited number of learning outcomes may be determined by the designer (Rieber, 1992). This entails a somewhat instructivist approach to learning. However, in a problem-based learning environment, with meaningful puzzles to solve, learners are provided with an inductive approach to learning, where the interpretation of their own experience allows them to discover and construct their meaning of the concepts they are confronted with. Thus, computer games provide a continuum between inductive and deductive learning (Rieber, 1992). This allows the designer to draw from the strengths of both instructivist and constructivist approaches to learning. Herein may the lie the success of this game in addressing these students' misconceptions.

Where traditional instruction often fails to clarify student misconceptions (Sandoval, 1995), it appears that a problem-based learning approach was highly effective in this case. The game gave these concepts greater relevance by anchoring the learning activities to the larger, fairly authentic tasks of filling an oxygen cylinder to replenish the players air supply, and a CO_2 cylinder to extinguish a fire. To a certain degree, the students were given ownership of the process used to develop a solution, and they were allowed to test their alternative views. These are conditions Savery and Duffy (1995) consider essential for meaningful learning.

In order to alter learners' cognitive schemata, Sandoval (1995) states that the following criteria must be met. Dissatisfaction must be created by anomalous data; there must be an understanding of the concept being presented; the new concept must be plausible; the new concept must be preferable and useful. In the context of the game, students' misconceptions resulted in dissatisfaction, in that they failed as a basis for solving the puzzles and achieving the game objectives. Accommodating the new concept, that respiration occurs continuously, and that it is a complementary process to photosynthesis, allowed the students the satisfaction of solving the puzzles and achieving their aim to fill the cylinders. The puzzles presented the learners with the new concept in an authentic setting and in a manner that made sense to them.

Previously, these learners studied the processes of photosynthesis and respiration in isolation. Each process, its reactants, products and the organelle in which it occurs, has been taught as a separate topic. By making the conceptual separation at the cellular level (i.e. the similarities and difference between plant cells and animal cells), and not at the organelle level, (the differences between the chloroplast and the mitochondria), the students were confronted with the processes occurring in unison. The game provided a means of integrating the topics in the complex system of the cell, in a manner that students could visualise. Computer games may provide the most effective means for addressing misconceptions, since they have the capacity to allow visualisation and problem solving in complex systems (Betz, 1996).

Further contributions to learning success were based on the fact that the students found the game enjoyable. The game provided challenge, mental stimulation, authentic goals, and a measure of fantasy. Students were given clues to solve the puzzles, providing some guidance, but also, some mystery. They were provided with a number of ways of managing the gas panel in order to fill their cylinders, providing them some control over the game environment. These were identified by the students in the focus groups as factors contributing to their enjoyment of computer games (Adams, 1998a;1998b). Rieber (1996) also identifies them as contributing to the intrinsic motivation provided by computer games. While the less experienced players felt a need for greater feedback, the more seasoned players felt that there was adequate feedback provided in the form of tokens given for solving the puzzles, gaining access to the gas panel, and satisfaction of watching their gas cylinders being filled.

The only enjoyable factor listed by students that was not incorporated into the game design was competition. Rieber (1992) states that the use of computer games in a learning environment requires an attitude of playfulness and exploration. Group learning, particularly where an inductive approach is used, is only successful when there is a lack of aggression and competition. Canada and Brusca (1996) also suggest that the performance of female students in particular, is poorer in highly competitive learning environments.

Lack of familiarity with the game interface caused frustration with less experienced players. These students were less adept at navigation and solving puzzles, indicating less developed problem solving skills. Oliver and Perzylo (1994) show that this is true of inexperienced learners in other hypermedia-based learning environments. Learning style, age and experience in such environments affect students' learning efficiency. However, these authors report that students become better users with appropriate instruction.

Learning style has been shown to change over time, particularly with exposure to computer-aided learning environments. Clariana (1997) reports that mathematics learners over a five-month period in a computer-assisted learning environment showed a change in their learning styles from more concrete experiential to active experimentation. This is supported by the fact that the more seasoned computer game players in this study attributed their competence not only to a willingness to explore, but also to experience. Even the less experienced players, Tarryn, Rebecca and Paul, showed improved navigational ability and awareness of what was required of them, over the two hour period that they played the game.

While these students felt they had benefited from playing the game for a short period only, the effect of the game as a learning tool may only be experienced with extended play. As Paul put it,

> "If you played the game regularly, you'd know those processes backwards." (Adams, 1998c)

Alex's statement that the game had not taught him anything new, but that it had simply clarified his understanding of the concepts, suggests that this game would be most effectively used to complement traditional lectures, where the more detailed factual information of these processes could be delivered. It is probably also necessary to recognise the role of a facilitator for students using this game as a learning tool. Less experienced players, particularly, required guidance while playing the game. This, along with a discussion of their conceptual development during the interviews, provided a facilitative component in their learning process. Such a shift in the teaching role, from instructional to facilitative, is necessary in problem-based learning environments, and those using computer technology as a learning tool (Carey, 1993; Savery and Duffy, 1995).

The possibility also exists that this game could be used for assessment purposes. Kumar (1994) advocates the use of hypermedia, not only as a teaching tool, but also as tool for alternative assessment. Because hypermedia provides an environment where students' processes of learning and problem solving can be studied, he also recommends its use as a research tool. The virtual world developed in this study may be appropriate for all of these uses.

4. Conclusion

Unpublished studies by Bioped in 1997 and 1998 have shown that South African Matric pupils consider photosynthesis and respiration two of the most difficult topics in the Matric Biology syllabus. These topics were identified also by teachers as topics which are difficult to teach (Chacko, 1996). Attempts have been made to identify specific misconceptions held by students regarding the processes. These studies have revealed consistently that the greatest misconceptions lie in the relationship between photosynthesis and respiration, and when a plant is thought to respire (Haslam and Treagust, 1987; Amir and Tamir, 1994; Hazel and Prosser, 1994). Similar results were described in this study among South African students.

It is likely that an unintegrated approach to teaching biological topics has contributed to these misconceptions. The fact that many school Science and Biology curricula are designed and taught in a linear, compartmentalised fashion, with little relation of topics within the syllabus has been sharply criticised (Lucas, 1995; Bunce, 1996). This was one of Tema's (1995) criticisms of the South African Matric Biology syllabus. Students interviewed in this study also reported that they had studied photosynthesis and respiration in isolation at school, and had never been taught or expected to relate the two topics (Adams, 1998a).

Learners' misconceptions often persist into adulthood and are difficult to alter through traditional instruction (Driver, 1991; Sandoval, 1995). This is evident in the results presented in Tables 1 to 13, where senior students, who had been exposed to traditional instruction, only showed a partial increase in their understanding of the relationship between photosynthesis and respiration. An alternative approach to teaching these topics was needed. Such an endeavour required the design and use of an appropriate learning tool.

With the development of learning theories, there has been a concurrent evolution of learning tools (White and Purdom, 1996). The linear programs of Skinnerian teaching machines were tools of the Behaviourist approach to learning (Kolesnik, 1970; Spencer, 1988). With the development and acceptance of Cognitive Learning, it was argued that branching programs were more appropriate learning tool (Kolesnik, 1970). Increasingly more sophisticated cognitive learning aids became possible with the advent of hypermedia (Kozma, 1987). In many respects, the capacity of this technology to develop cognitive learning strategies may have culminated in the use of computer-based virtual worlds.

A virtual world (or microworld) represents a small, but complete version of some domain of interest. Learners do not merely study the domain in the virtual world, they become immersed in it (Dede, 1995; Rieber, 1996). Piaget believed that learning takes place when the learner's knowledge structure is in a state of disequilibrium, and a resolution of that disequilbrium leads to a conceptual change (Driver, Asoko, Leach, Mortimer and Scott, 1994). A virtual world can trigger disequilibrium and foster equilibrium resolution, leading to re-organisation of cognitive schemata (Rieber, 1996). This makes it an ideal learning tool for addressing persistent misconceptions which traditional instruction fails to alter.

Furthermore, virtual worlds provide intrinsic motivation by providing the learner with challenge, curiosity, fantasy, control (Thomas and Macredie, 1994; Rieber, 1996) and visual feedback of their actions (Betz, 1996). They also require that learners are metacognitively and behaviourally active throughout the learning process (Rieber, 1996). Here, the learner is presented with authentic problems that are anchored in a complex system, and require integration of knowledge from a number of disciplines (Betz, 1996). The use of virtual worlds could bring a more holistic approach to the somewhat fragmented teaching of Science.

In this study, the game that encapsulates a virtual world, appears to have corrected many of the misconceptions held by students regarding photosynthesis and respiration. Previously held views were challenged by the puzzles, and assimilation of the new concept held value for them in that it allowed them to solve authentic problems within the game environment.

The game also required the use of inductive reasoning. Traditional instruction often coaches students in deductive reasoning. A rule is presented, and then students are given specific examples in which to apply the general concept. In contrast, by solving individual puzzles in the game, students constructed their own general concept. Rieber (1992) recommends a balance between the two forms of reasoning by using virtual worlds as a learning tool along with traditional classroom instruction. This complementary relationship proved effective, in that many of the students felt that they relied on their previous classroom instruction as a factual base from which to approach the puzzles. The game then provided a means to clarify concepts.

While Kumar (1994) recommends the possibility of using hypermedia not only for teaching, but also for assessment purposes, factors such as gender, culture, and previous computer experience must be taken into consideration. All of these affect students' competence in a hypermedia environment (Colley, Hill, Hill and Jones, 1995; Canada and Brusca, 1996; Freedman and Liu, 1996; Gipson, 1997). This was evident among the students who played the game. Those with more computer game experience found navigation easier, and were quicker to notice and interpret clues and solve puzzles. Should the virtual world developed in this study be used as courseware on photosynthesis and respiration it may serve as both a learning tool and an assessment tool. However, the presence of a facilitator would be required, particularly for students who are less experienced game players.

Thus far, the game has proved effective as a learning resource to address misconceptions regarding the relationship between photosynthesis and respiration. This was reflected by responses on the questionnaire, and by students' attitudes during the interviews. The majority of these students found the game both challenging and enjoyable. They also felt that their understanding of the concepts being probed had been clarified, and that playing the game had been a worthwhile learning exercise (Adams, 1998c; 1998e; 1998f; 1998g; 1998h).

The completion of the remaining rooms, housing the mathematical-logical puzzle and the bodily-kinaesthetic puzzle, will allow the students a greater diversity of means to achieve game objectives. When fully incorporated as a level of Zadarh, these objectives will be become clearer and more authentic, as they are seen in the larger context of Zadarh's mission. Further levels to be added to Zadarh include problem solving based on genetics and protein biochemistry, topics identified as conceptually difficult (Amory, unpublished).

Computer games, such as Zadarh, offer realistic learning environments, where students' knowledge from a range of disciplines may be used to solve complex problems. It is hoped that educators continue to recognise the potential of using virtual worlds for learning, and making learning fun.

References

Adams, J.C. (1998a). Transcript of focus group, 17th of September

Adams, J.C. (1998b). Transcript of focus group, 18th of September

Adams, J.C. (1998c). Transcript of interview with Paul, 26th of October

Adams, J.C. (1998d). Transcript of interview with Kevin, 26th of October

Adams, J.C. (1998e). Transcript of interview with Tarryn, 26th of October

Adams, J.C. (1998f). Transcript of interview with Mark, 26th of October

Adams, J.C. (1998g). Transcript of interview with Alex, 26th of October

Adams, J.C. (1998h). Transcript of interview with Rebecca, 27th of October

Adams, J.C. (1998i). Transcript of interview with Terence, 26th of October

Alexopoulou, E. and Driver, R. (1997). Gender differences in small group discussion in physics, *International Journal of Science Education*, **19**: 393-406

Alonso, D.L. and Norman, K.L. (1996). Forms of control and interaction as determinants of lecture effectiveness in the electronic classroom, *Computers Education* **27**(3/4): 205-214

Amory, A. (1997). *Integration of technology into education: theories, technology, examples and recommendations, Contract Report: Open Society Foundation of South Africa,* Open Society Foundation of South Africa, Cape Town

Amory, A., Naicker, K., Vincent, J. and Adams, C. (1998). Computer games as a learning resource, (ed. T. Ottmann and I. Tomek), *Proceedings of Ed-Media and Ed-Telecom, the tenth World Conference on Educational Media and Hypermedia and World Conference on Educational Telecommunications*: 50-55, Association for the Advancement of Computing in Education, Charlottesville

Amir, R. and Tamir, P. (1994). In-depth analysis of misconceptions as a basis for developing research-based remedial instruction: The case of photosynthesis, *The American Biology Teacher*, **56**(2): 94-100

Barak, J. (1997). Understanding of energy in biology and vitalistic conceptions, *International Journal of Science Education*, **19**(1): 21-30

Bell, B. (1995). Interviewing: A technique for assessing science knowledge, (ed. S.M. Glynn and R. Duit), *Learning Science in the Schools: Research Reforming Practice*, Lawrence and Erlbaum Associates, New Jersey

Betz, J.A. (1995-1996). Computer games: Increase learning in an interactive-learning environment, *Journal of Educational Technology Systems* **24**(2): 195-205

Birnbaum, R. (1982). Games and simulations in higher education, *Simulations and Games*, **13**(1): 3-11

Bodner, G.M. (1986). Constructivism: a theory of knowledge, *Journal of Chemical Education* **63**: 873 -878

Bostow, D.E., Kritch, K.M. and Tompkins, B.F. (1995). Computers and Pedagogy: Replacing telling with interactive computer-programmed instruction, *Behaviour Research Methods, Instruments and Computers* **27**(2): 297-300

Bunce, D.M. (1996). The quiet revolution in Science education – teaching Science the way students learn, *Journal for College Science Teaching,* **40**: 169-171

Burtonwood, N. (1996). Culture, identity and the curriculum, *Educational Review* **48**(3): 227-235

Canada, K. and Brusca, F. (1996). The technological gender gap: evidence and recommendations for educators and computer-based instruction designers, *Educational Technology Research and Development*, **39**(2): 43-51

Carey, D.M. (1993). Teacher roles and technology integration: moving from teacher as director to teacher as facilitator, *Computers in the Schools,* **9**(2/3): 105-118

Chacko, C.C. (1996). Student teacher's views about difficult and unfamiliar topics in Matriculation Biology, *Proceedings of the Fourth Annual General Meeting of the Southern African Association for Research in Mathematics and Science Education (SAARMSE),* University of the North, Pietersburg

Chen, A-Y. (1993). The use of interactive multimedia systems to improve the learning of classroom practices, *Educational Research and Perspectives*, **20**(2): 24-32

Chitty, C. and Lawn, M. (1995). Introduction; Redefining the teacher and the curriculum, *Educational Review*, **47**(2): 139-142

Clariana, R.B. (1997). Considering learning style in computer-assisted learning, *British Journal of Educational Technology*, **28**(1): 66-68

Clarke, P.A. and Cronje, J.C. (1998). Teaching "Teaching on the Internet" on the Internet, Media for the new millenium: looking into the future, (ed. A. le Roux), *Conference proceedings of the Educational Media Institute (EMI) of the South African Association for Research and Development in Higher Education (SAARDHE)*, SAARDHE, Pretoria

Colley, A., Hill, F., Hill, J. and Jones, A. (1995). Gender effects in the stereotyping of those with different kinds of computing experience, *Journal of Educational Computing Research*, **12**: 19-27

Cornbleth, C. (1995). Curriculum knowledge: controlling the 'great speckled bird', *Educational Review*, **47**(2): 157-164

Dede, C. (1995). The evolution of constructivist learning environments: immersion in distributed, virtual worlds, *Educational Technology*, **35**(5): 46-52

Doricott, D. and Wilson, M. (1997). *Red Tower Web: Weaving new models of Learning*, unpublished mimeo

Douglas, J. (1985). *Creative Interviewing*, Sage Publications Inc., New York

Driver, R. (1991). Culture clash: children and science, *New Scientist*, **29**: 46-48

Driver, R., Asoko, H., Leach, J., Mortimer, E. and Scott, P. (1994). Constructing scientific knowledge in the classroom, *Educational Researcher*, **23**(7): 5-12

Edward, N.S. (1997). Computer-based simulations of laboratory experiments, *British Journal of Educational Technology* **28**(1):51-63

Freedman, K. and Liu, M. (1996). The importance of computer experience, learning processes, and communication patterns in multicultural networking, *Educational Technology Research and Development*, **44**(11): 43-59

Galloway, S. (1998). Web-based discussion classes in the literature classroom, (ed. A. le Roux), *Conference proceedings of the Educational Media Institute (EMI) of the South African Association for Research and Development in Higher Education (SAARDHE)*, SAARDHE, Pretoria

Gardner, H. (1983). *Frames of Mind: The Theory of Multiple Intelligences*, Basic Books Inc., New York

Gardner, H. (1993). *Multiple Intelligences. The Theory in Practice*, Harper Collins, New York

Gipson, J. (1997). Girls and computer technology: barrier or key? *Educational Technology*, **35**(2): 41-43

Grabowski, B. and Aggen, W. (1984). Computers for interactive learning, *Instructional Innovator*, **29**: 27-30

Hall, C., Hall, T.L. and Kasperek, J.G. (1995). Psychology of computer use:XXXIII, Interactive instruction with college-level courses, *Psychological Reports* **76**: 963-970

Hansen, E. (1990). The role of interactive video technology in higher education: case study and a proposed framework, *Educational Technology*, **30**(9): 13-21

Haslam, F. and Treagust, D.E. (1987). Diagnosing secondary students misconceptions of photosynthesis and respiration using a two-tiered multiple choice instrument, *Journal of Biological Education*, **21**(3): 203-211

Hazel, E. And Prosser, M. (1994). First-year university students understanding of photosynthesis, their study strategies and learning context, *The American Biology Teacher*, **56**(5): 274-279

Hoffman, S. (1997). Elaboration Theory and hypermedia: is there a link? *Educational Technology*, **37**(1): 57-64

Jansen, J.D. (1997). *Why OBE will fail*, unpublished mimeo

Jaspers, F. (1994). Target group characteristics: are perceptional modality preferences relevant for instructional materials design? *Educational Technology*, **31**(1): 11-17

Jih, H.J. and Reeves, T.C. (1992). Mental models: a research focus for interactive learning systems, *Educational Technology Research and Development*, **40**(3): 39-53

Jonassen, D.H. (1988). Designing structured hypertext and structuring access to hypertext, *Educational Technology*, **28**(11): 13-16

Jones, A. and Kember, D. (1994). Approaches to learning and student acceptance of self-study packages, *Educational Technology*, **1**(2): 93-9

Jones, I., Mixing qualitative and quantitative methods in sports fan research, *The Qualitative Report*, **3**, (1997), http://www.nova.edu/sss/QR/QR3-4/jones.html, access date: 28 October 1998

Katz, Y.J. (1992). Toward a personality profile of a successful computer using teacher, *Educational Technology*, **32**(2): 39-41

Kearsley, G. (1988). Authoring considerations for hypertext, *Educational Technology*, **28**(11):21-28

Keats, D. (1998). Educational technology in a student-centered approach to learning: a practical example using a six-week third year module in Marine Botany, (ed. A. le Roux), *Conference proceedings of the Educational Media Institute (EMI) of the South African Association for Research and Development in Higher Education (SAARDHE)*, SAARDHE, Pretoria

Kolesnik, W.B. (1970). *Educational Psychology*, McGraw-Hill, New York

Kozma, R.B. (1987). The implications of cognitive psychology for computer based learning tools, *Educational Technology*, **27**(11): 20-25

Kumar, D.D. (1994). Hypermedia: a tool for alternative assessment? *Educational Technology, Trends and Innovations*, **31**(4): 59-66

Language Development and Hypermedia Research Group, (1992). "Open" software design: a case study, *Educational Technology*, **32**(2): 43-55

Lucas, A.M. (1995). Playing the notes but ignoring the tune: the narrowness of biology education research, *Journal of Biological Education*, **29**(3): 195-200

Lumpe, A.T. (1995). Peer collaboration and concept development: learning about photosynthesis, *Journal of Research in Science Teaching*, **32**(1): 71-98

Marchionini, G. (1988). Hypermedia and learning: freedom and chaos, *Educational Technology*, **28**(11): 8-12

Mayoh, K. and Knutton, S. (1997). Using out-of-school experience in science lessons: reality or rhetoric? *International Journal of Science Education*, **19**(7): 849-867

Morariu, J. (1988). Hypermedia in instruction and training: the power and the promise, *Educational Technology*, **28**(11): 17-20

Morgan, D.L. and Krueger, R.A. (1993). When to use focus groups and why, (ed. D.L. Morgan), *Successful Focus Groups. Advancing the state of the art,* Sage Publications Inc., New York

Murray, J.D. and McGlone, C. (1997). Topic overviews and processing of topic structure, *Journal of Educational Psychology*, **89**(2): 251-261

National Department of Education (1998). *Curriculum 2005: Implementing OBE-1: Classroom Practice,* South African Department of Education, Pretoria

Needham, R. (1987). Teaching strategies for developing understanding in science, *Children's Learning in Science Project*, Centre for Studies in Science and Mathematics Education, University of Leeds, Leeds

Oliver, R. and Perzylo, L. (1994). Children's information skills: making effective use of multimedia sources, *Educational Technology*, **31**(3): 219-230

O'Neill, M. and Pitney, D. (1993). Multimedia in pre-service and in-service teacher education programs, *Education Research and Perspectives*, **20**(1): 71-80

Ornstein, A.C. and Levine, D. U. (1993). *Foundations of Education*, fifth edition, Houghton Mifflin Company, Boston

Raubenheimer, C.D. (1992-1993). An emerging approach to teacher development: Who drives the bus? *Perspectives in Education*, **14**(1): 67-80

Rieber, L.P. (1992). Computer-based microworlds: a bridge between constructivism and direct instruction, *Educational Technology Research and Development* **40**(1): 93-106

Rieber, L.P. (1995). A historical review of visualisation in human cognition, *Educational Technology Research and Development* **43**(1): 45-56

Rieber, L.P. (1996). Seriously considering play: designing interactive learning environments based on the blending of microworlds, simulations and games, *Educational Technology Research and Development* **44**(2): 43-58

Ross, K.A. (1993). There is no energy in food and fuels – but they do have fuel value, *School Science Review* **75**(271): 39-47

Salomon, G. (1984). Television is "easy" and print is 'tough": the different investment in mental effort in learning as a function of perceptions and attributions, *Journal of Educational Psychology*, **76**(4): 647-658

Sandoval, J. (1995). Teaching in subject matter areas: Science, *Annual Review of Psychology,* **46**: 355-374

Savery, J.R. and Duffy, T.M. (1995). Problem based learning: An instructional model and its constructivist framework, *Educational Technology*, **35**(5): 31-38

Scott, P. (1987). A constructivist view of learning and teaching in science, *Children's Learning in Science Project*, Centre for Studies in Science and Mathematics Education, University of Leeds, Leeds

Sokal, R.R. and Rohlf, F.J. (1981), *Biometry*, second edition, W.H. Freeman, San Franscisco

Spencer, K. (1988). *The Psychology of Educational Technology and Instructional Media*, Chapman and Hall, New York

Sprinthall, N.A. and Sprinthall, R.C. (1990). *Educational Psychology. A Developmental Approach,* fifth edition, McGraw-Hill, Singapore

Stanton, N.A. (1994). Explorations into hypertext: spatial metaphor considered harmful, *Educational Technology*, **31**(4): 276-294

Tema, B. (1995). Democratising the matric biology syllabus, *Perspectives in Education*, **16**(1): 105-130

Thomas, P. and Macredie, R. (1994). Games and the design of human computer interfaces, *Educational Technology Training and Innovations,* **31**(2): 34-142

Treagust, D.F. (1995). Diagnostic assessment of students' science knowledge, (ed. S.M. Glynn and R. Duit), *Learning Science in the Schools: Research Reforming Practice*, Lawrence and Erlbaum Associates, New Jersey

Tribe, J. (1996). Core skills: a critical examination, *Educational Review*, **48**(1): 13-27

van der Merwe, A. S. (1998). Qualitative data analysis - a few candles to light the way, publication forthcoming

Van der Westhuizen, D, Nolte, A. and Fourie, E. (1998). Where do you stand with your virtual classroom? We're in a box, (ed. A. le Roux), *Conference proceedings of the Educational Media Institute (EMI) of the South African Association for Research and Development in Higher Education (SAARDHE)*, SAARDHE, Pretoria

Waddick, J. (1994). Case study: the creation of a computer learning environment as an alternative to traditional lecturing methods in chemistry, *Educational Technology*, **31**(2): 98-103

Wade, C. and Tavris, C. (1990). *Psychology,* Second Edition, Harper Collins Publishers, New York

Waheed, T. and Lucas, A.M. (1992). Understanding interrelated topics: photosynthesis at age 14+, *Journal of Biological Education* **26**(3): 193-199

Wainwright, D., Can sociological research be qualitative, critical and valid? *The Qualitative Report,* **3,** (1997), http://www.nova.edu/sss/QR/QR3-2/wain/html, access date: 28 October 1998

White, J.A. and Purdom, D.M. (1996). Viewing modern instructional technology through conceptions of the curriculum, *Educational Technology Review*, **6**: 5-9

Wolff, B. Knodel, J. and Sittitrai, W. (1993). Focus groups and surveys as complementary research methods, (ed. D. Morgan), *Successful Focus Groups. Advancing the State of the Art,* Sage Publications Inc., New York

Appendix 1: Questionnaire developed to identify specific misconceptions held by students regarding photosynthesis and respiration

Questionnaire on photosynthesis and respiration

This questionnaire forms part of my Masters project. Its purpose is to assess students' knowledge about photosynthesis and respiration in order to identify common misconceptions. The information will be used to develop more effective teaching in this area.

The questionnaire contains 13 questions about photosynthesis and respiration in plants. Each question has three parts. The first part is a standard multiple-choice question on a particular concept of photosynthesis. Please mark the option that you feel answers the question most fully.

The second part asks you why you chose the answer you did. This is also multiple choice. Again, please mark the reason that most fully explains your answer. If you feel that none of the options provide a satisfactory answer, space is provided for you to write your reason. The last part asks you how confident you feel about your answer, either not at all confident, somewhat confident, confident, or very confident. The appropriate choice should be marked.

Thank you for your assistance.

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Question 1

Plants produce "food" (chemical compounds which can be broken down to meet the energy requirements of the plant) through which process?

a) absorption of minerals through the roots
b) photosynthesis
c) transpiration
d) respiration

The reason for my answer is that:

a) Transpiration is the process whereby water and nutrients are transported to all parts of the plant.

b) Minerals in the soil are directly metabolised by the plant for energy.

c) Respiration is the production of glucose and other sugars which are used as a source of energy for the plant.

d) Light energy is trapped by chlorophyll molecules and used to convert CO_2 and water to glucose and other simple sugars, which are used as a source of energy for the plant.

e) ____

How confident are you of your answer?
a) not at all
b) somewhat
c) confident
d) very confident

Question 2

Photosynthesis and respiration are

a) the same process

b) opposite processes

c) complementary processes

The reason for my answer is that:

a) Both processes use light energy and release O_2.

b) Both processes use light energy and release CO_2

c) Photosynthesis is a constructive process that may lead to an increase in mass of the plant, whereas respiration is a destructive process that may lead to a decrease in mass of the plant.

d) the products of photosynthesis are used as reactants in respiration (i.e. the simple sugars produced by photosynthesis are broken down through respiration to release energy for the plant.

e) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 3

What gas is given out in largest amounts by green plants in the presence of sunlight?

a) CO_2

b) O_2

The reason for my answer is that:

a) This gas is given off in the presence of light because green plants respire only during the day.

b) Green plants only photosynthesize and do not respire in the presence of light energy.

c) There is more of this gas produced by the plant during photosynthesis than is needed by the plant for respiration and other processes, so the excess gas is given off.

d) This gas is a by-product given off by green plants as they photosynthesize.

e) ______________________________

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 4

Which gas is taken in by green plants in the largest quantities in the presence of light energy?

a) CO_2

b) O_2

The reason for my answer is that:

a) This gas is used in respiration which takes place only in the presence of light energy

b) This gas is used in photosynthesis which takes place only in the presence of light Energy.

c) This gas is used in photosynthesis, which takes place continuously

d) This gas is used in respiration, which takes place continuously.

e) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 5

Which gas is taken in by green plants in large amounts when there is no light present?

a) CO_2

b) O_2

The reason for my answer is that:

a) This gas is used in photosynthesis, which takes place only in the dark

b) This gas is used in photosynthesis, which takes place continuously

c) This gas is used in respiration, which takes place continuously

d) This gas is used in respiration, which takes place only in the dark.

e) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 6

What gas is given off in large amounts when there is no light energy at all?

a) CO_2

b) O_2

The reason for my answer is that:

a) Green plants stop photosynthesizing when there is no light energy, but they continue to respire, and therefore they give off this gas.

b) This gas is given off by the green plant during photosynthesis, which takes place when there is no light energy.

c) Because plants respire only when there is no light energy, they give off this gas.

d) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 7

The light phase of photosynthesis takes place

a) only in the presence of light
b) only in the dark
c) continuously

The reason for my answer is that:

a) the light phase involves electron transport, which only takes place when sunlight excites chlorophyll molecules, causing them to give up electrons.

b) the light phase involves the uptake of CO_2, which takes place only in the light.

c) the light phase involves the uptake of CO_2, which takes place only in the dark.

d) the light phase involves the uptake of CO_2, which takes place continuously.

e) ____

How confident are you of your answer?
a) not at all
b) somewhat
c) confident
d) very confident

Question 8

The dark phase of photosynthesis takes place

a) only at night (in the dark)

b) only in the day (in the presence of light energy)

c) during the day and night (continuously)

The reason for my answer is that:

a) the dark phase involves the excitation of chlorophyll molecules by light, leading to electron transport.

b) the dark phase involves the uptake and reduction of CO_2, which takes place only in the presence of light.

c) the dark phase involves the uptake and reduction of CO_2, which takes place only in the absence of light.

d) the dark phase involves the uptake and reduction of CO_2, which does not necessarily require light, and so takes place continuously.

e) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 9

The light phase of photosynthesis

a) is the opposite of the dark phase.

b) uses products of the dark phase for reactants in the light phase.

c) is complementary to the dark phase, and the products of the light phase act as reactants in the dark phase.

The reason for my answer is that:

a) The light phase products are NADPH and ATP, which are used in the dark phase to combine CO_2 and ribulose bisphosphate to produce glucose.

b) Products of the dark phase are NADPH and ATP, which are used in electron transport during the light phase.

c) The light phase produces NADPH and ATP for electron transport in the dark phase.

d) The light phase occurs only in the light and produces ATP, while the dark phase occurs only at night and produces NADPH.

e) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 10

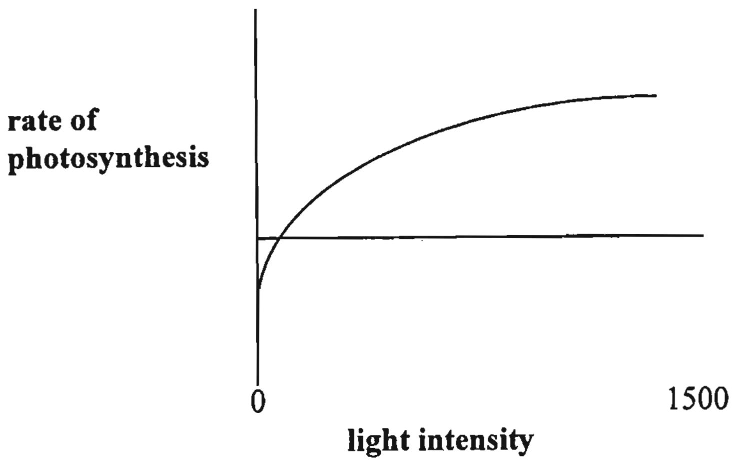

Figure 1. The rate of photosynthesis in relation to light intensity

Figure 1 shows the rate of photosynthesis measured at different light intensities. Point I on the graph is the

a) light compensation point
b) point at which light saturation has occurred

The reason for my answer is:

a) At this point, increased light leads to an increase in photosynthesis.

b) At this point, an increase in light intensity yields no further increase in photosynthesis.

c) At this point, the rate of photosynthesis equals the rate of respiration.

d) At this point, the rate of respiration is greater than the rate of photosynthesis.

e) ______________________________

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 11

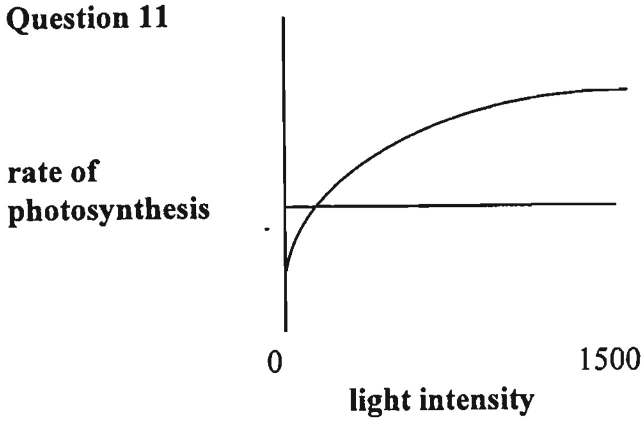

Figure 2. The rate of photosynthesis in relation to light intensity

Figure 2 shows the rate of photosynthesis measured at different light intensities. At point I,

a) photosynthesis has ceased.

b) the rate of photosynthesis increases as light intensity increases.

c) the rate of photosynthesis stays the same even though light intensity increases.

The reason for my answer is that:

a) At this point, light has become the limiting factor .

b) At this point, some other factor has become the limiting factor.

c) At this point, there is too much light and the plant is no longer photosynthesizing.

d) At this point, respiration is greater than photosynthesis.

e) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 12

Which of the following equations best represents the overall process of photosynthesis?

a) Glucose + oxygen $\xrightarrow[\text{light energy}]{\text{chlorophyll}}$ CO_2 + water

b) CO_2 + water $\xrightarrow[\text{light energy}]{\text{chlorophyll}}$ Glucose + oxygen

c) CO_2 + water + energy > Glucose + oxygen

The reason for my answer is that:

a) The green pigment, chlorophyll, combines with the CO_2 in the presence of light energy and produces glucose and water.

b) The energy from sunlight is used by plants containing chlorophyll to combine CO_2 and water to form glucose and oxygen.

c) Glucose and oxygen is combined in the presence of chlorophyll and light energy to Form CO_2 and water.

d) ____

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident

Question 13

Which of the following equations best represents the process of respiration in plants?

a) Glucose + oxygen > energy + CO_2 + water

b) CO_2 + water > energy + glucose + water

c) CO_2 + water (light energy / chlorophyll) > oxygen + glucose

d) Glucose + oxygen > CO_2 + water

The reason for my answer is that:

a) During respiration, green plants take in CO_2 and water in the presence of light energy to form glucose.

b) CO_2 and water are used by the green plant to produce energy during which time Glucose and oxygen waste are produced

c) During respiration green plants take in oxygen and give off CO_2 and water.

d) During respiration, green plants derive energy from glucose, using oxygen, and releasing CO_2 and water in the process.

e) ______________________________

How confident are you of your answer?

a) not at all

b) somewhat

c) confident

d) very confident