IDENTIFICATION OF MISCONCEPTIONS HELD BY TEACHERS AND STUDENTS WITH RESPECT TO CONCEPTS OF MENDELIAN GENETICS AND ASSESSMENT OF TEACHING METHODS TO OVERCOME SUCH MISCONCEPTIONS

By

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Submitted in partial fulfillment of the requirements for the degree of Masters of Education,

In the

Department of Education

University of Natal

Durban

December 1998

DEDICATION

In memory of my beloved brother Patrick Mulumba Ukumu

PREFACE

I declare that this thesis is my own work and that all sources I have used have been acknowledged by means of complete references.

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DECEMBER 1998

ACKNOWLEDGEMENTS

I am greatly indebted to the following:

Professor Alan A Amory and Ms Anne Ziervogel for their invaluable supervision, guidance, insight and belief in me.

Dr Paula Watt for wise advice and interest in my research.

To all the teachers and students who took their time to share their invaluable ideas, experiences and perceptions with me. Their contribution culminated to the success of this study.

The members of bioped research unit for co-operation in all the activities.

My wonderful family and friends for their concern and encouragement.

Finally, to my husband, to my tower of strength: my husband, Joseph Kioko for assisting me in every step of the way- for his criticisms, guidance, apt suggestions, diligent proof-reading, unstinting moral and financial support. His unconditional support, encouragement and understanding motivated me to complete this study.

ABSTRACT

Education is considered as an essential tool for the long-term development of most countries. While substantial funds are annually spent supporting educational facilities, there appears to be little cost effectiveness as many people leave school significantly illiterate. This may in part be due to factors such as the use of obsolete educational practices and lack of adequate teaching resources.

The objectives of this study was to contribute to effective ways of teaching and learning by developing, in consultation with teachers, constructivist methods of teaching; making the community of teachers aware of the role of computer technology in educational reform; and to evaluate the effectiveness of computer technology as an educational tool. In this study, workshop and qualitative surveys were conducted in KwaZulu Natal, using samples of high school biology teachers, grade 11 high school students, first year cell and medical biology undergraduates of University of Natal, Durban in order to: identify which teaching theories and materials high school biology teachers use in their teaching, topics that students find cognitively difficult, content areas that teachers find hard to teach, and to determine the misconceptions students have in specific topics. Also, the study was aimed at making teachers aware of the potentials of computer technology as an educational tool. The study further investigated on; the teachers computer literacy, availability of computers in the schools, the accessibility of the computers to teachers, to what use they are put into, whether there is institutional pressure to integrate computers into instruction, and the willingness of the teachers to use computers in their teaching. Additionally, the development and evaluation of constructivist materials devised.

Results of the first workshop showed that the majority of the biology teachers surveyed relied heavily on behaviorist theories (instructivist) in their teaching and that the chalkboard was the most widely used teaching resource. Mostly the teachers were computer illiterate and most of the schools had no computers. In schools were computers were available, they were not freely accessible to teachers and were used for administration and recreation. In only one school were computers, which were freely accessible to teachers and were used for administration, teaching, research and recreation. In most of the schools represented, there was no institutional pressure to integrate computers into instruction with an exception of only one school. On the other hand, the entire teachers surveyed expressed their willingness to use computers in their instruction.

Genetics was identified by teachers as one of the most difficult topics in the high school biology syllabus to teach and for the students to understand. Questionnaires on mitosis meiosis and genetics indicated that teachers have crucial difficulties in the understanding of DNA replication in relation to mitotic and meiotic process, problems related to dihybrid crosses, mathematical aspects of genetics, and the formation of gametes from dihybrid and trihybrid genotypes. Grade 11 students, first year cell and medical biology students were found to hold similar misconceptions. Also, students from rural and urban schools seemed to have the same misconceptions. Thus, it could be argued that these misconceptions exist because of lack of understanding of the topic shown by the teachers, and may also be due to teaching methods used by these teachers, that promotes rote learning.

Working with teachers, teaching resources on mitosis and meiosis were devised to help both teachers and the students in understanding this concepts. An evaluation of the effectiveness of these constructivist materials was conducted using eighteen first year Medical Biology students who had failed a test after receiving instruction using the lecture method. Results suggest that there was a significant difference in performance of the students after receiving instructions using the constructivist materials developed in this study. Thus, it is concluded that the constructivist materials devised were more effective in teaching than the lecture method.

Recommendations are made for implementation of the research findings to develop effective teaching materials for mitosis, meiosis and genetics. Further research possibilities on evaluation of effectiveness of the use of computer technology as an educational tool are also suggested.

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CHAPTER 1

Review of Literature, Background Information and Study Objectives

1.1. Introduction

Educators world-wide are facing increased pressure from governments, business, industry (Downey, 1990) and parents (Fennel, 1993) to develop leadership skills in learners and thereby enable communities to compete globally. It is argued that education is the most effective tool to stimulate economic development (Bacchu, 1992). While substantial funds are annually spent supporting educational facilities, there appears to be little cost effectiveness (Hidson, 1992). Many people leave school significantly illiterate (Amory, 1997). However, to function in complex, participative democracies, students need to acquire more than a discrete thesaurus of unrelated facts.

In this section the current educational practices (instructivism) are highlighted, alternative educational theories (constructivism) presented, the role of computer technology in education assessed, science education in Africa discussed and scope and objectives of this study introduced.

1.2. Current educational practices

1.2.1. Instructivism

Students leave school functionally illiterate due to a number of factors, including the use of out-dated educational practices, poorly qualified teachers and lack of adequate resources. Many teachers have adopted the traditional (instructivism) method of teaching. This method of teaching is based on application of behavioural and neo-behavioural principles (Mayer, 1964; Ausubel, 1968; Carey, 1993), where meaningful learning is seen as a progression through a series of stages along a continuum from expert (teacher) to novice (learner). It incorporates carefully designed instruction with systematic relationships among pre-specified behavioural objectives, instructional strategies and evaluation. Therefore, the teacher is seen as the subject matter expert and is responsible for organising and transmitting the information (typically via lecture or lesson) and the passive learner as the empty vessel into which knowledge can be poured. In this tradition, knowledge is conceived as representing a real world that exists separately and independently of the learner. Knowledge is considered 'true' only if it correctly reflects the independent world (Jonassen, 1991).

This didactic system of education emphasises the notion that students passively accept, without questioning, what they are taught. They learn by memorising and repetition. Teachers on the other hand are responsible for ensuring that pupils learn and thus their personalities determine how much motivation they provide to their pupils. The syllabus is rigid and non-negotiable (rigid structures that in most cases do not deal with related fields of study). Subject matter is restrained by textbook content (with teachers providing the main source of information within a specified period of time). Examinations are the main methods of evaluating students. Inputs from parents or the public, on what and how students are taught, are unwelcome. Such a system provides learners with isolated pieces of inert knowledge (Hannafin, 1992). Teachers, on the other hand, have little or no say in curriculum development or content. Such systems are developed and controlled from a distance, oblivious of the fact that teachers remain significant curriculum gatekeepers, not only in excising a pocket veto over external curriculum initiatives, but also in actively fashioning curriculum experiences within their own classroom (Kirst and Walker, 1971; Thorntorn, 1992).

1.2.2. Advantages and disadvantages of a instructivist system of education

Instructivism is praised for its emphasis on formative and summative evaluation (Dick and Carey, 1990) which is seen as one of its greatest advantages. It's ability to prescribe steps, order and conditions of learning, is also seen as strength (Divesta and Rieber, 1987). It is also a cheap form of instruction as teachers do not depend upon individual student access to 'high-tech' equipment and requires few resources. Lessons are easy to prepare and require only minimal ancillary support (for example: chalkboard and chalk, overhead projector facilities, slide projector and possibly cassette players). However there are a number of weaknesses with this model. Examples of these are that instructivism focuses primarily on the development of intellectual skills and fails to address the components of affective domains (Reigeluth, 1989).

According to educational psychologists, instructivism undermines the development of autonomous self-evaluation to the extent that such practices are experienced by the learners as efforts to control their behaviour (Deci *et al.*, 1991). There are also problems associated with the normal distribution of human ability, for example, while lecturers may aim their exposition at the 'average' students in the group, they run a risk of boring the high-flyers and of overwhelming the less able. It is therefore difficult to teach students with varying degrees of prerequisite knowledge, reasonably complex subject matter with a high degree of efficiency and effectiveness. Note taking in lectures is equally problematic. Some students are able to write quickly and capture all the points, while others who write more slowly miss considerable amount of materials. This method of instruction also has the limitation of working on narrowly defined goals that do not prepare students for creative investigation of knowledge, promotes meaningless application of decontexualized procedural and conceptual knowledge and relies on memorisation at the expense of understanding (Hannafin, 1992). Instructivism also uses grading to provide motivation and punishment for poor grades. Wiggins (1993) argued that test scores are not synonymous with educational achievement and do not measure process-oriented problem-solving, currently emphasised in science education. Instructivism is also criticised for not engaging students in the learning process and fails to develop creative or problem solving skills.

The objective of education, according to Roger (1969), is not to create pedagogical cripples, who cannot fed for themselves in the learning experience and who require the services of an autocratic teacher; rather it is to aid in the development of self-reliant learners which instructivism has failed to produce. Reigeluth (1987) stated that, as progress towards highly technological and rapidly changing information oriented society occurs, the present structure of our educational system, which is instructivist, will become more and more inadequate.

1.2.3. Restructuring of the educational system

With developing countries at risk of poverty, hunger, pollution, under-qualified staff et cetera, we are forced to restructure and re-evaluate the way schools operate, the approaches used in teaching and the manner in which students learn. Skills that are appropriate in an information age are those of problem solving and investigation. We now live in a global society where instructors must deal with the multiplicity of effects of socio-economic, cultural and linguistic differences. A shift from providing students with information to providing students with opportunities to find and evaluate information on their own is needed. This restructuring of learning will not only enhance the critical thinking skills of students, but will also empower them for a life of learning.

Sheffield (1997) described five strategic issues in the restructuring of schools: schools and teachers need to make use of a variety of instructional resources including technology-based programs; design and delivery of instruction has to reflect changing needs of individual students; a need for a revised curriculum along with realistic assessment; classroom environment could be altered to foster more personalised and collaborative learning; and schools, work-places and community should be linked.

Key research findings and insights of many experts (Websters, 1972; Calderhead, 1990; Nolan and Francis, 1992; O'neil, 1992 and Wood 1996) agreed on at least three fundamental and related principles underlying the practice of effective teaching and learning which can be expressed in terms of 3Cs. The first C is constructivism, which is defined as the cognitive-developmental process by which individuals learn by actively engaging in personal and meaningful associations, as they seek to integrate new knowledge with their prior understanding. The second C is collaboration, which may be conceptualised as the social interchange of co-operation among a group of learners for the purpose of facilitating decision making and problem solving. Learners share hypotheses, revise thinking and work through their cognitive discrepancies. The third C is the concept of contiguity, meaning the complete contact, adjoining or connection of two or more elements. Such a system describes an optimum environment conducive to effective teaching and learning, which is characterised by realistic, relevant and meaningful situations which address real life problems and participants (both teachers and students) are engaged in authentic or experiential learning. Although direct teaching and rote memory may often be required, the most productive learning contexts are those which require participants, individually and collaboratively, to confront the unfamiliar questions or non-routine problems which arise in actual daily living (O'Neil, 1992). So, the best instructions will inspire students to explore, create and refine complex conceptual frameworks for themselves (Wood, 1996). Therefore, any model of teaching and learning adopted by an education system, should include the participation of students, parents, teachers, educational authorities and the community. It should also provide for the best possible environment that incorporates technology to enhance active learning.

1. 3. Constructivism

1.3.1. Introduction

The roots of constructivism can be found in the assertion that individuals do not store verbatim representations of reality, but during recall, actually construct knowledge (Bartletts, 1932). Piaget (1973) defined this as the notion of equilibration while Vygotsky (1978) introduced the idea of social construction of knowledge. Dewey

(1938) asserts that a truly democratic classroom provides an optimal environment for students to discover, explore, ask questions, investigate, experiment, and in short, construct knowledge.

Constructivists in education are closely aligned with the theories of Jean Piaget (Fosnot, 1989), where knowledge is presented as explicitly being constructed, both personally and in interaction with others as well as the physical world (Jonassen, 1991). They hold that learning is an active process, during which we construct reality from our own experiences. Whatever we learn cannot be independent of the context in which it was learned and what we already know (Duffy *et al.* 1991; Spiro *et al.* 1991). There is no tabularasa on which new knowledge is etched. Rather, learners come to learning situations with knowledge gained from previous experiences and such prior knowledge influences what new or modified knowledge they will construct during new learning experiences. A learner is perceived as someone who is not only an active discoverer, but also an inventor and problem-solver (Lawton and Hooper, 1978). Piaget (1964), Novak and Gowin (1984) and Osborne and Wittrock (1985) viewed the goal of education as empowering the learner with the ability to discover new knowledge and ideas, and to foster creativity and inventiveness. This is because it is in the learner's mind where new meanings are to be formulated and understood. This can only be achieved if the learner is an active participant in the learning process.

According to Duckworth (1987), Hannafin (1992) and Muncey and McQuillan (1996) reflective teaching that emphasises engaging learners with phenomena, and then working to understand the sense they are making of these phenomena, is needed. Teachers should act as facilitators, mentors and guides while the students actively engage in their learning. Within the dynamics of the model it is important not to seek to control all the many activities that take place under the rubric of teaching, but to be able to ascertain their nature and potential effectiveness at will, and to direct them differentially to learners as needed, and with full awareness of the extent to which external agencies (such as parents and the community) are also influencing teaching and learning process. A broader range of approaches to assessment may be necessary in order to provide a useful picture for teachers, of pupils progress in understanding (Wiggins, 1993).

Constructivists call for elimination of grades and standardised testing. They see assessment as part of the learning process in the service of the learner and feel that it should involve multiple perspectives in the evaluation (Wiggins, 1993). Students should be given more responsibility for self-assessment (Boyd and Cowan, 1985; Edwards, 1989). Constructivists also advocate the elimination of a standardised curriculum and emphasise more use of curricula customised to the prior context of students, that is emphasis on integrating the different types of knowledge relevant to the pupils, and use of raw data and primary sources. Syllabi are seen as a guide, with teachers having to adopt innovative and creative ways of helping pupils to learn, focusing on working on real problems. This philosophy holds that play and experimentation are valuable forms of learning (Daiute, 1989). Play involves the consideration of novel combination of ideas, and the hypothetical outcomes of imagined situations and events. It is a form of mental exploration in which children create, reflect on and work out their understanding. Collaborative learning is also emphasised (Bruner, 1986; Cunningham, 1991; Rysavy and Sales, 1991). The advantage of these collective efforts is that children are able to reflect on and elaborate not just their own ideas, but those of their peers. They view their peers as resources, not competitors. Mutual tutoring, a sense of shared progress and feeling of team work are the natural outcomes of co-operative problem solving, and this process has been shown to produce substantial advances in learning.

Constructivists suggest several directions for instructional designers: increased emphasis on the affective domain of learning; to make instruction personally relevant to the learner; to help learners develop skills, attitudes and beliefs that support self-regulation of the learning process and to balance the tendency to control the learning situation with a desire to promote personal autonomy. They believe that instructions must relate to the interests, experiences and personal goals of the learner in order to adequately support motivation. They also claim that an environment, which promotes active learning, should have authentic activities. According to DeCort (1991), Papert and Harel (1991) and Perkins (1992) learning happens especially felicitously when the learner is consciously engaged in meaningful activities that can provide many opportunities for social interaction and is rich in learning resources. Examples of these activities are exploration, collaboration and computer-based learning (Fedler *et al.*, 1993; Laws, 1991). Also in this environment, students views and values should be sought and valued as they are windows to their knowledge and reasoning (Brooks *et al.*, 1993). "Authentic" assessment is also required. It occurs most naturally when it is in a meaningful context and when it relates to authentic concerns and problems faced by students (Brooks *et al.*, 1993). Student progress has to be interpreted via professional judgements together with samples of their work, with both formalised and informal assessments gathered over time. By the same token it is contended that in education, mastery is likely to be more validly inferred via patterns of performance over time, and in various contexts, rather than from single events isomorphically related to narrowly conceived outcome statements such as performance objectives.

1.3.2. Advantages and disadvantages of a constructivist system of education

Constructivism weaknesses, and some of the constructive views which render it open to criticism, is the fact that knowledge is constructed by individuals. For example, if learning occurs by construction, it is costly in time and when the search is lengthy or unsuccessful, learners' motivation commonly flags. Critics argue that in other cases students remember as well, or even better, when information is provided to them, than when they recreate it (Slamecka and Katsaiti, 1987). Even when discovery learning is successful in acquiring the desired construct, it may take a great deal of time that could have been spent practising this construct if it had been instructed. Opponents of constructivism point out, that to assume that a persons scientific intuitions directly reflect the nature of structure of their knowledge (their alternative frameworks), is to be guilty of a gross over simplification of their psychology. "Alternative frameworks" need be no more than the ephemeral reflection of a purpose-built and tentative attempt to cope with the social and intellectual demands of the present.

Constructivists recommend that children learn in the context of complex problems (Wiggins, 1993). Critics say that this recommendation is put forward without any evidence of its educational effectiveness. There are two problems with this approach both related to the fact that a complex task will require a large number of competencies. First, the learner who is having difficulty with many of the components can easily be overwhelmed by the process demands of the complex task and secondly, if many components are well mastered, the student will waste a great deal of time repeating the mastered components to get an opportunity to practise the few that needs additional efforts. Critics agree that there are reasons to practise skills within their complex setting. While it seems important, both to motivation and learning, to practise skills from time to time in their full context, this is not a reason to make it the principal mechanism of learning. This warrants the critics view that constructivism as terribly utilitarian because it assumes that everything that works is good enough for learning.

The rejection of standardised evaluation to assess learning by constructivists is also criticised. Critics claim that the fundamental problem is the failure to specify precisely the competencies being evaluated and a reliance on subjective judgements, that will open doors to a great deal of cultural bias in assessment (Rist, 1970). The other problem is that, if student self-assessment were to dominate education, it would no longer be clear when instructions had failed or succeeded. Also, the notion that instruction should not be pre-planned is also criticised. Critics claim that this cannot be an absolute point of view (need a reference). There are some learning situations where preparing instructions and specific outcomes would not be debated. An example is in the training of pilots and doctors. While medical students and pilots may still construct meaning in accordance with previous knowledge and experiences, they will have to learn, and at times to pre-specified standards. So, some level of pre-planned instruction is needed. Critics also criticise the philosophy by saying that it is a new form of solipsism, meaning that it locates reality entirely in the mind of the learner (beholder). Thus, it specifically denies the existence of involuntary experiences with an outside world, be it through direct perception of something or through vicarious experiences created in the process of communication. Social context of learning is a vital part of constructivism. Critics agree that one should take into account cultural contexts in explaining the ways people learn, and conversely, constructivists must avoid excessive generalisation no matter how well a study seems to be replicated in different countries (Villalbi and Lucas, 1991). While this does include the social transfer of knowledge, rather than its individual creation a fresh by each learner responding alone to physical phenomena, constructivists still suffer from the difficulty of making precisely testable predictions.

Despite the above criticism, it is suggested here that constructivist philosophy offers instructional designers an alternative set of values that may significantly influence learning. It is viewed as a solution to the potentially detrimental side effects of the existing instructional practices. For example, it provides a context for learning that supports autonomy and relatedness. According to Joyce and Weil (1986) existing methods of teaching (instructivism) emphasise subject matter, social climate, and relationship among participants. In constructivist classrooms, constructivists support development of autonomy by the teacher providing scaffolding to extend the potential development of the learner, by engaging students in using knowledge in modelling problem solving process and by coaching students in self questioning and other metacognitive skills. In the area of relationships, preferred teaching methods require both collaboration and positive interdependence and emphasise personal responsibility and accountability. Such approaches as co-operative group learning, reciprocal teaching and computer assisted intentional learning environments (Scardamalia *et al.*, 1989) strongly support such constructivist priorities. Secondly, the learners engage in the learning activity itself. Nowadays students find much of what is presented in school to be inconsistent with their experiential beliefs that form the basis of their world-view. So much of what they learn does not transfer to other applicable settings. Constructivists favour problem solving activities that are linked to student interests, have at least some of the 'messy' attributes of real-world problems and are meaningful and satisfying for students to solve. They further recognise that personal goals, motives, expectations and attitudes critically influence what the individual learns

This philosophy also supports self-regulated learning by promoting skills and attitudes that enable the learner to assume increased responsibility for the developmental restructuring process. Inherent in instructivist approach is the assumption that desired changes in behaviour and capabilities will occur as a result of students' successful execution of lesson-controlled instructional strategy. Constructivists recognise that students can develop the capacity to exercise control over their own thought processes, motivation and actions so as to effect desired changes in themselves and their situations (Bandura, 1989; Kember, 1991). Constructivism also strengthens the learners tendency to engage in intentional learning processes by encouraging the strategic exploration of errors. They see errors as a positive stimulant for the kind of perturbations that create disquilibrium necessary for self-reflection and conceptual restructuring. Constructivists focus on error recovery procedures and are primarily concerned with learners' ability to apply and manipulate knowledge within authentic task environments and are far less interested in the learners' ability to simply acquire knowledge and to produce right answers. Their framework standards serve the interest of learners in goal setting activities and self-assessment, which research shows provide critical support for continuing motivation to learn (Schunk, 1990).

1.4. Introduction of new technologies into the process of teaching

1.4.1. Introduction

The process of teaching has not changed much even with the introduction of new technologies such as computers (David, 1990). The majority of educators in most institutions tend to teach in ways resembling those practised 50-100 years ago (Binenbaum, 1991; Tausig, 1991). This is partly because computer-aided instruction, with its focus on tutorial, drill and practice functions reflects the behavioristic view of learning, whereby knowledge is presented to students in a linear, didactic manner. Owing to this continuing dominance of the behaviourist tradition over the design of computer-based instruction, it is not suprising that technology in education has not changed the process of teaching and learning. Teachers, instead of taking their role as facilitators of learning, have persisted in their role as the arbiter of instructions (Cuban, 1983; Bostow *et al.*, 1995; Gbomita, 1997). Reasons exist for the dominance of the teacher centred role, including the fact that teachers saw this role modelled through most of their own schooling experience and that much of teacher education today prepares them for this type of role (Cuban, 1983). Many have claimed that teacher development programs are inefficient and evidence exists indicating that many of the most widely used regimens in teacher education do not show significant effects into transfer of mastered skills to the work setting (Aulehla, 1991; Shore *et al.*, 1990). Beginning teachers have a chronic theory-practice gap which arises from the lack of transfer of university based theory into school-based practice. Novak and Knowles (1991) showed that beginning teachers are often so preoccupied with the initial 'survival' process in the classroom that they tend to view the incorporation of instructional media during their initial period of teaching as being of secondary importance or as extra work.

Many young teachers simply lack confidence in, and the positive attitudes towards, using advanced media technologies in their teaching. Also Seidman (1986) and Carter and Schmidt (1985) in their studies of the pattern of media use in schools found that teachers, particularly at the elementary level, more frequently used traditional media (such as overheads, book pictures, games, bulletin boards and posters) than newer technologies such as computers. They argued that this was due to lack of exposure to the potentials of computer technology as a tool for learning. Brook and Kopp (1989) stated that if teacher education is to succeed in its responsibility to prepare teachers for the information age, teacher educators should teach the full potential of existing and emergent technologies. Computer integration courses should also be available to teacher candidates. Such courses might include computer-assisted instruction, application software, telecommunications, multimedia and interactive videodisk technology. Thus in helping teachers to make effective use of instructional media, training should be embedded in a broader, reconceptualised view of good teaching and learning, and should include, and go beyond the traditional 'telling', transmission mode, and embrace the notion of cognitive constructivism and collaborative problem solving.

The resolution of this divergence between students and appropriate educational practices lies in drastic educational reform. What is needed is a guiding philosophy that suggests principled changes in the curriculum, with the effective use of computer technology as part of these changes. This philosophy must be based on constructivism, a theory of cognitive growth and learning that has gained many adherents in the recent years (Piaget, 1973; Vygotsky, 1978; Newsman *et al.,* 1989; Resnick, 1989).

1.4.2. Integration of computers into educational practice

Many authors have argued that a constructivist approach should be used when integrating computer technology into curriculum. Computers could be used to foster educational reforms. The term 'computers' means more than the machine. It includes multimedia capabilities, present and emerging, which computers can integrate and direct, and the ancillary technology connected with computers like communications through modems. The emphasis for integrating computer technology into new pedagogical practices is that it supports the deeper, more reflective, self-directed activity that children must use if they are to be competent adults in the future. There is also a change in the goals towards which computers can be used. While in the initial days computers were used for programming, increasingly more computer activities are now designed to serve curricula goals. For example, logo is often taught as part of the mathematics curriculum and comes to serve the attainment of those curricula goals. There is also growing acceptance of computers as a technology that allows more independent exploration, more personal tailored activities, more teamwork and significantly less didactic instruction. It also introduces novel, or often unique, kinds of activities with computer tools such as intelligent electronic spreadsheets that allow new modes of interaction with academic materials.

Computers are also well suited to promote active exploratory learning and in recent years promising approaches, facilitated by computer technology have been developed. For example, microworlds (Papert, 1980; Yerushalmy and Schawrts, 1993; Yerushalmy and Houde, 1986), offers student opportunities to investigate the properties of a self-contained mathematical environment, graphing utilities, convenient manipulation of functions for graphical problem solving and exploration of functional relationship. Geometric construction tools invite students to formulate and test conjectures through interactive exploration of various cases. Driscoll (1994) explains that the computer offer an effective means for implementing constructive strategies that would be difficult to accomplish using other media. All other educational technologies are restricted to particular kinds of symbol systems and hence have limited range of content. Computers are not limited to either one. They are tools that can allow a large variety of content and symbolic modes ranging from printed word to dynamic schemes and graphs to musical notations. Therefore, the same information can be represented in different modes.

Computers also afford a variety and kinds of activities, for example from responses to questions in drill-and-practice programs to autonomous hypothesis testing in simulations; from discovery like activities via game playing to rigorous logical planning as in programming and from writing and revising to categorising calculations. They allow the development of partner like interactive and individual relations with their user which no other technology can (Selnow, 1988). Computers extend in many ways our mental capabilities and serve as possible models for certain kinds of thinking that learners could use to discover powerful ideals, as well as newly acquired mental tools (Papert, 1980).

Other advantages of computers as an educational resource are; they interact with the user so that it is impossible for the student to address a computer passively (Vygotsky, 1962; Guest, 1986; Selnow, 1988), they have abilities to adapt to individual differences and to allow the learner to control the path of their study and they can provide customised interfaces for students use with varying levels of guidance (Guest, 1986). Some studies have shown that a learner-controlled environment can be more effective than a program that adapts automatically to learner differences (Hannafin and Colamaio, 1987; Allred, and Locatis, 1988). Computers can also provide information in a variety of modalities, providing a context for the information and allowing multiple paths through this knowledge.

The system allows the learner to select information in the format best suited to their learning style, ability level and information needs. All these will increase the learner's engagement with the learning situation as they elaborate on their current knowledge. Computers can also be used in co-operative learning or group composition, with the group contributing to a common database of information (Hooper and Hannafin, 1991; Hooper, 1992). Computers also have the merit of removing the time and distance barrier of conventional classroom instruction. For example, teachers can alert students when they cannot make it for classes and give assignments through electronic mail and students are able to leave messages requesting for information or help at the time they have a problem. Teachers can also communicate with parents on the progress of a learner through e-mail.

Computers also have the capacity to present to the students information resources of many kinds and from many sources through networks (Cotton, 1996). As an educational resource, they provide immediate and private feedback especially with the use of simulations (Bostow *et al.,* 1995). This enables correction of wrong answers to occur in a reliable representation of the actual process (Kozma, 1987) and increases student enthusiasm and motivation to learn (Lauterbach and Frey, 1987). Computers also have a large memory capacity that permits the storage and instantaneous retrieval of a large quantity of learning materials. Furthermore, there is the presence of a multiplicity of communication channels, which allows the adaptation of the communication to the characteristics of different topics and users. Through computer-based learning, learning can take place directly at the work place, that is, exactly when and where the need for learning arises. It also has the advantage of control of learning success. Here learners' input is stored, systematised and evaluated in order to provide immediate feedback on the status of acquired knowledge (Parsons *et al.*, 1991). This will reduce tutor-time spent marking assessments, making lesson plans, schemes of work and developing and keeping necessary records (Bostow *et al.*, 1995; Bennet, 1996). Lesson plans and schemes won't be needed as students will learn using computer programs. Marking and assessment will be done by the computer and it will develop and keep necessary records and print them or transmit them instantaneously and accurately to other files when needed and it also provides remote access to information by consulting databanks, file archives, gopher and world-wide web.

Other merits of computers, according to Bennet (1996), are that they can remove prejudice, since their memories are not influenced by what takes place around them. The machine, through programming, merely adjusts its teaching to meet the needs of the individual learner using it. He also argues that computers can eliminate the need for substitute teachers because no teacher is needed to deliver instruction, but researchers disagree with him and suggest that computers should be used as a partner in the learning process and not merely as a replacement teacher (Akingbe, 1995). Human teaching provides the backbone of the class and computers simply enhance these characteristics. Teaching will not be bound by current time constraints, as computers are tireless and can work and instruct at any time under virtually any circumstances. They are infinitely patient. Burnout for a computer can be remedied by simply replacing either part of the machine or the whole computer. Computer-based learning will always be current because computer programs are flexible and they can be updated more cheaply and faster than the working knowledge of teachers. As an educational resource, it will help to equalise educational opportunities because computers can teach the same way everywhere with equivalent or the same software. They can provide the means of helping children from the poorest environments to receive a suitable education. It will also eliminate the problem of inclusion. Handicapped children will be educated in the regular classrooms without interfering with the rights of the other students. Moreover, the weaknesses of those handicapped children who are slower in learning for any reason will not stand out. Only the leader teacher will be fully aware of how rapidly or slowly the child is progressing. This is because computer-based learning will enhance individualised instruction. Lastly, computers will enhance other teaching aids by controlling and totally integrating audio-visual presentations into the instruction of each student. Computer games teach high level thinking skills such as analysis, synthesis, and evaluation, and enhance learning through visualisation, experimentation and creative play (Darghi *et al.*, 1994).

On the whole, many parts of society will profit from the use of computer-based education in the schools. For example, the business world will benefit since the work force will be better educated and will not require additional education. School administrators will have few discipline problems. Since crime and literacy are so intimately connected, a literate society will lessen lawlessness to the benefit of all, but especially to law enforcement officials. Parents will be happy their children are better educated and teachers will find more personal satisfaction in their profession. Their work will be exciting, challenging and enjoyable and they will see more accomplishments for their efforts.

1.4.3. Problems and weaknesses

However, the computer as an educational resource has its own weaknesses. The first is a language problem. It is impossible to translate computer programs to different vernaculars for all nations of the world, so programs will be written in major languages such as English. Secondly, there is also a likelihood of a problem relating to cognitive overload. This is exposure to information that vastly exceeds that required by the problem in question. Thirdly, distraction may also result due to a lot of freedom given to the learners in the learning process. Freedom to learn is not a sufficient condition to assure effective learning. It can be confusing because it increases decision making and workload. It can be compounded by the vast quantities of information easily accessible, much of which may be only peripherally relevant. The rich learning environment can thus become an environment of hyper-chaos, and guidance is therefore needed.

There is also a set of instructional problems apparent to teachers and designers who apply computers for instruction, such as authoring principles and methods for creating exemplary software, managing learning in an electronic environment, and creating assignments and evaluation materials. These problems will only be eliminated if teachers are taught how to design or use software, which assignments and activities best help students develop the self-discipline to work in electronic environment effectively and efficiently while reserving the freedom to explore and browse for pleasure and relaxation, when goals to providing computer assignments are related to process and interaction, and then invent new strategies of evaluation that address interaction. Both quantitative (time, number of nodes connected, number of key paths discovered) and qualitative (appropriateness of paths, satisfaction of experience) measures must be used if a true image of how students are augmenting their intellect with computer-based learning is to be gained.

Another limitation concerns co-operative educational activities where interpersonal communication is oriented towards discussing a certain topic. The presence of too many partners can create serious co-ordination problems in much the same way a debate often risks becoming chaotic and inclusive in a very crowded classroom. A further complication is that learners have to communicate in written form, a system that does not foster convergence in a discussion. This is why it is suggested that only a few dozen subjects should be involved each time. Here, too, there must be well-defined objectives, activities must be planned and participants must have clear expectations.

There is also the problem of disorientation or getting lost (Laurillard, 1994), which can be caused by jumping around throughout the database and can result if guiding instructions on data base size, content and guiding instruction is not given. On the other hand, computers in education are very expensive. Besides the cost of the basic computer, there are also costs associated with pepherals (printers, monitors, ribbons, modems, extra disk drive, software facilities development, maintenance and auxiliary material like books, kits, curriculum development, teacher training and the preparation of teacher trainers). It is difficult to use computers to teach subject matter that involves judgements, intuition and improvisation as most software is designed using behaviourist approaches. There is also a shortage of high quality educational software and these results in the use of multiple choice or simple completion questions, which is a major limitation of computer-based instruction.

As computer based-education advances, most of the above problems should be solved and the advantages that computers as an educational resource can offer are so profound and significant that they outweigh the few disadvantages.

1.4.4. Ways in which computers can transform education systems

Case studies on application of computers in instruction show that the computer can transform teaching and learning. Edwards and Sutton (1991) developed and delivered an undergraduate first year course in which students were encouraged to take more responsibility for their own learning, while arranging and moderating their own computer based electronic conferencing. They found that students liked working at their own pace, undertakings, self-assessment, being responsible for their progress and gained confidence in using computers. The informal and frank relationships between students and lectures lead to a learning atmosphere in which students felt free to seek help and admit to difficulties. Work by Askar, Hulya and Koskal (1992), Kumar (1994) and Waddick (1994) produced similar findings.

However, Ford and Ford (1992) in their study of investigating learning strategies in an ideal computer-based learning environment, found that some learners were relatively unsuccessful and needed more structure and direction. According to Bennet (1996) the use of computer assisted instruction at Veron Beach High School in Florida in

1987 increased retention rate from 60% to 80% in students considered to be at risk. These pupils realised that school was fun, started absorbing knowledge better and faster and also stopped misbehaving.

Computer simulation games can also change education systems that do not emphasise inventiveness and creativity (Darghi *et al.*, 1994). Many simulation games available today stimulate students to think and help them become critical thinkers. They teach higher-level thinking skills like analysis, synthesis and evaluation. Computer mediated communication via electronic mail, conferences, and bulletin boards have also empowered students and teachers. For example, e-mail can transform the way teaching and learning is done by disseminating class information to team teaching across continents. D'Souza (1991), in a study on instructional benefits of integrating e-mail into college curriculum, concluded that it is a viable mean of supporting classroom communication and dissemination of information. Scott (1991) noted that the flexibility of e-mail increased the effectiveness of faculty-student communication and student writing skills. The communication revolution has altered the way many students and teachers communicate, conduct research and design and take courses (Raimondi, 1981; Kurshan, 1991).

Computer conferencing, where learners come together in virtual classrooms and use the network capabilities, can help overcome some of the problems associated with distance education (Harasim, 1987). But, as a general educational tool, it can also be used in 'conventional' learning. Its flexibility as a mean of communication and data storage and retrieval also suggests uses within the normal class situation. It can be used for discussion and seminars, and its use is exploratory as participants choose for themselves when to write and what to write. One advantage of it is that it extends the human facilitative aspect of education, underlying educational values and beliefs (democratic participation, collaboration and sharing) are changed (Hodgson, 1989).

Several researchers, such as Levin *et al.* (1987), Waugh and Levin (1989), Hooper and Hannafin (1991), Wolpert and Lowney (1991), Hooper (1992) and Harris (1995), have demonstrated that computer mediated communication (i.e. conferencing, e-mail and computer bulletin board) are particularly suited to co-operative learning. Tele-apprenticeship is a well-documented computer mediated communication application used for co-operative learning (Levin *et al.,* 1987). This system provides a forum in which students from different geographical areas use electronic networks to learn content and problem solving skills by jointly addressing problems with each other. Curricula areas that have been addressed by Tele-apprenticeships include social sciences, news writing and the physical sciences (Waugh and Levin, 1989). In addition, Tele-apprenticeships can help educators stay current with the best practises in their field and help them overcome problems such as teacher isolation and limited on-site information (U.S Congress, Office of Technology Assessment, 1995). Tele-apprenticeship makes distinguished and comprehensive library resources and databases far richer in resources than today's libraries (Riel, 1985). However, because of numerous social and psychological factors, computer networks should be used to support, but not to replace face to face communication. One reason for this is the lack of non-verbal cues. Whatever the role the instructional applications of computer mediated communication serve, research has demonstrated that such applications can change the context in which students learn (Goldberg, 1988).

Thus, computers can transform educational systems by managing instruction, class records, maintaining individual pupil daily progress, assessment, managing learning materials and administering and scoring of tests. This relieves the teacher of these laborious tasks and thus more time is available for direct attention to the learner.

Computer technology can also transform educational administration. Participants in a Delphi survey (Waggoner and Goldberg, 1986) identified the following administrative areas in which computers are seen to have potential applications: budgeting, record keeping, tracking students, communication, access to information and reduction of paper-work and face to face meetings. Computers can also transform the way educational research is done and have played a role in the improvements in research techniques, provide access to information rapidly (searching) and rapid data analysis.

Thus, computers will inevitably subvert didactic views and shift schools to a more constructive approach (students constructing their own understanding and developing capabilities by carrying out challenging tasks). Collins (1991) argues that this will happen because of eight restructuring trends that typically happen when schools use computers as an educational tool. These are a shift from: whole class to small group instructions, lecturing and recitation to facilitation and coaching, working with better students to working with all students, less engaged to more engaged students, assessment based on test performance to assessment based on products, progress and efforts, and a shift from competitive to co-operative learning. There is considerable evidence that such learning results in higher level cognitive reasoning, increased achievement and retention and higher level conceptual understanding (Johnson, Johnson and Maruyama, 1983).

Thus computer based instruction is gradually reshaping the image of the classroom from the four walled, self-contained structure to a global classroom and expanding educational practices from didactic, classroom-based instruction to problem based student-generated learning in open classrooms across the world (Cotton, 1996). However, in most parts where it is used, it still operates in a piecemeal, disjointed, and incremental way, rather than functioning in a truly integrative fashion in supporting and managing curriculum, pedagogy and assessment in an information dependent environment.

1.4.5. Factors hindering full integration of computers into the curricula

Many teachers who have tried using microcomputers in their classroom, usually with initial enthusiasm, have been discouraged by practical problems of implementation such as the lack of enough time to access networks and review software (Gallo and Horton, 1994). Also, there is the problem of lack of vividness in presentation of the potentials of computers in education. Due to this, both administrators and teachers are confused about the role computers can most effectively play in education programmes and fear to change established educational methods (Norris, 1985). This is due to lack of training, full awareness of computers as an educational resource, and lack of consultation in the implementation of computers in education. Simply providing a technology that supports facilitation is not enough. Teachers, if they are to use computers as tools in facilitative classroom environment, need models they can emulate, training that help them to support the facilitative model and a school environment that supports the model. That is, teacher education programmes must prepare teachers to work as facilitators (Gallo and Horton, 1994; Kook, 1997)

Consequently, unless teachers are teaching computer-programming courses, they usually stop using computer altogether or begin to use them in ancillary roles (Brophy and Hannon, 1985). Teachers also report that computers make teaching more difficult, are intimidating and are difficult to master. Many schools also have limited resources to buy hardware and software, to repair and maintain machines they have purchased, and cannot afford the large scale teacher retraining efforts required to enable teachers to make effective use of computers in the classroom (Woggoner and Goldberg, 1986; U.S. Congress, Office of Technology Assessment, 1995).

Educational systems that emphasise the process of children constructing their own new ideas, require alternative assessment techniques (Collins *et al.,* 1991; Wolf *et al.,* 1991). For example, forms of assessment have been developed (New York State systemic, Web; Pierce *et al.*, 1992 and Jo-Ellen, 1996) and others are being developed.

Educators also anguish that machines could bring a mechanistic world where machines dominate learning and students become more automatons than human. However, computer based education should not result in bring a harsh unfeeling school system. Teachers, who are essential for successful computer-based education, will prevent the catastrophe: they will remain in schools and will provide a uniquely human element as machines provide the vast stones of knowledge. Lastly, teachers fear that the use of the computer in instruction will replace their position (Underwood and Underwood, 1990). In the real essence computers will not replace teachers, but will make them work in partnership with students and will provide them with an invaluable educational tool, while the teachers assume such uniquely human roles as being guides, facilitators, coaches, mentors and collaborators in the construction of knowledge (Steen, 1989; Carter, 1993). They will also act as leader teachers, who have the responsibility of assisting students to learn, grow and progress. They will act as resource persons to students but not sources of information (Bowser, 1990). They will be giving technical advice, helping students in deciding optional courses they want to take, and in choosing of careers. They will be able to have conferences with parents, as they will have been relieved of some of the enormous work of teaching, lesson planning, marking exams and scheming. Parents need to direct and assist their children in learning. To do this, they have to meet with teachers to get the progress records of their children. Teachers will also assume the role of devising and carrying out seminars, workshops, debates and other co-operative and interactive projects (McCauley, 1988). In these projects, students will find learning enjoyable, learn new ideas, develop advanced thinking skills and learn to work together. Teachers will aid education beyond simple teaching by being empowered by authorities to make decisions that higher authorities formerly imposed upon them.

Therefore computer-based education will never eliminate teachers. Instead, it will make the profession more satisfying, engaging and fulfilling and teachers will devote more of their limited time to their primary passion of educating the youth (Bostow *et al.*, 1995). Then, when the pupils enjoy education, their learning will improve, and much of their current revolt against the system will dissipate. An immediate result will be fewer discipline problems in schools. Authorities will then be able to devote more of their time and resources to improving education instead of keeping it together.

1.4.6. Computer-based education in Africa

In most parts of Africa computer based education is non-existent or in its infancy. For example in Kenya, it is only in Aga Khan, a private co-educational secondary school in Nairobi where a pilot project started in 1983. By 1989, the school had advanced in computer aided learning, and had a library containing databases, graphic and word processing software, games, computer aided learning programmes in arts, biology, chemistry, economic, English, French, geography, history and Islamic religion, mathematics, physics and typing (Wray, 1989). A few other schools such as Starehe Boys Centre, use computers for vocational training.

In South Africa, the use of computer based education is also in its infancy especially in tertiary institutions. For example, according to van der Wal and van der Linde (1991) the faculty of education at the Orange Free State is attempting to remedy at least some of the problems experienced by black science teachers by using computer aided instruction. The aims are to introduce teachers to computer technology, create awareness of possible applications in science and to investigate the possibility of an alternative science teacher education program which is more relevant to future needs. There is also western cape schools' network (WCSN, Web). It is a dynamic, independent schools networking organisation, which provides a range of Internet services, and training and educational resources. It is funded and led by independent schools and is dedicated to bring Internet access to all schools in the western cape. In Pretoria also an independent school, St. Alban's College is a school which has a well constructed (though excessively graphical website) covering all areas of high school education including science and language. On the whole, computer aided instruction is a relatively new field of interest in South Africa and very few teachers of any population group have been exposed to it, and there are few national programmes for students and teachers.

1.5. Science education in Africa

During the colonial era most science taught in Africa was at a basic level. The science curriculum reform which occurred in the late 1950s and early 1960s in the United States of America and United Kingdom, inspired by the Russia Sputnik 1, also influenced educational practices in Africa in that Africans borrowed, or adopted, programs developed by western countries (Abimbola, 1983). This was not preceded by any prior determination of what the new science programmes were expected to achieve for the students or countries. Only minimal changes in knowledge of scientific facts have been noticed in the learners, although the new programs significantly departed from the factual expository method of teaching the learner to a more progressive one of teaching the learner what science is and how the scientists work.

The imported science curriculum's, even in Nigeria, where national policies on education, science and technology have been developed, were not grounded in any philosophical foundations. Furthermore, these curricula, apart from supporting an empiricist view, did not achieve some of the targets that were envisaged in the countries of origin (Hodson, 1988). The social-cultural and cosmological background of the learner of science in Africa has been seriously ignored (Chacko, 1991). Chacko (1996) argued that biology, with its vocabulary derived from Greek and Latin, often presents problems to African students. This problem arises because scientific terms are often intended to convey a different meaning from an everyday interpretation.

Specific statements of terms have little bearing on the lives of individuals in a society that emphasises human interactivity and communal individual living, and consists of learning facts through rote memorisation and regurgitation. Wilkinson *et al.* (1987) argues that large sections of the black communities still retain close ties with the rural and traditional cultures. These students therefore experience problems when moving from one word-view to another world-view. According to Powell (1997) and Sheffield (1997) culture should not be ignored in the science curriculum, as science is embedded in, and influenced by, society and culture. The influence occurs because scientific knowledge is socially constructed (Harding, 1993; Kelly *et al.*, 1993). Culture appears to influence achievements at school (Jegede and Okebukola, 1989; Okebukola and Jegede, 1990; Reeves, 1997). Glaser (1991) asserted that culture is closely allied to cognitive activity (in and outside school). This is supported by anthropologists like Ogbu (1992) who stated that school learning and performance are influenced by complex social, historical and cultural factors. Culture is the totality of all humans, and subsumes every endeavour we undertake, including science education. Science education at present is seen as a human and social activity laden with values, beliefs and conventions of the western culture that gave birth to science and any society that supports scientific activity. So any western science curriculum in an non-western classroom environment, which does not take particular considerations of the traditional worldview of the learner, risks destroying the framework through which concepts are likely to be interpreted.

Science education around the world has moved to an increasingly complex aspects (American Association for the Advancement of Science, 1993; New Zealand Ministry of Education, 1993; Australian Education Council, 1994). The definition of school science has widened and includes the many faces of science (e.g. integrated science, technology and society education), and the social, economic and the environmental context in which science is practised. The goals have broadened from a narrow focus on acquiring science knowledge and skills, giving more emphasis to depth of learning, competence and practical applications of scientific knowledge. Learning theories have moved from behaviourists (closed system approaches) towards constructivism (open system approaches). There is a need to redesign science education to satisfactorily meet the needs of Africa in such away that the African view of nature, socio-cultural factors and the logical dialect reasoning embedded in African metaphysics are catered for within a changing global community. Africa's saviour will be the adoption of an appropriate STS (science-technology-society education) with a tailored pedagogy, which will explore how science can be integrated into the cultural traditions and practices of Africa.

STS education brings scientists, science educators and all groups of people to think of the scientific enterprise as a human enterprise. It relates what is taught in science classes to our day to day living and is cognitively accessible at different levels to the majority of those who enjoy science studies, want a science based career or need it for certification purposes. It also uses local resources for the understanding of science concepts and demonstrates in concrete terms that science and technology are major factors that will influence the future of the world. Jegede (1997) and other educators propose that the best way to achieve the desired results is to use what they called an ecocultural paradigm. A conceptual ecocultural paradigm is a state of an individual perception of knowledge as drawn from the socio-cultural environment, in which the learner lives and operates. It consists of generating information about the African environment to explain natural phenomena, identifying and using indigenous scientific and technological principles, theories and concepts within the African society and teaching the values of the typical African humane feeling in relation to, and in the practise of, technology as a human enterprise. This paradigm addresses two major interrelated educational issues that have emerged recently. The first is the issue of constructivism, in which the learner constructs their knowledge from new experiences. In terms of an existing conceptual framework, constructivism, which uses the epistemological, sociological, historical and psychological statics of knowledge in an integrative manner, is actually not foreign to Africa. The communally determined, social inter-relationship and hence the derivations of the meaning from nature, dwells on the understanding and knowledge already possessed by an individual. The initiation ceremonies and learning of roles in the society as part of traditional African education, are typical examples where constructivism is a vibrant component. So, introducing it into science learning in Africa will not be something new.

The second issue relates to the worldview that learners in traditional societies take into the classroom. The worldview of the learner acts as a framework within which the mechanistic science concepts are assimilated. The current format to integrate technology into education as a way of helping provide liberal education and showing science and technology as a human enterprise is not new in Africa. The indigenous technology of the African communities (which some people misconstrue as primitive or crude) has as its bases the practice of technology as a human purpose for survival in a harsh world. The parallels drawn illustrate the fact that ideas from the mechanistic and the anthropomorphic worldviews could be exploited to strengthen each other.

Cole (1975) stated that there has always been a rich collection of cultural objectives and beliefs with scientific bases in all African societies. The scientific base may be very elementary but could serve as valuable links between what is familiar and the new knowledge and understanding that is to be acquired. Yoloye (1986) proposed that socially relevant curricula in Africa should provide opportunities for learning towards the fulfilment of the needs of the society, becoming thoroughly familiar with the characteristics of the society and utilising the available resources in the society for the promotion of learning. Teachers must be able to capitalise on new knowledge, exercise data-based professional judgement, and acquire intimate knowledge of the changing needs of the learner in the exercise of their own creativity and spontaneity, a holistic approach to learning and teaching (constructivism) and an appropriate technology (computers) should be adopted. Research findings have found positive effects associated with microcomputer use in science education application. It was found that microcomputers enhance higher achievement and more positive attitudes in a high school biology course that was computer loaded (Hounshell and Hill, 1989), enhanced scientific reasoning (Friedler, Nachmias and Songer, 1989), and inquiry skills. Another study found that computer use by students enhanced their self-esteem (Robertson, Ladweg, Strickland and Boschung, 1987). This may also account in part or in whole for the increased interest in science by lower achieving students who have computers incorporated in their curriculum.

1.6. The present study

In this study it is hypothesised that the integration of computers into South African science curricula can provide an invaluable educational resource that can help initiate a change from a didactic to a constructivist philosophy of learning, without threatening or intimidating educational practitioners. To test the hypothesis, a topic in biology that students find cognitively difficult to understand and teachers find hard to teach, was used to develop, in consultation with teachers, constructivist methods of teaching.

This project included the identification of (i) teaching theories and materials high school biology teachers use in their teaching, (ii) biology topics that students find cognitively difficult, (iii) content areas that teachers find hard to teach, (iv) and misconceptions students have in a specific topic. The project also included exposing teachers to the role of computer technology in education, and the implementation and evaluation, with students, of the effectiveness of constructivist materials and methods used in this study.

In the first part of the study workshop techniques were employed whereby high school biology teachers were provided with worksheets on educational theories, and learning styles. Also, the use of computer technology in instruction was demonstrated using software, and a questionnaire on assessment of teacher computer literacy and the state of computer-based education in the schools represented was utilised. In this part of the study, the research attempted to identify which educational theories, learning materials and type of motivation teachers use in their teaching. It was also aimed at making teachers aware of the potentials of computers as educational tools and the different learning styles employed by learners in their learning. Information on the availability of computers in the teachers schools, what use they are put to, how accessible they are to teachers, whether there is institutional pressure to use computers in instruction, the computer literacy of the delegates, whether they would like to use computers in their teaching and the problems they would incur if they integrate computers into instruction was collected.

In the next part of the study workshop technique and a questionnaire on biology topics were employed to identify which topics in the biology syllabus teachers regard as the most difficult to teach and for the learners to understand.

Thereafter, a survey using a questionnaire based on the most difficult topic identified by the teachers was administered to high school biology teachers to help identify the difficult content areas of the specific topic. A survey on the misconceptions held by Grade 11 high school students and first year Cell Biology undergraduates on the identified difficult topic was also carried out as part of this research using an open-ended questionnaire based on mitosis, meiosis and Mendelian genetics.

In the final section of the project a survey of misconceptions held by a highly selected group of students (first year Medical Biology undergraduates) was carried out on the identified difficult topic. Also, the implementation and evaluation of constructivist learning materials to overcome the identified misconceptions was carried out in this section of the study. Tutorials, using constructivist materials and methods, were then used to overcome misconceptions held by some of the first year Medical Biology students. Here pre-tests (prior to instruction), post-tests (after traditional didactic instruction) and a post-post tests (after constructivist instruction) were used to evaluate the effectiveness of the constructivist approach to teaching.

Each part of the study, including materials, methods, results and discussion on each section, is reported separately in the next chapter. This method of reporting was selected so to highlight the phases of the study and to allow the reader to easily understand the many facets of this investigation.

CHAPTER 2

PART I

Identification of Teaching Theories and Materials High School Biology Teachers Use in Their Teaching and Assessment of Teachers Computer Awareness and State of Computer-Based Education in Schools

2.1.1. Introduction

The major objectives of this part of the study were to illustrate to teachers the potentials of computers in education, that teaching strategies should be based on an educational theory, that learners have different learning styles and that teaching strategies should therefore cater for diverse learners. Other minor objectives were to assess the teachers computer literacy skills, and the availability, accessibility and use of computers in their schools. Additionally, the institutional pressure to use computers in teaching, interest in the use of computer software in their classroom and difficulty they would encounter if they had computers in their classrooms, were also assessed. Lastly, the effectiveness of the workshop used in this section of the study was tested.

2.1.2. Materials and Methods

A workshop was used to investigate the educational theories and practices of teachers in KwaZulu Natal and to determine the use of computers in schools. Twenty high school biology teachers from 19 schools from KwaZulu Natal attended the workshop. Materials used included worksheets on educational theories and learning styles (adopted from

Gregorc learning style delineator test, Web) and (Howard Gardeners multiple intelligence's, 1993) (Appendix A). The workshop also included a demonstration on the use of computers in education and a questionnaire to assess computer literacy skills and use in schools (Appendix B).

2.1.3. Results and Discussion

Results from the discussions on educational theories showed that the majority of the teachers relied heavily on behaviourist theories (instructivist). Ausubel (1968), Carey (1993), Sylwester (1994) contended that behaviourism dominates educational thought and practices. Cuban (1983) argues that the dominance of teacher centred role methods of teaching is due to the fact that teachers were taught this and much of teacher education today re-inforced this mode of instruction.

Researchers in science education argue that the quality of teaching and learning could be improved if educators applied educational theories and research findings to educational situations (McPhie, 1978; Mitzel, 1977; Sanders, 1988). Kathyryn (1995) suggested that for any teaching resource to be of value to students, it should be grounded on a sound educational theory. For example, Maddux (1994) argued that teachers are only concerned with making the Internet accessible to students but appear to be unable to integrate this resource into their teaching.

Participants of the workshop reported that the chalkboard was the most widely used teaching resource and relied on extrinsic motivators for motivating students. Results of the learning style exercises showed that teachers themselves had different learning styles, and this illustrated to them that their learners also have diverse learning styles, which ought to be considered when designing instructions. Regarding the designing of self-instructional materials for instance, Rowtree (1992) posits that designers of self-instructional materials appear to assume that learners are by and large uniform. In addition, the design of teaching materials may unconsciously reflect the styles and preferences of the designers or teachers, which may not be congruent with the styles and preferences of at least some of the intended audience. This part of the workshop demonstrated to the participants that instructional materials need to be designed to take into account the learning styles of pupils and teaching strategies.

Out of the 20 delegates, 85% were computer illiterate (Table 1).

Table 1. Evaluation of computer literacy (n=20 teachers) and computer use in schools (n=19 schools).

Questions	%
Teachers who were computer literate	15
Teachers who had attended a course on computer technology	0
Schools with computers	16
Schools with institutional pressure to use computers in teaching	16

Sixty-seven percent of the computer literate teachers could use only one programme (Word Perfect, DOS Version) and 33% could only access the Internet and none had attended courses on computer technology. Among the 19 schools represented, 84% (16 schools) had no computers, and 84% of the schools represented had no institutional pressure to use computers in teaching.

In 33% of the schools with computers, computers were not accessible to teachers and were used for administration only, while in another 33%, computers were not accessible to the teachers and were used for administration and games (Table 2).

Table 2. The accessibility of computers to teachers and computer uses in schools (n=19)

Questions	Answers	Schools (%)
Accessibility	Not accessible	67
	Rarely accessible	0
	Frequently accessible	0
	Freely accessible	33
Computer use	Teaching	33
	Research	33
	Administration	100
	Games or Recreation	67

In the remainder of schools computers were freely accessible to teachers and were used for teaching, research, administration and games or recreation (Table 2).

Two basic measures were used to assess the effectiveness of the workshop used in this study: the enthusiasm of the delegates to use computer software in their classrooms and whether they would like to attend similar workshops. Throughout the day of the workshop, delegates were extremely enthusiastic about the materials presented, particularly the activities on learning styles and the software demonstrated. A more objective assessment of the workshop effectiveness was obtained from an analysis of the workshop evaluation questionnaires (Appendix B). All of the delegates commented that they would like to use computers in their instruction and wished to attend more of similar workshops (Table 3).

Table 3. Delegates willingness to use computers in their teaching, to attend more of these workshops and the overall rating of the workshop (n=20).

Questions	%
Teachers willing to use computers in their teaching	100
Teachers willing to attend more of these workshops	100
Workshop ratings	
Bad	0
Fair	5
Good	25
Excellent	70

Five percent of the delegates rated the workshop as fair, 25% rated the workshop as good and 70% of the teachers rated the workshop as excellent.

Teachers identified a number of problems related to the use of computers in the classroom, including: overcrowded classrooms, disruptions, computer illiteracy, security and lack of finances for maintenance. These results are in agreement with findings of Waggoner and Goldberg (1986) and U. S Congress Office of Technology Assessment (1995) who found that many teachers who have tried microcomputers in their classroom, usually with initial enthusiasm, have been discouraged as schools often have little money to buy hardware and software and to repair or maintain machines. Few schools have been able to afford the large-scale teacher retraining efforts that will enable teachers to make computers an integral part of classroom instruction. Another problem is the lack of enough time for learners to use computers in turn, and at the same time allow teachers to finish the syllabus. Similar results were reported by Gallo and Horton (1994) who assert that teachers are discouraged by practical problems of implementation such as lack of enough time to access networks and review software.

2.1.4. Conclusion

This part of the study reveal that majority of the teachers surveyed relied on behaviourist theories of teaching and learning, the chalkboard was the most widely used teaching resources and they relied on extrinsic motivation. The workshop demonstrated to the participants that instructional materials need to be designed to take into account the learning styles of pupils and the teaching strategies. Results also indicated that most of the schools had no computers and the few which had computers they were not freely accessible to the teachers, and were mostly used for administration, games or recreation. Most of the participants were computer illiterate and all of them expressed their willingness to integrate computers into instruction, although institutional pressure to integrate computer into instruction was minimal (only in one school). Problems teachers would encounter integrating computers into instruction were also revealed.

In conclusion, the delegates willingness to integrate computers into instruction shows that an environment exists where the use of computers in education is welcomed. However, in order to achieve this, teachers need to be retrained on the best educational practices and design of educational materials. The next part of the study investigates on the most difficult biology topics in high school biology syllabus.

PART II

Identification of Biology Topics that Teachers and Students Find Cognitively Difficult to Teach and to Understand Respectively

2.2.1. Introduction

A number of approaches were used to determine the most difficult content area of the school biology syllabus and include the identification of the topic that teachers find hard to teach, misconceptions held by teachers and students in this topic. In this part of the study research was undertaken to identify the topic teachers find difficult to teach.

2.2.2. Materials and Methods

A workshop and a questionnaire (Appendix C) was used to determine biological topics teachers find difficult to teach. The questionnaire consisted of two sections, A and B. In section A, a list of topics was provided and respondents ranked each topic as very easy, easy, difficult or very difficult. This section of the questionnaire was designed to determine which sections (topics) of the work teachers found easy or difficult to teach. Responses were coded using a ranking scale of 4 to 1, where "very difficult" was ranked 4, "difficult" was ranked 3, "easy" was ranked 2 and "very easy" was ranked 1. In Section B, each question consisted of four concepts related to a single topics. These questions were constructed to find out those concepts within specific topics teachers find hard to teach. Responses were coded in the same way as that used in Section A of the questionnaire.

Twelve high school biology teachers from 12 school in KwaZulu-Natal participated in this workshop. Microsoft Excel was used to analyse the results (means and standard deviations).

2.2.3. Results and Discussion

Teachers identified genetics, respiration and molecular genetics as the topics most difficult to teach and human anatomy, virus and bacteria, cells and ecosystem as very easy to teach (Table 4).

Table 4. Ranking of biological topics by teachers (n=12).

Topics	Mean ± Std Dev
Genetics	3.67 ± 0.65
Respiration	3.25 ± 0.75
Molecular genetics	3.17 ± 1.53
Biological compounds	2.75 ± 0.45
Animal tissues	2.67 ± 0.65
Plant tissues	2.58 ± 0.67
Human physiology	2.58 ± 0.90
Animal physiology	2.58 ± 1.00
Invertebrates	2.50 ± 0.90
Enzymes	2.42 ± 0.79
Homeostasis	2.42 ± 0.90
Population dynamics	2.17 ± 0.58
Vertebrates	2.17 ± 0.72
Plant physiology	2.17 ± 1.19
Human anatomy	2.00 ± 0.85
Virus and Bacteria	1.92 ± 0.79
Cells	1.92 ± 0.79
Ecosystem	1.92 ± 0.51
Reproduction	1.75 ± 0.62
Plant types	1.67 ± 0.78

The remaining topics appear to be easy to teach.

In the second part of the questionnaire teachers identified specific problem areas within topics (Table 5).

Table 5. Identification of specific content areas teachers find difficult to teach (n= 12).

Specific areas within topics	**Mean ± Std Dev**
Mendelian genetics	3.83 ± 0.39
Protein structure	3.67 ± 0.65
Proteins	3.67 ± 0.65
Photosynthesis	3.58 ± 0.79
Population growth	3.50 ± 0.67
Protein synthesis	3.33 ± 0.78
Meiosis	2.92 ± 0.79
DNA replication	2.92 ± 1.00
Homeostasis	2.92 ± 1.24
Enzyme structure	2.83 ± 1.03
Excretion	2.67 ± 0.89
Water relations	2.67 ± 0.65
Carrying capacity	2.67 ± 0.78
Carbohydrates	2.42 ± 1.00
Animal nutrition	2.33 ± 1.30
Lipids	2.33 ± 0.89
Energy flow in ecosystem	2.33 ± 1.30
Transpiration	2.25 ± 0.97
DNA structure	2.08 ± 1.16
Mitosis	2.08 ± 0.29
Gaseous exchange	2.08 ± 1.00
Co-factors	1.92 ± 0.67
RNA structure	1.67 ± 0.78
Energy function	1.58 ± 0.79
Vitamins	1.58 ± 0.90
Growth and development	1.50 ± 1.00
Competition	1.50 ± 0.67

Here, Mendelian genetics was identified as the most difficult area, followed by protein structure, proteins, photosynthesis, population growth, protein synthesis, meiosis, DNA replication, homeostasis, enzyme structure, excretion, water relations, carrying capacity, carbohydrates, animal nutrition, lipids, energy flow in ecosystem, transpiration, DNA structure, mitosis, gaseous exchange, CO-factors, RNA structure, energy functions, vitamins, growth and development and competition.

Overall results from both sections indicate that genetics was the most difficult topic with (3.67 mean ranking) and within it Mendelian (3.83 mean ranking) genetics the most difficult concept for teachers to teach. Other problem areas include protein structure (3.67 mean ranking), proteins (3.67 mean ranking), photosynthesis (3.58 mean ranking) and population growth (3.50 mean ranking). These results are similar to those of Johnstone and Mohmoud (1980), Stewart (1982), Finley *et al.* (1982), Dunn (1986) and Thomas (1988). Mitchell (1992) noted that students perceive genetics as either an abstraction that has very little meaning to them as individuals or as one of those magical scientific phenomena.

2.2.4. Conclusion

This workshop identified Mendelian genetics as that biological topic teachers find difficult to teach but did not probe specific misconceptions. Research to determine specific problems related to Mendelian genetics was therefore undertaken using a questionnaire administered to teachers (Part III) and also to pupils (Parts IV and V).

Part III

Identification of Misconceptions Held by Teachers on Concepts Related to Mendelian Genetics

2. 3.1. Introduction

Teachers identified the teaching of Mendelian genetics as one of the most difficult content areas of the Matric biology syllabus (Part II). Such difficulties may be due to either problems in teaching abstract concepts or to lack of understanding of the material. A questionnaire was therefore designed to determine the concepts within Mendelian genetics that teachers find problematic.

2.3.2. Materials and Methods

To identify the most difficult content areas within Mendelian genetics, a survey was undertaken with 23 high school biology teachers from 22 high schools in KwaZulu Natal, using a questionnaire containing 13 open-ended questions on mitosis, meiosis and Mendelian genetics (Appendix D). Respondents also assessed how confident they were in their answer. Therefore, each question consisted of two parts: concept question and confidence rating in answering question.

The questionnaire was marked and questions were grouped according to the concepts they probed. Thereafter, answers to each question were analysed to identify the misconceptions related to each concept.

The highest marks and the level of confidence per concept were analysed to help identify the most difficulty concept. The questionnaire assessed 10 concepts (Table15).

2.3.3. Results and Discussion

Various authors have listed different criteria used in judging understanding (Osborne and Gilbert, 1980; MacQuire and Johnstone, 1987). Individuals who understand a concept should know and be able to recognise the name and definition of a concept; be able to define the concept in their own words; be able to recognise instances (not previously encountered) of the concept; be able to distinguish between and classify instances and non-instances of the concept (not previously encountered); and be able to apply the concept to new situations (Sanders and Mokuku, 1994).

The assumption made in the analysis of the results is that answers given by respondents indicate facets of their conceptual knowledge of the topic, hence inappropriate answers are taken as lack of conception or as misconceptions, and non-answers as lack of conception.

Teachers understanding of chromosome number in relation to mitosis was determined using the questions "A cell with 52 chromosomes undergoes mitosis. How many chromosomes are present at prophase and in each of the daughter cells at telophase?" (Appendix D, question 1) and "A cell with 20 pairs of chromosomes undergoes mitosis. How many chromosomes are present at prophase and in each of the daughter cells at telophase?" (Appendix D, question 5). All the teachers attempted question 1 (Table 6),

Table 6. Responses given by teachers (n=23) to the questions on chromosome number in relation to mitosis. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Questions	Answers	Responses (%)
1	None	0 (0)
	Both phases correct	70 (44)
	Prophase correct	9 (0)
	Telophase correct	13 (0)
	Incorrect	9 (0)
5	None	4 (0)
	Both phases correct	65 (20)
	Incorrect	26 (17)

70% gave correct answers for both phases, with 44% being confident in their responses. Nine percent of the sample answered telophase correctly, but none were sure of their answers. Another 13% of the sample got telophase correct and none were sure of their answers. The incorrect answer given was 104 chromosomes at both phases given by 9% of the sample. In question 5, that relates to chromosome number and mitosis, 4% of the sample gave no answers. Sixty five percent correctly identified both phases and 20% were confident of their responses. Some of the incorrect answers included: 10 chromosomes at both phases (4%); 80 chromosomes at both phases (4%); 400 chromosomes at both phases (9%); and 80 chromosomes at prophase and 160 at telophase (4%). These teachers who gave the incorrect answer of 104 chromosomes at both phases appear to have confused chromosomes with chromatids and had no idea of chromosome behaviour at telophase of mitosis. These results suggest that teachers confused chromosomes with chromatids at prophase and added chromosome number of the two daughter cells at telophase to determine chromosome number. These results are in agreement with findings by Sanders *et al.* (1997).

The concept of chromatid number in relation to mitosis was probed using the question "A cell with 52 chromosomes undergoes mitosis. How many chromatids are present at prophase and in each of the daughter cells at telophase?" (Appendix D, question 2). Teachers appeared to have some understanding of chromatid number in relationship to mitosis as only 13% gave the incorrect answer (Table 7).

Table 7. Responses given by teachers (n=23) to the question related to chromatid number in relation to mitosis. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Answers	**Responses (%)**
None	0 (0)
Both phases correct	30 (43)
Prophase correct	57 (31)
Incorrect	13 (0)

However, only 30% of the sample understood the relationship between prophase, telophase and chromatid number.

Understanding of the concept of DNA replication in relation to mitosis was assessed using the questions "The DNA content of a cell is measured in the G1 Phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after telophase?" (Appendix D, question 3) and "The DNA content of a cell is measured in the G2 phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after telophase?" (Appendix D, question 4). Over half of the teachers (question 3: 57% and question 4: 61%) did not attempt the questions on DNA content in relation to mitosis (Table 8).

Table 8. Responses given by teachers (n=23) to the questions on DNA content in relation to mitosis process. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Questions	Answers	Responses (%)
3	None	57 (0)
	Correct	22 (20)
	Incorrect	22 (20)
4	None	61 (0)
	Correct	0 (0)
	Incorrect	39 (44)

However in question 3, 22% of the teacher gave the correct answer and only 20% of them were sure of their responses while 22% gave incorrect answers. In question 4, none of the teachers gave the correct answer (61% gave no answer). Some of the incorrect answers given in both questions included DNA shortened and thickened; single DNA molecule; and DNA replicates and nucleotides. Teachers giving incorrect answers seemed to confuse DNA replication with the DNA molecule, chromatid network or nucleotides. Lack of conception of where DNA replicates could have led to this confusion. Yip (1996) found that students erroneously think that chromosomes duplicate at prophase when they appear as thread like structures and as they become thickened and double stranded.

Most teachers do not understand DNA replication in relation to meiosis. This concept was assessed using questions "The DNA content of a cell is measured in the G1 phase. What is the DNA content of that cell at metaphase I and each of the daughter cells at metaphase II?" (Appendix D, question 6) and "The DNA content of a cell is measured in the G2 Phase. What is the DNA content of each of the daughter cells immediately after telophase I and telophase II?" (Appendix D, question 7). Most teachers did not answer either questions 6 or 7 (Table 9).

Table 9. Responses given by teachers (n=23) to questions 6 and questions 7 on DNA content or replication in relation to the meiotic process. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Questions	**Answers**	**Responses (%)**
6	None	70 (0)
	Correct	4 (100)
	Incorrect	26 (17)
7	None	65 (0)
	Correct	0 (0)
	Incorrect	35 (0)

Only 4% correctly answered question 6 on DNA replication. Here the most common incorrect answers included: DNA content at metaphase I is the same as at G 1 (9%), same at G1 and DNA replicates (4%), DNA content (4%) and chromosomes at the equator and chromosomes replicating (4%). While 35% of the teachers answered question 7 on replication, none gave the correct answer (Table 9). Incorrect answers included ½ of G1 (13%), chromosome moves to the poles (4%), nucleotides (9%) and DNA replicates (4%). Results indicate that these teachers appeared to confused DNA replication with chromosomes or chromatid separation and results support the findings of Longden (1982) and Cho *et al.* (1985). The teachers also appeared to confuse DNA replication with nucleotides.

The concept of bivalent number in relation to meiosis was assessed using the question "In an organism with 52 chromosomes, how many bivalents would be expected to form during meiosis 1?" (Appendix D, question 8). Seventeen percent of teachers did not attempt question 8.

(Table 10). **Table 10**. Responses given by teachers (n=23) to the question on the number of bivalent, or homologous chromosomes, in relation to meiosis 1. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Answers	Responses (%)
None	17 (0)
Correct	61 (21)
Incorrect	22 (0)

However, 61% of the teacher gave the correct answer, and yet only 21% of them were confident of their responses. Some of the incorrect answers given were: 208 bivalent (4%) and 104 bivalent (13%). Results may imply that the teachers who gave the incorrect answer (104 chromatids) confused bivalents and chromatids. Radford and Bird-Stewart (1982) reported similar results. All the other incorrect answers showed lack of conception of the concept.

Understanding of chromatid number in relation to meiosis was probed using the questions "If a diploid number of a cell is 20, how many chromatids are present in that cell at metaphase I of meiosis?" (Appendix D, question 9) and "If a cell has 5 pairs of chromosomes, how many chromatids are present in the daughter cells at prophase II of meiosis?" (Appendix D, question 10). Only 57% correctly answered question 9 (Table 11).

Table 11. Responses given by teachers (n=23) to the question related to chromatid number in relation to meiosis. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Questions	Answers	Responses (%)
9	None	13 (0)
	Correct	57 (31)
	Incorrect	30 (0)
10	None	9 (0)
	Correct	22 (40)
	Incorrect	70 (13)

Six chromatid (4%), 80 chromatids (4%) and 20 chromosomes (17%) were the common incorrect answers given for this question. While 22% of the teachers answered question 10 correctly, 70% gave incorrect answers (Table 11). Incorrect answers included 5 chromatids (17%), 20 chromatids (35%). Seventeen percent of the teachers who gave 20 chromatids in question 9 may have confused chromatids with chromosomes. While, 17% who gave 5 chromatids at prophase II in question 10, may have had no understanding of chromosome behaviour at prophase II. These results are complement by findings of Smith (1991), Sanders *et al.* (1997) and Longden (1982).

The concept of gamete formation from trihybrid genotypes was assessed using question 11 "Where respondents were asked to produce gametes from AaBb, AaBbCc, AABb, AaBBCc and AABBCc and where a capital letter represented a dominant allele and a lower letter a recessive allele." Only 4% of the sample correctly produced gametes from AaBbCc, 4% gave six correct answers, 17% five correct answers, 4% two correct answers and 13% one correct answer (Table 12).

Table 12. Responses given by teachers (n=23) to the questions related to formation of gametes from trihybrid and dihybrid genotypes. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Genotypes	Answers	Responses (%)
AaBbCc	None	39 (0)
	Correct	4 (100)
	6 correct	4 (0)
	4 correct	17 (25)
	2 correct	4 (0)
	1 correct	13 (0)
	Incorrect	17 (0)
AaBBCc	None	57 (0)
	Correct	26 (23)
	1 correct	4 (0)
	Incorrect	13 (0)
AABBCc	None	57 (0)
	Correct	26 (33)
	1 correct	4 (0)
	Incorrect	13 (0)
AaBb	None	35 (0)
	Correct	44 (20)
	2 correct	4 (0)
	1 correct	13 (0)
	Incorrect	4 (0)
AABb	None	39 (0)
	Correct	44 (20)
	1 correct	4 (0)
	Incorrect	13 (0)

For the genotype AaBBCc and AABBCc, 26% gave the correct answers with the same teachers scoring one correct answer (4%) for each. Also most respondents were unsure of their answers. Similar results were found for gamete formation from dihybrid genotypes except that more teachers had correctly produced gametes (44% for AaBb and 39% for AABb) (Table 12). The majority of the teachers appeared to form gametes from alleles of one gene, form gametes from dominant genes only, repeat or interchange the genes in the genotypes. This result is in agreement with findings of Tolman (1982) who found that students assigned two alleles to each parent.

The concept of symbolism and mathematical aspects of genetics were assessed using question 12. This question asked "Copy and complete the schemes given to answer each part of the question. In the fruit fly, white eye colour is recessive to red eye colour. (a) Show clearly the phenotype and the genotype of a white-eyed fly and a heterozygous red-eyed fly (use the symbol R to represent the gene giving red-eyed colour). (b) If a homozygous red and a homozygous white are bred together, what colours appear in the offspring's and in what proportions? (c) If the F1 flies are inbred what percentages of offspring's are white-eyed? What proportion of red-eyed flies are heterozygous (carries of white allele)?" In part A of the question, which asked for the symbolic representation of a genotype, 30% of the teachers gave no answer (Table 13).

Table 13. Responses given by teachers (n=23) to the question on symbolism and mathematical aspects of genetics. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Questions	Answers	Responses (%)
a	None	30 (0)
	Correct	17 (50)
	Genotype correct	22 (40)
	Incorrect	30 (14)
b	None	26 (0)
	Correct	4 (100)
	Phenotype correct	4 (0)
	Proportion correct	4 (100)
	Incorrect	61 (14)
c	None	65 (0)
	Correct	4 (100)
	Percentage correct	13 (0)
	Incorrect	17 (50)

Seventeen percent gave the correct answer and only 50% of them were sure of their response, 22% of the teachers got the genotype correct and 40% of them were sure of their answers (Table 13). Some examples of incorrect answers given were: heterozygous

W, R, all pink (4%); WR x Ww, 1 white-eyed (4%) and phenotype aaBB, and genotype aaBB (4%). In part B, 26% of the teachers did not attempt the question and only 4% of the sample gave the correct answer and were sure of their responses. Another 4% got the phenotype correct and were unsure of their answers and 4% also got the proportion correct and were confident of their responses. Some of the incorrect answers given were: RR (red) x Ww (red) heterozygous red (4%); RR X WW all pink offspring's (9%) and aB, AB all red, (4%). In part C, 65% gave no answer, 4% of the teachers gave the correct answer and were confident of their answers, 13% of the sample got the percentage correct, but were unsure of their responses. Some of the incorrect answers were: red homozygous, heterozygous red, and homozygous white (4%); 50% of all offspring are carriers (4%) and 50% white-eyed and 50% red-eyed (4%). Results show that teachers who gave incorrect answers in parts A, B and C (30%, 61% and 17% respectively) had no understanding of the formation of symbols, genotype and phenotype as they named the genotype as the phenotype and vice versa. They also showed lack of understanding of heterozygoity and homozygoity as they gave these answers in sections requiring answers in percentages or proportions. This problem was also prominent among students according to findings by Longden (1982) and Kargbo *et al.* (1980).

The concept of dihybrid cross was assessed using the question "In the mouse, C- animals are pigmented, cc individuals are albinos. Another pair of genes determines the difference between black (B-) and brown (bb). What F2 will be produced as a result of the cross CCBB X ccbb?" (Appendix D, question 13). Lack of conception was shown by 39% of the teachers who did not attempt the question on dihybrid cross (Table 14).

Table 14. Responses given by teachers (n=23) to the question on calculating F2 generation from the dihybrid cross CCBB X ccbb. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Answers	Responses (%)
None	39 (0)
Correct	9 (0)
Incorrect	52 (2)

While 9% of the teachers gave the correct answer, none of them was sure of their response. Over half of the teachers (52%) gave incorrect answers. Some of the incorrect answers included: all pigmented and black (4%); Cccc, Bbcc, Ccbb (9%) and ccBb, one species (9%). Teachers appeared unable to illustrate gamete formation from a dihybrid genotype or to determine the F2 generation. Similar findings were reported by Finley *et al.* (1982) and Stewart (1982) who reported that most students are unable to determine gamete formation in monohybrid and dihybrid crosses. It is therefore not surprising that teachers found gamete formation from dihybrid genotypes and trihybrid genotypes difficult (Table 15). All results, grouped according to concept, were finally ranked from most to least misunderstood (Table 15).

Table 15. Concepts tested ranked in order of difficulty and the percentage of teachers (n=23) getting the correct answers. [The percentage of teachers confident of their answers is given in brackets after the responses.]

Concepts	Correct answers (%)
DNA replication and meiosis	4 (100)
Dihybrid cross	9 (0)
Symbolism and mathematics	17 (50)
DNA replication and mitosis	22 (20)
Gamete formation (trihybrid genotype)	26 (33)
Chromatid number and mitosis	31 (43)
Gamete formation (dihybrid genotypes)	44 (20)
Chromatid number and meiosis	57 (31)
Homologous chromosomes and meiosis	61 (21)
Chromosome number and mitosis	70 (44)

Overall results indicate that the most difficulty concept for the teachers was DNA replication and meiosis, followed by dihybrid cross, symbolism and mathematical aspects of genetics, gamete formation from trihybrid genotypes, chromatid number and mitosis, gamete formation from dihybrid genotypes, chromatid number and meiosis, homologous chromosomes and meiosis and chromosome number and mitosis. A number of misconceptions related to the probed concepts were identified (Table 16).

Table 16. Concepts tested and Misconceptions identified among the teachers (n=23) within specific concepts.

Concepts	**Misconceptions**
DNA replication, meiosis, mitosis	Confusion of DNA replication with chromosomes or chromatids separating, the DNA molecule and nucleotides
Dihybrid cross and gamete formation from dihybrid and trihybrid genotypes	Lack of understanding of how to illustrate gamete formation from dihybrid genotypes or how to show the combination of gametes to get the F2 generation
Symbolism and mathematical aspects of genetics	Lack of understanding of how to form symbols, meaning of genotype, phenotype heterozygoity and homozygoity Confusion between percentages and proportions
Chromatid number and mitosis/meiosis	• Lack of understanding of chromosome behaviour at metaphase I and prophase II of meiosis and • Lack of understanding of the importance of mitosis and meiosis
Homologous chromosomes and meiosis	Confusion of bivalents number with chromatids
Chromosome number and mitosis	Confusion between chromosomes number and chromatids number

Results on this part of the study revealed that teachers held the following misconceptions in specific concepts and are summarised in Table 16. These results clearly demonstrate that these teachers did not understand the fundamental processes of mitosis and meiosis and were therefore unable to answer questions related to DNA replication and gamete formation, and show little understanding of heterozygoity, homozygoity, bivalents, chromatids and chromosomes.

2.3.4. Conclusion

In this part of the study a number of misconceptions related to Mendelian genetics that are held by teachers from KwaZulu Natal were identified. Results reported here are supported by findings of researchers such as (Cho *et al.*, 1982; Finley *et al.*, 1982; Longden, 1982; Brown and Lehman, 1988; Moletsane and Sanders, 1995; Yip, 1996; Sanders *et al.*, 1997). While the sample number is small and therefore no generalisations can be drawn, results indicate that teachers from disadvantaged schools do not understand the basic concepts of Mendelian genetics. In the next part of the study the misconceptions held by students is investigated.

Part IV

Identification of Misconceptions Held by Students on Concepts Related to Mendelian Genetics

2. 4.1. Introduction

In the previous section teacher misconceptions related to Mendelian genetics were identified. The objectives of this part of the study were to investigate misconceptions held by school (Grade 11) and undergraduate (first year Cell Biology) students, and to determine if there were any differences in the understanding of students from either rural or urban areas.

2.4.2. Materials and Methods

Questionnaires, similar to the one used with the teachers on mitosis, meiosis and Mendelian genetics, were used to identify misconceptions, and included items adapted from Kargbo *et al.* (1980) and Moletsane and Sanders (1995). The questionnaire used with teachers was modified to remove problematic and very easy questions (Appendix E) and was administered to 249 Grade 11 and 142 first year Cell Biology students (University of Natal, Durban). The questionnaire was administered prior to instruction at both the school and university level. However, it is assumed that the majority of University students had studied Mendelian genetics at the school level.

To analyse the questionnaires, marks were allocated for each question and misconceptions identified from the answers given by the students. Poorly answered questions were used to identify misconceptions. Thereafter questions were grouped according to concepts that they probed. Therefore, 24 concepts were identified in the questionnaire used with school and first year Cell Biology university students (Table 33).

Statistical analyses were performed using the SPSS INC. statistical programme. The Wilcoxon-Mann-Whitney test was used to determine significant differences in performance.

2.4.3. Results and Discussion

Research on conception, misconceptions and conceptual change has shown that students bring to instruction, views and explanations of natural phenomena that often differ from the consensus views of scientists (Driver, 1981; Osborne, 1982). Educationists have during the last three decades focused on the importance of prior knowledge in successful learning. Ausubel (1968) asserts that the most important single factor influencing learning is what the learner already knows. According to that author, meaningful learning occurs if only the new concept to be learned is consciously related by the learner to relevant concepts, which the learner already knows. Learners must integrate (subsume) new ideas (concepts) into their existing mental structures. If this linkage is not successful, rote learning will occur, rather than meaningful learning. Meaningful learning is the crux of learning in the sciences, which demand understanding, logical reasoning and abstract thought. Preconceptions, or alternative frameworks, are not easily extinguished or corrected (Gunstone *et al.*, 1981) as they have been developed through interpretation of personal experience. Identifying these misconceptions is a vital pre-requisite if the teacher is to provide appropriate feedback to the learners to help them to rectify erroneous ideas. However, what is more imperative is that unless erroneous ideas about basic science concepts are eradicated, students will have problems understanding new knowledge which depends on the understanding of those more fundamental concepts.

The following concepts were assessed in this study: inheritance of boy's height from his parents; inheritance of environmentally induced characteristics; identification of whole chromosomes; identification of chromatids; identification of homologous chromosomes; defining and identification of genes and allele; gamete formation from dihybrid and trihybrid genotypes; ploidy and chromosome number; symbolism and mathematical aspects of genetics; chromosome number in relation to mitosis; chromatid number in relation to meiosis; chromatid number in relation to mitosis; bivalent number in relation to meiosis; DNA replication in relation to meiosis and DNA replication in relation to mitosis.

The assumption made in the analysis of the results is that answers given by the respondents indicate facets of their conceptual understanding. Respondents not attempting the questions indicate lack of conception and inappropriate answers are taken as a lack of conception or as a result of misconceptions.

Students understanding of the concept of inheritance of boy's height from parents' height was assessed using the question: "If a tall man and a short woman have a child and this child is a boy, how tall will he be when he is fully grown?" (Appendix E, question 1).

A small percentage of Grade 11 (5%) and Cell Biology (8%) did not attempt the question on inheritance (Table 17).

Table 17: Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question on predictions of children's (boy's) height from parents height.

Answers	**Responses (%)**	
	Grade 11 Students	**Cell Biology Students**
None	5	8
Tall	51	22
Short	4	1
Medium	12	14
It depends on whom he takes after	29	55

However, 51% of the Grade 11 and 22% of the first year Cell Biology students answered incorrectly that the boys would be tall. Reasons given for their answers were that the chromosomes, or genes, of the father are dominant, that the father has 24 chromosomes and the mother 23 chromosomes; that men are stronger than women; and "like father like son". Students used similar arguments (e.g. "he would take after the mother") to justify their answer that the boy would be short (4% Grade 11 students, 1% Cell Biology 1 students). Such answers clearly indicate that answers are not based on any understanding of heredity but appear to be related to the sexist attitudes about the role of males and females prevalent in society. That the boy would be of medium height was predicted by 12% of Grade 11 and 14% of Cell Biology students. Reasons for these answers included height has continuous variation; because of a mixture of genes from the father and the mother; kin determines height; and the boy received chromosomes from both parents. The answer that the boy's height would depend on whom he takes after was given by 29% of the Grade 11 and 55% of the Cell Biology students. These students understood that both parents contribute to the genetic make up of their offspring's. Workers such as Kargbo *et al.* (1980) and Clough and Wood-Robinson (1985) reported similar results. Students appear to confuse the role of gender (male and female) with genotype and phenotype expression. These incorrect answers may also be due to a lack of understanding of genes and the process of meiosis and segregation.

The concept of inheritance of environmentally acquired traits was determined using the question: "While crossing the road, two female dogs and one male dog were unfortunately hit by a car. The leg of one of the female dogs was broken by the car. As a result, the dog limps after it became well. Will the puppies of this dog be born with a lame leg?" (Appendix E, questions 2). Most students answered the question on environmentally acquired traits as only 8% of Grade 11 and 1% of Cell Biology students gave no answer (Table 18).

Table 18. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question of predictions about environmentally induced characteristics on offspring.

Answer	Responses (%)	
	Grade 11 Students	Cell Biology Students
None	8	1
Yes, they will have limp	5	1
No, they won't have limp	87	99

Also, few of the students believed that environmentally induced characteristics could be transmitted to the next generation (5% of Grade 11 and 1% of Cell Biology students). Such answers were argued to be due to the assumption that the genetic make up of the bitch was altered in the accident. Most students (>86% for both groups) answered correctly that the puppies would not limp. Reasons given for this answer was that the genetic make up was not affected by the accident; the bitch was born with a limp; the leg being lame does not affect the puppies; injuries to an adult do not affect its children; and male dogs have well-developed genes. Similar results were found by Kargbo *et al.* (1980), Hackling and Treagust (1984) and Clough and Wood-Robinson (1985). Some of the students who correctly answered this question do not understand the concept. The incorrect answer that male dogs have well-developed genes once again indicates that some student believe that males are superior to females and this may in part be due to the sexist attitudes prevalent in society.

To investigate student understanding of chromosomes, chromatids and homologous chromosomes, students were required to record letters presenting these structures in diagrams provided (Appendix E, question 3). Each structure will be dealt with separately. Only 5% of the Grade 11 students appeared to have a completely satisfactory understanding of a chromosome but 17% of these were unsure of their answers (Table 19).

Table 19. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) on the question on identification of whole chromosomes. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	Responses (%)	
	Grade 11 Students	**Cell Biology Students**
None	0 (0)	6 (0)
Correct	5 (83)	0 (0)
5 correct	1 (33)	1 (0)
4 correct	12 (76)	16 (22)
3 correct	2 (20)	0 (0)
2 correct	16 (16)	33 (13)
1 correct	38 (34)	19 (18)
Incorrect	24 (25)	23 (15)

Some of these students who identified all six chromosomes also identified chromatids and homologous chromosomes as chromosomes (2%). Nearly a quarter of the sample were unable to identify a single chromosome. Most of the remainder of this group were unable to identify chromosomes with 38% giving only one correct answer. Similar results were obtained from Cell Biology students except that none of them identified all six chromosomes. The commonest error students made was identifying chromatids or homologous chromosomes as chromosomes. Results also suggest that Cell Biology students appeared to be weaker in the identification of chromosomes than the Grade 11 students. Also, most students were unable to distinguish between whole chromosomes, chromatids, homologous and non-homologous chromosomes. Students (12% Grade 11 and 16% Cell Biology students) who only identified four unreplicated chromosomes appear not to understand that chromosomes can exist as double structures, or replicated chromosomes. Those students (13% of Cell Biology) who only identified the two replicated chromosomes may have held the erroneous idea that chromosomes exist as double structures only.

In both groups 10% of the students correctly identified all the 6 chromatids, with 73% of them being sure of their responses and less than 3% identified 5 chromatids correctly (Table 20).

Table 20. Responses given by Grade11 students (n=249) and first year Cell Biology students (n=142) on the question on identification of chromatids. [The percentage of students confident in their answers is given in brackets after the responses.]

Answers	**Responses (%)**	
	Grade 11 Students	**Cell Biology Students**
None	3 (0)	10 (0)
Correct	10 (73)	10 (36)
5 correct	2 (67)	1 (0)
4 correct	6 (40)	9 (17)
3 correct	2 (0)	1 (0)
2 correct	8 (14)	11 (13)
1 correct	6 (7)	4 (0)
Incorrect	62 (23)	55 (12)

Most students, 62% of Grade 11 and 55% of Cell Biology students, did not identify any chromatids accurately. The remainder of the students correctly identified between 1 and 4 chromatids but often labelled whole, non-homologous and homologous chromosomes as chromatids. Results indicate that the majority of students who gave partially correct answers showed a limited understanding of what chromatids are. Those who gave incorrect answers appear to have confused chromatids, whole chromosomes, homologous and non-homologous chromosomes.

Most students answered the question on homologous chromosomes (96% Grade 11 and 91% Cell Biology students) and the question was correctly answered by 25% of each group with the school students being more confident of their answers (Table 21).

Table 21. Responses given by Grade 11 students (n=249) and first year Cell Biology students (n=142) on the question on identification of homologous chromosomes. [The percentage of students confident in their answers is given in brackets after the responses.]

Answers	**Responses (%)**	
	Grade 11 Students	**Cell Biology Students**
None	4 (0)	9 (0)
Correct	25 (62)	25 (31)
2 correct	15 (18)	22 (13)
1 correct	25 (21)	18 (4)
Incorrect	31 (18)	28 (13)

However, more of the Cell Biology students (28%) provided incorrect answers when compared to the Grade 11 students (9%). Of the Grade 11 and Cell biology students who correctly identified 3 homologous chromosomes, 3% of Grade 11 and 11% of Cell biology students added either a whole chromosome or non-homologous chromosomes. Some Grade 11 and Cell Biology students correctly identified either 2 (15% and 22% respectively) or 1 (25% and 18% respectively) homologous pairs. However, these students also identified chromatids, non-homologous or whole chromosomes as homologous chromosomes. Those students who included non-homologous chromosomes in their answer may have thought that all double structures are homologous chromosomes. The other incorrect answers suggested that students confuse these terms and therefore show limited understanding of the concept of homologous chromosomes.

Analysis of the question related to the concepts of identifying whole chromosomes, chromatids, homologous and non-homologous chromosomes indicated that students have little understanding of these terms and therefore cannot understand the processes of mitosis and meiosis. Similar results were reported by Moletsane and Sanders (1995) and Sanders *et al.* (1997).

Students understanding of chromosome number in relation to mitosis was determined using the questions: "A cell with 6 chromosomes undergoes mitosis. How many chromosomes are present at prophase and in each of the daughter cells at telophase?" (Appendix E, question 4) and " A cell with 3 pairs of chromosomes undergoes mitosis. How many chromosomes are present at prophase and in each of the daughter cells at telophase?" (Appendix E, question 6). In question 4, 31% of the Grade 11 and 19% of the first year Cell Biology students gave the correct answer, with 54% and 22% respectively being confident in their responses (Table 22).

Table 22. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the questions on chromosome number in relation to mitosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Question	Answers	Responses (%)	
		Grade 11 Students	**Cell Biology Students**
4	None	3 (0)	17 (0)
	Both phase correct	31 (54)	19 (22)
	Prophase correct	4 (22)	12 (6)
	Telophase correct	2 (0)	17 (13)
	Incorrect	60 (15)	35 (8)
6	None	6 (0)	22 (0)
	Both phases correct	32 (15)	18 (9)
	Prophase correct	10 (20)	13 (6)
	Telophase correct	2 (33)	15 (5)
	Incorrect	50 (10)	33 (9)

More students (4% of Grade 11 and 13% of the first year Cell Biology) successfully answered prophase correct and 22% of them were sure of their responses. Two percent and 17% of the students got telophase correct (Table 22). More Grades 11 than Cell Biology students, 60% compared to 35%, gave incorrect answers. The incorrect answers given by Grade 11 students were: 3 chromosomes at prophase and 12 daughter cells at telophase; 12 chromosomes at both phases; bivalent and crossing over, 2 daughter cells, double stranded structure, and twelve cells at telophase. In the case of first year Cell students incorrect answers included: 12 chromosomes at prophase and 24 chromosomes at telophase; 3 chromosomes at both phases; and 12 chromosomes at prophase. In question 6, 32% of the Grade 11 and 18% of the first year Cell students got both phases correct, with 15% and 9% respectively being sure of their responses. Ten percent and 13% got prophase correct, and 2% and 15% respectively got telophase correct. Some of the incorrect answers given were; 6 pairs of chromosomes at both phases, 6 daughter cells, chromatid network, haploid, and chromosomes come together. These incorrect answers suggest that students do not understand the sequence of events that occur during mitosis and confuse chromosomes and chromatid number, ploidy and daughter cells. Results further denoted that the 3% of the Grade 11 and 11% of the first year Cell Biology who gave 6 chromosomes at prophase and 12 chromosomes at telophase in question 4 may have added up the chromosomes in the two daughter cells. The same mistake was also identified in question 6, whereby 4% of Grade 11 and 9% of the first year Cell Biology students gave 12 chromosomes at telophase. These results are in agreement with findings of Sanders *et al.* (1997).

The concept chromatid number in relation to mitosis was probed using the question: "A cell with 4 chromosomes undergoes mitosis. How many chromatids are present at telophase and in each of the daughter cells in telophase?" (Appendix E, question 5).
Only 8% of the Grade 11 and 6% of the first year Cell Biology students correctly answered the question, while 39% and 38% respectively got prophase correct and only 58% and 29% were confident of their answers (Table 23).

Table 23. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question on chromatid number in relation to mitosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Answer	**Responses (%)**	
	Grade 11 Students	**Cell Biology Students**
None	4 (0)	18 (0)
Both phase correct	8 (2)	6 (2)
Prophase correct	39 (58)	38 (29)
Incorrect	49 (16)	37 (18)

Quite a large number of students (49% and 37% respectively) gave incorrect answers. 4 chromatids at both phase (7%), 2 chromatids at both phases (14%), and in prophase chromatids disappear and appear in telophase (1%) were some of the incorrect answers given by Grade 11 students on this question. Incorrect answers given by first year Cell Biology students included: 64 chromatids at both phases; 4 chromosomes; chromosomes separate in prophase; and no chromatids at telophase but chromosomes. Further analysis of results indicate that the 2% of Grade 11 and 7% of the first year Cell students who gave 8 chromatids at prophase and 16 chromatids at telophase may have added the number of chromatids in both daughter cells to come up with the chromatid number at telophase. Those students for example, 5% of first year Cell students who gave the answer 4 chromatids at prophase and 8 chromatids at telophase may have confused chromosomes for chromatids. Also, all students who got one phase correct may have had limited understanding of the importance of mitosis.

The concept of bivalence in relation to meiosis was probed using the question: "In an organism with 4 chromosomes, how many bivalent or homologous pairs would be expected to form during meiosis I?" (Appendix E, question 7).

Four percent of the Grade 11 and 21% of the first year Cell Biology students did not attempt the question (Table 24).

Table 24. Responses given by Grade 11 students (n=249) and first year Cell Biology students (n=142) to the question on bivalent number in relation to meiosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	Responses (%)	
	Grade 11 Students	**Cell Biology Students**
None	4 (0)	21 (0)
Correct	51 (46)	53 (9)
Incorrect	45 (12)	25 (60)

However, 51% and 53% respectively gave the correct answers, and yet only 46% and 9% respectively were confident of their responses. More Grades 11 than Cell Biology students, 45% compared to 25%, gave incorrect answers. Some of the incorrect answers given by Grade 11 students were: 8 bivalent (10%); 4 bivalent (12%) and 16 chromosomes (1%); heterozygous. Some incorrect answers given by first year Cell Biology students included: 4 bivalent (8%) and 8 bivalents (13%). These incorrect answers suggest that students do not understand the concept bivalent number. Twelve percent of Grade 11 and 8% of the first year Cell Biology students who gave the incorrect answer 4 bivalent may have confused bivalent number for chromosome number. The 10% of Grade 11 and 13% of the first year Cell Biology students who gave the incorrect answer 8 bivalent may have had confusion between bivalent number and chromatid number. Some of the Grade 11 students who gave incorrect answers also confused bivalent number with heterozygoity and cells.

Students understanding of the concept chromatid number in relation to meiosis was assessed using the questions: "If a diploid number of a cell is 6, how many chromatids are present in the cell at metaphase I of meiosis?" (Appendix E, question 8) and "If a cell has 3 pairs of chromosomes, how many chromatids are present in the daughter cells at prophase 11 of meiosis?" (Appendix E, question 9). Only 35% of Grade 11 and 23% of the first year Cell Biology students correctly answered question 8 (Table 25).

Table 25. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question on chromatid number in relation to meiosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Question	Answers	Responses (%)	
		Grade 11 Students	Cell Biology Students
8	None	8 (0)	30 (0)
	Correct	35 (31)	23 (6)
	Incorrect	57 (20)	47 (0)
9	None	10 (0)	35 (0)
	Correct	30 (22)	25 (3)
	Incorrect	60 (17)	40 (3)

Six chromatids, chromatids come together in the equator, 3 chromosomes, 12 cells and haploid were some of the incorrect answers given for this question. While 30% of Grade 11 and 25% of first year Cell Biology students answered question 9 correctly, 60% and 40% respectively gave incorrect answers (Table 25). Incorrect answers included: 12 chromatids; 40 chromatids; 9 chromosomes; 33 daughter cells; different nucleus; and spindle forms. These incorrect answers indicate that majority of these students do not understand the chromosome behaviour at metaphase I and prophase II of meiosis. Students (30%) who gave 6 chromatids as the answer for question 8, may have confused chromosomes for chromatids. This is further illustrated by many students in the two samples giving their answers in form of chromosomes. Longden (1982) found similar results. Some of the Grade 11 students also confused chromatids with daughter cells, ploidy, spindle and nucleus.

The concept of defining genes and alleles was assessed using the question: "Define the term genes and alleles?" (Appendix E, question 10a). When asked to define genes, 14% of Grade 11 and 30% of first year Cell students gave no answer; 27% and 24% respectively gave the correct definition, with 50% and 38% respectively being confident of their answers (Table 26).

Table 26. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) on the question of defining genes and alleles. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	**Responses (%)**	
	Grade 11 Students	**Cell Biology Students**
GENES None	14 (0)	30 (0)
Acceptable explanation of what is a gene	27 (50)	24 (38)
Unacceptable explanation of what is a gene	60 (30)	46 (17)
ALLELE None	30 (0)	58 (0)
Acceptable explanation of what is an allele	10 (73)	9 (46)
Unacceptable explanation of what is an allele	60 (34)	33 (17)

More Grade 11 than Cell Biology students, 60% compared to 46%, gave incorrect answers. Some examples of incorrect definitions given by Grade 11 students were: it is a part of a chromosome which is transmitted through bodily fluids by the parents; it is ones similarities of male and female; phenotype; it is a cell not mature for sexual intercourse; and it is a sperm and an egg combining to form a baby. Incorrect answers given by first year Cell Biology students included: organisms which transfer inheritable characteristics; hereditary related hormones that are responsible for the features; information warehouse;

substance which makes an organism; and a group of chromosomes which function together. On the other hand, 10% of Grade 11 and 9% of first year Cell Biology students defined the term allele correctly, with 73% and 46% respectively being sure of their responses (Table 26). Twenty seven percent of the students, who correctly defined a gene, only 5% of them could correctly define the word allele. Some of the unacceptable explanations of the term 'allele' given by Grade 11 students were: it is a combination of young ones and its parents; it is crossing over of genes; signs in a baby; two sex organs, mans' sperm and egg which are not combined; and arrangement of genes. Examples of unacceptable explanation of the term 'allele' given by first year Cell Biology students included: a pair of chromatids that make up a chromosome; points of connections; a single stranded chromosome; are homologous pairs of chromosomes; locus; and points at which replication occurs.

Results suggest that 60% of Grade 11 and 46% of the first year Cell Biology students who gave a variety of unacceptable (incorrect) definitions lacked the understanding of these two concepts or confused the two terms. Smith (1991) also found that definitional understanding of the concept "genes" and "alleles" caused difficulty.

Most Grade 11 and first year Cell Biology students did not understand identification of alleles and genes. (Table 27).

Table 27. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question on identification and writing down genes and alleles in diagram 4. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	Responses (%)	
	Grade 11 Students	**Cell Biology Students**
GENES		
None	11 (0)	37 (0)
Correct	10 (0)	18 (8)
2 correct	9 (0)	11 (0)
1 correct	21 (14)	13 (0)
Incorrect	49 (0)	22 (3)
ALLELE		
None	13 (0)	35 (0)
Correct	0.4 (0)	1 (0)
2 correct	2 (50)	2 (0)
1 correct	12 (21)	6 (0)
Incorrect	73 (13)	56 (4)

Question 10 b was used to determine students understanding of this concept (Appendix E). Question 10 b "Look at the diagrams below. Identify genes and alleles. Write down the letters of all the genes and alleles shown in diagram 4 in the table below. Show or mark on diagram 5 all the genes and alleles after DNA replication" There were three genes and three alleles shown in the diagram. A fairly large number of Grade 11 and first year Cell Biology students did not identify genes correctly (Table 27). Only 10% of Grade 11 and 18% of first year Cell Biology students correctly identified genes. Nine percent and 11% respectively identified two genes, and were not sure of their answers. Twenty one percent and 13% respectively identified only one gene. B, b (24%), Ab (1%), B and b (1%) and Bb (4%) were some of the common incorrect answers given by Grade 11 students for this concept. Incorrect answers given by first year Cell students were: Bb, Aa (5%); A, b, d, A, B, D (4%) and D, d, A, a (13%). On the concept of identifying alleles, Only 0.4% of the Grade 11 and 1% of the first year Cell Biology students correctly identified alleles, and were unsure of their answers. Two percent respectively identified only two alleles and 12% and 6% respectively identified one allele. While 73% and 56% respectively answered the question, none identified the correct alleles. In correct answers Given by Grade 11 students included: Ab, AD (2%); A and D, a and d (3%); AD, ad (13%); A, D, a, d (7%). Some incorrect answers given by first year Cell Biology students were AD, ad, Bb, bA, bAd (22%) and A, d, A, D (8%).

These incorrect answers suggest that these students confused genes and alleles. These results complement findings by Longden (1982), Hackling and Treagust (1984), Stewart and Dale (1989), Moore (1990), Kindfield (1991), Pashley (1994). Their studies based on students of different ages and in different countries, showed that students struggle to differentiate between the two terms. Possible reasons for this confusion according to Kinnear (1992) is that the term 'gene' and 'alleles' are often used interchangeably. The word gene is used to refer to a specific gene and also in place of allele. For example, the phrase 'the gene for dwarfness' is often used when in fact the phrase the 'allele for dwarfness' is more correct (Longden, 1982; Radford and Bird-steward, 1982; Kinnear, 1992). Smith (1991) criticises an article by Browning and Lehman (1988) for using 'gene' instead of 'allele'. Pearson and Hughes (1988) used the phrase 'misapplied terms' to refer to such concepts. Students were also found to confuse non-allelic pairs and genes and alleles and genotypes for genes and alleles.

The concept of gamete formation from trihybrid and dihybrid genotypes was assessed using the question: "Where respondents were asked to produce gametes from AaBb, AaBBCc, AABb, AaBBCc and AABBCc and where a capital letter represented a dominant allele and a lower letter a recessive allele." (Appendix E, question 11). Only 23% of Grade 11 and 16% of first year Cell Biology students correctly produced gametes from AaBb (Table 28).

Table 28. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question on gamete formation from dihybrid and trihybrid genotypes. [The percentage of students confident of their answers is given in brackets after the responses.]

Genotypes	Answers	Responses (%)	
		Grade 11 Students	Cell Biology Students
AaBb	None	49 (0)	63 (0)
	Correct	23 (59)	16 (9)
	3 correct	3 (30)	5 (0)
	2 correct	4 (11)	6 (0)
	1 correct	6 (14)	9 (0)
	Incorrect	16 (13)	2 (0)
AABb	None	58 (0)	75 (0)
	Correct	26 (62)	18 (8)
	1 correct	2 (0)	1 (0)
	Incorrect	14 (9)	6 (0)
AaBbCc	None	59 (0)	76 (0)
	Correct	0.4 (100)	2 (0)
	4 correct	11 (68)	1 (50)
	2 correct	2 (33)	1 (0)
	1 correct	2 (0)	7 (0)
	Incorrect	25 (36)	13 (0)
AaBBCc	None	59 (0)	87 (0)
	Correct	11 (71)	2 (33)
	3 correct	0.4 (0)	0 (0)
	2 correct	2 (40)	0 (0)
	1 correct	1 (0)	1 (0)
	Incorrect	27 (33)	10 (0)
AABBCc	None	61 (0)	87 (0)
	Correct	11 (75)	1 (50)
	1 correct	2 (0)	2 (0)
	Incorrect	26 (34)	10 (0)

Three percent and 5% respectively gave 3 correct answers, 4% and 6% gave 2 correct answers and 6% and 9% gave one correct answer. More Grades 11 than Cell Biology students, 16% and 2% gave incorrect answers. Some examples of the incorrect answers given included: A is a dominant gamete; heterozygous; Aaaa; Abab; Abba; AABb, Aa; A, b, c, a; AA, AO; AaBb; genotype and alleles.

For genotype AABb, 26% and 18% of the Grade 11 and first year Cell students gave the correct answer, with 62% and 8% respectively being sure of their responses. Two percent and 1% gave one gamete correct, 14% and 6% of the students gave incorrect answers. Some examples of incorrect answers given included: b is recessive to gametes; AABb dominant; aB, ab; homozygous and heterozygous; AABBbb; genotype and gene. Similar results were found for gamete formation from trihybrid genotypes except that far few students had correctly produced gametes (0.4% and 2% for AaBbCc, 11% and 2% for AaBBCc and 11% and 1% for AABBCc) (Table 28).

Analysis of the question related to gamete formation indicate that majority of the Grade 11 students confused gametes with alleles, dominance, genotypes, recessiveness, gene, homozygoity, heterozygoity, co-dominance, meiosis, mitosis and fertilization, while most of the first year Cell Biology undergraduates erroneously identified each gene in a genotype as a gamete, alleles of the same gene to form gametes, and used only dominant genes or recessive genes to form gametes. These results are complemented by findings of Brown and Lehman (1988) in their study of identifying student misconceptions in genetic problem solving via a computer program using college students. They found that students had difficulties in determination of gametes. Wrong determination of gametes from monohybrid or dihybrid crosses or genotypes, showed a weak understanding of meiotic division in relation to monohybrid and dihybrid cross problems, as argued by Stewart (1982). Castello (1984) asserts that a weak understanding of the relationship of meiosis to monohybrid and dihybrid cross problems interferes with the ability to develop meaningful solutions. Stewart and Dale (1989) reported that prior knowledge of meiosis was critical for the meaningful understanding of genetics and of the relationship between the topics.

The concept of chromosome number or ploidy was assessed using question 12, where students were required to give the ploidy and the chromosome number of cells A to D provided (Appendix E). In diagram A, 55% of the Grade 11 and 37% of the first year Cell students got the correct answer, with 13% and 6% being sure of their answers (Table 29).

Table 29. A summary of the responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) to the question on chromosome number or ploidy. [The percentage of students confident of their answers is given in brackets after the responses.]

Diagrams	**Answers**	**Responses (%)**	
		Grade 11 Students	**Cell Biology Students**
A	None	36 (0)	49 (0)
	Correct	55 (13)	37 (6)
	Incorrect	9 (0)	14 (0)
B	None	38 (0)	50 (0)
	Correct	37 (12)	22 (7)
	Incorrect	26 (13)	28 (3)
C	None	38 (0)	51 (0)
	Correct	18 (7)	20 (7)
	Incorrect	44 (15)	30 (2)
D	None	45 (0)	51 (0)
	Correct	12 (21)	21 (7)
	Incorrect	43 (10)	28 (3)

More First year Cell Biology than Grade 11 students, 14% and 9%, gave incorrect answers. Some example of incorrect answers given by Grade 11 students were: 2 chromosomes (1%); 46; and 36. The most confusing answers given by first year Cell Biology students were zero (6%) and 2 chromosomes (4%). In diagram B, only 37% of the Grade 11 and 22% of the first year Cell Biology students correctly answered the question (Table 29). Example of a confusing incorrect answers given by Grade 11 students was 8 chromosomes (17%). The most incorrect answer given by First year Cell Biology students was 8 chromosomes (23%), and 2 chromosomes (1%). In diagram C, 18% of the Grade 11 and 20% of the first year Cell students got the correct answer (Table 29). Some examples of incorrect answers given by Grade 11 students on this item were: 8 chromosomes (8%) and 4 chromosomes (26%). In the case of the first year Cell students, incorrect answers given included: 8 chromosomes (6%) and 4 chromosomes (19%). In diagram D, 12% of Grade 11 and 21% of the first year Cell students correctly answered the question (Table 29). The most confusing of the incorrect answers given by Grade 11 students were 'zero' (1%), 4 chromosomes (12%) and 8 chromosomes (21%). Incorrect answers given by first year cell biology students included: 4 chromosomes (6%); 8 chromosomes (14%) and zero chromosomes (3%).

These incorrect answers may imply that the 1% of Grade 11 and 4% of the first year Cell Biology students who gave the chromosome numbers of diagrams A and D as 2 chromosomes may have paired the unreplicated homologous chromosomes. In diagram D, 1% of Grade 11 and 3% of the first year Cell students who gave the chromosome number as zero, may have held the erroneous idea that chromosomes are double structures. Also in cell B, the 17% of Grade 11 and 23% of first year Cell Biology students who gave the chromosome number as 8, and the 8% of Grade 11 and 6% of the first year Cell Biology who gave 8 chromosomes in cell C, may have counted all the chromatids to come up with the chromosome number. In diagram C, 26% of the Grade 11 students who gave the chromosome number as 4, may have added up chromosomes in the two cells instead of giving the answer 2 chromosomes in each cell. In diagram D, the 12% of Grade 11 and 6% of first year Cell Biology students who gave the chromosome number as 4 may have grouped or paired similar chromosomes according to size and shape. Moletsane and Sanders (1995) and Sanders *et al.* (1997) reported similar results.

The concept of ploidy or chromosome number was assessed using question 12 where diagrams showing some steps occurring during meiosis are provided. Students were asked to show the ploidy or to state whether each of the cell is haploid or diploid and to give the number of chromosomes in each cell (Cell A to D) (Table 30).

Table 30. A summary of the responses given by Grade 11 (n=249) and first year cell biology students (n=142) to the question on ploidy. [The percentage of students confident of their answers is given in brackets after the responses.]

Diagrams	**Answers**	**Responses (%)**	
		Grade 11 Students	**Cell Biology Students**
A	None	34 (0)	47 (0)
	2n (diploid) *	17 (12)	11 (7)
	n(haploid)	49 (20)	43 (3)
B	None	34 (0)	47 (0)
	2n (diploid) *	49 (17)	51 (4)
	n(haploid)	17 (14)	1 (0)
C	None	34 (0)	47 (0)
	n (haploid) *	21 (17)	15 (10)
	2n (diploid)	45 (18)	38 (2)
D	None	37 (0)	49 (0)
	n (haploid) *	43 (13)	39 (2)
	2n (diploid)	20 (25)	11 (13)

* Denotes the correct answer.

Results indicate that the ploidy of cells in some diagrams was more problematic than in others (Table 30). For example, in diagrams A and B, which were both diploid, the percentages of correct answers were higher in diagram B for the two samples (50% Grade 11 and 51% first year Cell Biology students) than in diagram A (17% Grade 11 and 11% first year Cell Biology students). The only visual difference was that A showed undivided chromosomes whilst B showed chromosomes that had divided to reveal chromatids. The same trend was shown in diagrams C and D, which were haploid. The percentages of correct answers were higher in diagram D (43% Grade 11 and 39% first year Cell Biology students) than in diagram C (21% Grade 11 and 15% first year Cell Biology students), where the latter showed replicated chromosomes while the former showed unreplicated chromosomes. This may imply that some students perceived ploidy as being dictated by chromosome structure (i.e. if a diagram had showed unreplicated chromosomes, it was considered to be haploid, and if it showed replicated chromosomes it was considered diploid). Several authors have noted the existence of at least one form of this misconception among both high school and college biology students (Fisher *et al.*, 1986; Thomas, 1988; Stewart and Dale, 1989; Brown, 1990; Stewart *et al.*, 1990; Smith, 1991; Moletsane and Sanders, 1995; Sanders *et al.*, 1997). The students who gave answers suggesting that diagram B was haploid did not understand that chromosomes can exist as double structures. These students who harbour this misconception do not think of replicated chromosomes when an instructor uses the word 'chromosomes' in reference to one that is replicated and do not even recognise diagrams of replicated chromosomes, as argued by Kindfield (1991). Results may also imply that the 45% of Grade 11 and 38% of first year Cell Biology students who said that diagram C was diploid, and 20% of

Grade 11 and 11% of the first year Cell Biology students who identified diagram D as diploid, may have considered the number of cells, since in diagram C there were two cells and in diagram D, there were four cells.

Understanding of symbolism and mathematical aspects of genetics was probed using question 13. This question asked "Copy and complete the schemes given to answer each part of the question. In a fruitfully, white eye color is recessive to red eye color. (a) Write down the phenotype and genotype of a white eyed fly and a heterozygous red-eyed fly (use the symbol R to represent the gene giving red-eye color). (b) If a homozygous red fly and a homozygous white are crossed together, what colors appear in the FI generation and in what proportions? (c) If the FI are crossed, (I) what percentage of offspring's will be white eyed? (ii) What proportion of red-eyed flies are heterozygous (carriers of white allele)?"

In part A of the question, which asked for the symbolic representation of a genotype, 47% of the Grade 11 and 76% of the first year Cell Biology students gave no answer; 25% and 6% respectively gave the correct answer, with 33% and 25% being sure of their responses; 5% and 4% answered the genotype correctly and 2% of the Grade 11 students got the phenotype correct (Table 31).

Table 31. Responses given by Grade 11 (n=249) and first year Cell Biology students (n=142) on the question on symbolism and mathematical aspects of genetics. [The percentage of students confident of their answers is given in brackets after the responses.]

Question	Answers	Responses (%)	
		Grade 11 Students	Cell Biology Students
a	None	47 (0)	76 (0)
	Correct	25 (33)	6 (25)
	Genotype correct	5 (39)	4 (6)
	Phenotype correct	2 (50)	0 (0)
	Incorrect	21 (16)	15 (10)
b	None	45 (0)	70 (0)
	Correct	20 (54)	2 (67)
	Rr heterozygous red correct	7 (53)	4 (40)
	Incorrect	29 (11)	25 (14)
	None	45 (0)	67 (0)
	Correct	0 (0)	0 (0)
	Percentage correct	24 (44)	15 (38)
	Proportion correct	0.4 (0)	0 (0)
	Incorrect	31 (16)	18 (19)

More Grade 11 than Cell Biology students, 21% and 15%, gave incorrect answers. Some examples of incorrect answers were: phenotype of white eyed fly and heterozygous red; Rr and RR; dark brown; phenotype brown genes and genotype red genes; heterozygous; R phenotype R genotype; red eye genes; white eye allele; short part of DNA; and phenotype RR, Rr, rr and genotype RR, Rr, rr. In part B, 45% of the Grade 11 and 70% of the first year Cell students did not attempt the question and only 20% and 2% respectively got the correct answer, with 54% and 67% of them being sure of their responses. Another 7% and 4% got one part of the answer correct, with 53% and 40% being sure of their answers. Some examples of incorrect answers given by Grade 11 students were: magenta color; albinos; homozygous red; and red color and 1/3; Incorrect answers given by first year Cell students included: 25% red, 75% white; red and white, 50%: 50%; 100% and pink; and 50%: 50% pink.

In part C, 45% of Grade 11and 67% of the first year Cell Biology students gave no answer; none of the students gave correct answer; and 24% and 15% respectively got the percentage correct, with 44% and 38% being sure of their responses (Table 31). An additional 0.4% of the Grade 11 students got the proportion correct, and none of them were sure of their responses (Table 31). Some of the incorrect answers given by Grade 11 students were: 80% and heterozygous; 60% and short alleles; one homozygous and 3 heterozygous; 2% and chromosomes; 39% and genotype; 10% and membrane; 50% and phenotype; 100% and monohybrid; and 20% and dominant. Some examples of incorrect answers given by first year Cell students included: 12½, 25%; 60%, 30%; and 75%, 3. Results from the two samples show that almost half of the students (those not attempting the question and those giving incorrect answers) do not understanding the forming of symbols, the meaning of genotypes and phenotypes, and some confused percentages for proportions and vice versa. Also, some Grade 11 students confused proportions with percentages, heterozygoity, homozygoity, phenotype, genotype, allele, color, membranes, dominance and monohybrid. Kinnear (1983) argued that most of these problems arise because students consider genetic ratios as deterministic rather than probabilistic. Through the use of prunnet squares to solve genetic problems, students may memorize perfect ratios, rather than associating probability with the process of meiosis and the distribution of genetic traits. In addition, students who have difficulty in generating gamete types for prunnet squares may not have problems with combinational rule, rather they may not understand the algorithm in the context of chromosomal behaviour during meiosis (Stewart, 1983).

An analysis of the overall responses allowed a number of misconceptions to be identified (Table 32).

Table 32. Concepts tested and misconceptions identified among the Grade 11 (n=249) and first year Cell Biology students (n= 142) within specific concepts.

Concepts	Misconceptions
Ploidy/ chromosome number	Ploidy as dictated by chromosome structure
Chromosome number/ploidy	• Adding up chromatids in replicated chromosomes to come up with chromosome number • Erroneously believing chromosomes as only single structures (unreplicated)
Identification and definitions of genes and alleles.	Confusion of gene for alleles, alleles for genes, non allelic pairs for genes and alleles, and genotypes for genes and alleles
Bivalence and meiosis	Confusion of bivalent number with chromosome number and chromatid number
Identification of whole chromosomes, chromatids and homologous chromosomes	• Confusion among chromosomes, chromatids, homologous and non-homologous chromosomes • Erroneously believing chromosomes as only single structures (unreplicated) • Erroneously believing chromosomes are only double structures (replicated)
Symbolism and mathematical aspects of genetics	• Lack of understanding of how to form symbols, meaning of genotype, phenotype, heterozygoity and homozygoity • Confusion between percentages and proportions
Gamete formation from dihybrid and trihybrid genotypes	Lack of understanding of how to illustrate gamete formation from dihybrid and trihybrid genotypes or how to show the combination of gametes to get F2 generation
Chromosome number and mitosis	• Confusion of chromosomes and chromatids • Lack of understanding of importance of mitosis process
Chromatid number and mitosis/ meiosis	• Confusion of chromatid number with chromosome number at metaphase1 and prophase II • Lack of understanding of importance mitosis and meiosis processes

No statistical differences were found between the performance of Grade 11 and first year

Cell Biology students ($Z = -1.075$, two-tailed p value = 0.2826), suggestion that prior instruction (University students) had little effect on competency. Similarly, no statistical difference were found when the performance of first year Cell Biology students from urban areas were compared to those students from rural areas ($Z = -0.8517$, two-tailed $p = 0.3944$). These results seem to suggest that access to resources (urban areas) does not influence or improve the understanding of genetics concepts. However, analyses of misconceptions held by Cell Biology students indicated that rural students held more misconceptions than did urban students (Table 33).

Table 33. Percentages of first year Cell Biology students who had attended rural schools (n=13) and urban schools (n=110) with specific misconception on concepts related to Mendelian genetics.

Misconceptions	**% of students with specific misconceptions**	
	Cell Rural Students	**Cell Urban Students**
Confusion among chromosomes, chromatids, homologous and non homologous chromosomes	100	77
Lack of understanding of mitosis process	77	56
Confusion among chromosome number, chromatid number and number of bivalent	23	13
Confusion of gene for alleles, alleles for genes, non allelic pairs for genes and alleles, and genotypes for genes and alleles	77	64
Confusion between chromatid number and chromosome number at metaphase I and prophase II	46	32
Ploidy as dictated by chromosome structure	39	35
Erroneously believing chromosomes as only single structures (unreplicated)	16	37
Erroneously believing chromosomes are only double structures (replicated)	77	54
Adding up chromatids in replicated chromosomes to come up with chromosome number	0	31

All results, grouped according to concept, were finally ranked from most to least misunderstood in order to identify the most difficult content areas (Table 34).

Table 34. Concepts tested ranked from the most difficult to the least difficult for school (n=249) and University (n=142) students. [The percentage of students confident of their answers is given in the brackets after the marks.]

Concepts tested	**School Students (% correct)**	**University Students (% correct)**
Identification of alleles	0.4 (0)	1 (0)
Identification of whole chromosomes	5 (83)	0 (0)
Chromatid number and mitosis	8 (2)	6 (2)
Identification of genes	10 (0)	18 (8)
Definition of alleles	10 (73)	9 (46)
Identification of chromatids	10 (73)	10 (36)
Gamete formation from trihybrid genotypes	11 (75)	2 (33)
Chromosome number diagram D	12 (21)	21 (7)
Ploidy diagram A	17 (12)	11 (7)
Chromosome number diagram C	18 (7)	20 (17)
Ploidy diagram C	21 (17)	15 (10)
Symbolism and mathematical aspects	25 (33)	6 (25)
Identification of homologous chromosomes	25 (62)	25 (31)
Gamete formation from dihybrid genotypes	26 (62)	18 (8)
Definition of genes	27 (50)	24 (38)
Inheritance of boy's height*	29	55
Chromosome number and mitosis	32 (15)	19 (22)
Chromatid number and meiosis	35 (31)	23 (3)
Chromosome number diagram B	37 (12)	22 (7)
Ploidy diagram D	43 (13)	39 (2)
Ploidy diagram B	49 (17)	51 (4)
Bivalence and meiosis	51 (46)	53 (9)
Chromosome number diagram A	55 (13)	37 (6)
Environmentally induced traits*	87	99

* - questions where no confidence in answer was required

Results indicate that the most difficult concepts for the Grade 11 and first year Cell Biology students were identification of alleles, identification of whole chromosomes and chromatid number and mitosis (less than 10% of the groups answered correctly) (Table 34). Concepts related to ploidy, bivalence and meiosis, chromosome number and environmentally induced traits appear to be understood by more than 50% of the students. However, students showed little understanding of the concepts associated with Mendelian genetics.

Results also revealed that teachers held the same misconceptions in concepts related to Mendelian genetics as the students (see Table 16 and Table 47) on the similar questions included in the misconception questionnaires. While the sample size of the teachers was small, students hold similar misconceptions and therefore most teachers might not understand the basics of Mendelian genetics.

2.4.4. Conclusion

This part of the study revealed that Grade 11 students hold similar misconceptions as do first year Cell Biology students and that school instruction does not alter the misconceptions held by students. Results from the previous and this section clearly indicate that there are many deep seated problems associated with the learning of Mendelian genetical concepts. There appear to be many reasons for this and include a lack of understanding by teachers, the misunderstanding of specific scientific terms and might also be related to societal attitudes such as sexism.

It could be argued that because of the wide range of first year University student ability, it is difficult to statistically show differences between this group and school pupils. In an attempt to address this issue an experiment was conducted on first year Medical students, who are a highly selected group and require excellent school results to gain entry into this course. In the next part the understanding of Mendelian genetics by first year Medical School students was investigated. In this section the use of constructivist learning methods was also evaluated to determine if such an approach to teaching Mendelian genetics could overcome the problems associated with the understanding of this topic.

PART V

Use of Learning Resources and Constructivist Teaching Methods

2.5.1. Introduction

The understanding of two processes, mitosis and meiosis, is fundamental to the understanding of Mendelian genetics (Cho *et al.*, 1985; Mitchell, 1992; Sanders *et al.*, 1997). Also, misconceptions related to Mendelian genetics, held by teachers and students that were previously identified, are closely linked to the processes of mitosis and meiosis. The objective of this part of the study was to determine if the use of teaching resources (available on the Internet) and constructivist teaching methods could overcome the misconceptions related to mitosis and meiosis.

A single group of students (first year Medical Biology) was used for this part of the study. Therefore, this part of the study also attempts to document whether these students who performed better in Matric (Medical students) hold similar or different misconceptions of Mendelian genetics than do other University (Cell Biology) or Grade 11 students (previous section).

2.5.2. Materials and Methods

The experiment consisted of a number of phases including the identification of misconceptions of Mendelian genetics held by first year Medical Biology students prior to instructions (pre-test) and after (post-test) traditional instruction (lectures), evaluation of Internet-based learning resources on mitosis and meiosis used within a constructivist-like learning environment (post-post-test) and evaluation of the learning materials and teaching method by the students. The questionnaire used in this experiment was modified from that used with teachers and the Grade 11 and first year Cell Biology students. Questions that both teachers and students that found to be very difficult and provided no insight into misconceptions were therefore removed, while four questions on DNA replication were added to further investigate the concept of DNA replication.

The learning resources used in this study were developed by Professor Kathleen Fisher (San Diego State University, USA) and are available in the Internet (http://www.biology lessons.sdsu.edu/). The learning resources on mitosis (Appendix G) attempts to illustrate concepts of how cells reproduce, chromosomes are copied and how hereditary materials are conserved. The exercises also introduce students to the terms: allele, anaphase, chromosome replication, cytokinesis, diploid, life cycle, DNA synthesis, gene, homologous chromosomes, interphase, metaphase, mitosis, prometaphase, prophase, replicated chromosomes, sister chromatids, spindle fibres, telophase and unreplicated chromosomes. During the instruction phase students were also provided with notes, suggested reading materials and illustrations of how to model the mitotic process. Learning resources on meiosis (Appendix G) introduced students to the processes involved in the production of sex cells, or gametes. Notes, materials and illustrations of how to model meiosis were also provided.

Two group study sessions were used, one for each learning resource. During these study periods, students working in groups, used the learning resources (provided as printed materials) to investigate mitosis and meiosis. Two facilitators supported the students during these learning sessions.

A six-part questionnaire was used to evaluate student opinions of the constructivist learning materials and teaching method (Appendix H). The questionnaire was designed to determine which of the materials students liked or disliked, the method of instruction they preferred and whether they deepened their understanding of mitosis and meiosis. The questionnaire also allowed students to make suggestions on other appropriate materials that could be used to model these processes.

The pre- and post-test was administered to 151 first year Medical Biology students (University of Natal, Durban). Of this group, 18 students failed the post-test and voluntarily participated in the evaluation of the learning resources phase of the experiment.

Statistical analyses of results were calculated using SPSS (SPSS INC.) using the Wilcoxon-Mann-Whitney test. Statistical test comparing of results from Cell Biology and Medical students used only those questions common to both groups.

2.5.3. Results and Discussion

Since misconceptions persist (Champagne *et al.*, 1983; Brown, 1992), are well embedded in an individual's cognitive ecology and are difficulty to 'teach away' especially by didactic methods, this study embarked on the use of constructivist materials to teach mitosis and meiosis to students identified as not understanding the concepts related to genetics. Although there is no research which specifically proves that certain teaching methods will eradicate misconceptions held in genetics, learning theorists propose that the application of modern educational theory could help to improve the understanding of scientific concepts. For example Moletsane and Sanders (1995) assert that understanding would be improved if: students are made aware of common errors made by scholars of genetics and errors students make; learners are taught about the constructivist theory of learning and how the use of hand-on-mind-on task can promote understanding; and teachers to provide hands-on-mind-on activities, making sure that where possible they use physical models to concretise microscopic structures.

Identification of Misconceptions Prior to Traditional Instruction

Further research on misconceptions held by students on concepts related to Mendelian genetics was assessed among highly selected students (first year Medical Biology students of University of Natal, Durban).

Students understanding of the concept of DNA replication in relation to mitosis was assessed using the questions: "The DNA content of a cell is measured in the GI phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after telophase?" (Appendix F, question 1) and "The DNA content of a cell is measured in the G 2 phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after telophase?" (Appendix F, question 2).

A fairly large number of students (18% and 37% respectively) did not answer either question 1 or 2 (Table 35).

Table 35. Responses given by first year Medical Biology students (n=151) to the question on DNA replication in relation to mitosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Questions	Answers	Responses (%)
1	None	18 (0)
	Correct	46 (29)
	Incorrect answers	36 (13)
2	None	37 (0)
	Correct	7 (0)
	Incorrect	56 (18)

Only 46% correctly answered the questions 1 on DNA replication. In question 1, 46 chromosomes (9%) and ½ amount of DNA in G1 phase (14%) were the common incorrect answers given for this item. Other incorrect answers were; twice the amount in G1 phase, chromatids, chromatid network centromere, genes and ploidy. In question 2, 7% answered the question correctly, but none were sure of their responses. Some of the incorrect answers given were: the DNA content would be same as in G2 (36%); DNA content would be twice of G2 (5%); 46 chromosomes (9%). Other incorrect answers given by small groups of students were; haploid, diploid, two nuclei, centrioles and chromatids. Results indicate that majority of the students who gave incorrect answers may have had no understanding of the concept DNA replication. Some of the students confused DNA replication with chromosomes, chromatids, chromatid network, centrioles, genes, ploidy and nucleus.

To investigate the understanding of chromosomes, chromatids and homologous chromosomes, students were required to record letters presenting these structures in diagrams provided (Appendix F, question 3). Each structure will be dealt with separately. In the concept of identification of whole chromosomes, six of the letters provided in the question represented whole chromosomes, namely A, B, C, D, L and G (Appendix F). Two percent of the sample identified all the chromosomes, with 67% of being confident of their answers (Table 36).

Table 36. Responses given by first year Medical Biology students (n=151) on the question of identifying whole chromosomes. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	**Responses (%)**
None	9 (0)
Correct	2 (67)
5 correct	2 (67)
4 correct	25 (30)
3 correct	1 (0)
2 correct	44 (24)
1 correct	10 (13)
Incorrect	7 (18)

One percent of the students who identified the six chromosomes added incorrect options in the form of homologous chromosomes and non-homologous chromosomes. Seven percent of the sample were unable to identify a single chromosome and 18% of them were confident of their answers. Most of the reminder of the students were unable to identify all the chromosomes with 44% giving only two correct answers. Of these students 20% identified double chromosomes G and L, without an additional incorrect answer, 11% identified two of the unreplicated chromosomes (A-D), without any incorrect answers. Another 11% of these students identified two double (replicated) chromosomes (G and L), but added incorrect options in the form of chromatids, homologous and non homologous chromosomes, and none was sure of their answers. Also, 2% of these students identified two of the unreplicated chromosomes, but added chromatids and none was sure of their responses. 10% of the sample identified one correct whole chromosome. The most common errors students made was identifying chromatids or homologous and non-homologous chromosomes as whole chromosomes. Results also suggest that most of the students who added to the correct answer incorrect options and those who gave incorrect answers were unable to distinguish between whole chromosomes, chromatids, homologous and non-homologous chromosomes. Twenty five percent of the students who identified only the four unreplicated chromosomes and excluded (G and L) appear not to understand that chromosomes can also exist as double structures or replicated chromosomes. Also, 20% of the students who identified only two chromosomes (G and L) may have held the erroneous idea that chromosomes exist as double structures.

Results show that 27% of the students correctly identified all 6 chromatids, with 43% of them being sure of their responses (Table 37).

Table 37. Responses given by first year Medical Biology students (n=151) on the question on identification of chromatids. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	**Responses (%)**
None	9 (0)
Correct	27 (43)
5 correct	1 (100)
4 correct	13 (16)
3 correct	1 (0)
2 correct	9 (8)
1 correct	2 (0)
Incorrect	40 (10)

Of these students, 8% identified the six chromatids with no additional incorrect options, 17% identified the six chromatids, but added incorrect options in the form of unreplicated chromosomes (A, B, C, and D), 2% added to the six chromatids one of the double chromosomes. Forty percent of the students gave incorrect answers. Some examples of incorrect answers given were: unreplicated chromosomes A, B, C, D (25%); replicated chromosomes G and L (7%); homologous chromosomes, non homologous chromosomes and a mixture of replicated and unreplicated chromosomes (9%). The remainder of the students correctly identified between 1 and 5 chromatids but often labelled whole, none-homologous or homologous chromosomes as chromatids. Results show that the majority of the students who gave incorrect answers appeared to have confused chromatids, whole chromosomes, homologous and non-homologous chromosomes. Those who gave partially correct answers showed a limited understanding of the concept of chromatids.

Thirty seven percent of the sample correctly identified all 3 homologous chromosomes, with 25% being confident of their responses (Table 38).

Table 38. Responses given by first year Medical Biology students (n=151) on the question of identification of homologous chromosomes. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	**Responses (%)**
None	11 (0)
Correct	37 (25)
2 correct	20 (23)
1 correct	19 (7)
Incorrect	13 (0)

Of these students; 18% added to the three homologues, replicated chromosomes G or L and non-homologous chromosomes K or Q. Twenty percent and 19% of the students respectively identified 2 and 1 homologous chromosomes. However, some of these students identified whole chromosomes, chromatids and non-homologous chromosomes as homologous chromosomes.

Examples of some of the incorrect answers given were: unreplicated chromosomes (A-D) (2%); replicated chromosomes (G or L) (5%); non-homologous chromosomes (K or Q) (3%) and chromatids (3%).

Those students (18%) who included double chromosomes G and L, non-homologous chromosomes K or Q in their answers may have thought all double structures are homologous chromosomes. Also, the 10% who gave two correct answers and added chromosomes C, D, L, G, chromatids and non-homologous chromosomes and 13% who gave incorrect answers in the form of chromosomes, non-homologous chromosomes, and chromatids, may have had a confusion among these terms. Students giving partial answers may have had limited understanding of the term homologous chromosomes.

Analysis of the question related to the concept of whole chromosomes, chromatids homologous and non-homologous chromosomes indicate that students have little understanding of these terms and therefore do not understand the processes of mitosis and meiosis. Similar results were reported by Moletsane and Sanders (1995) and Sanders *et al.* (1997).

The concept of chromatid number in relation to mitosis was probed using the question: "A cell with 4 chromosomes undergoes mitosis. How many chromatids are present at prophase and in each of the daughter cells in telophase?" (Appendix F, question 5)

Only 19% gave the correct answer for both phases, with 9% of being confident of their responses (Table 39).

Table 39. Responses given by first year Medical Biology Students (n=151) on the question on chromatid number in relation to mitosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	**Response (%)**
None	7 (0)
Both phases correct	19 (8)
Prophase correct	32 (8)
Telophase correct	9 (0)
Incorrect	34 (8)

Thirty two percent answered prophase correctly, and 8% of them were sure of their responses. The incorrect answers given were: 2 chromatids at both phases (9%); 4 chromosomes at both phases (1%); and 3 chromatids at prophase and 6 chromatids at telophase (1%). Results indicate that 1% of these students who gave 8 chromatids at prophase and 16 chromatids at telophase may have added the number of chromatids in both daughter cells to come up with the chromatid number at telophase. Those students giving the answer 4 chromosomes and 8 chromosomes at telophase may have confused chromosomes for chromatids. Also, all students who answered one phase correctly may had no understanding of the importance of mitosis

Students understanding of chromosome number in relation to mitosis was determined using the questions: "A cell with 6 chromosomes undergoes mitosis. How many chromosomes are present at prophase and in each of the daughter cells at telophase?" (Appendix F, question 4) and "A cell with 3 pairs of chromosomes undergoes mitosis. How many chromosomes are present at prophase and in each of the daughter cells at telophase?" (Appendix F, question 6). In question 4, 5% of the students gave no answer. However, 37% gave correct answers for both phases, with 16% being confident of their answers, and 11% of the sample answered prophase correctly and 32% of the sample getting telophase correct, yet only 13% and 15% respectively were sure of their responses (Table 40).

Table 40. Responses given by first year Medical Biology students (151) on the question on chromosome number in relation to mitosis. [The percentage of students confident of their answers is given in the brackets after the responses.]

Questions	Answers	Responses (%)
4	None	5 (0)
	Both phases correct	37 (16)
	Prophase correct	11 (13)
	Telophase correct	32 (15)
	Incorrect	16 (17)
6	None	5 (0)
	Both phases correct	31 (9)
	Prophase correct	19 (21)
	Telophase correct	23 (0)
	Incorrect	22 (12)

Some of the incorrect answers given by these students were: 3 chromosomes in both phases (6%); 24 chromosomes in both phases (1%) and 12n chromosomes at both phases (5%). In question 6, which relates to chromosome number and mitosis, 5% gave no answers. Thirty one percent got correct answers for both phases of which 9% were sure of their responses. Nineteen percent of the sample got prophase correct and 23% of the students got telophase correct. Examples of some of the incorrect answers given to this item were: 3 chromosomes in both phase (12%); daughter cells (1%) and 3 chromosomes in prophase and 63 chromosomes at telophase (1%). Results indicate that the students giving incorrect answers and getting one phase correct for question 4 and question 6 (Table 40) had no conception of importance of mitosis and the concept chromosome number. Results further denoted that the 4% who gave 6 chromosomes at prophase and 12 chromosomes at telophase in question 4 might have added up the chromosomes in the two daughter cells. The same mistake was also identified in question 6, whereby 1% of the students gave 12 chromosomes at telophase. These results are in agreement with findings of Sanders *et al.* (1997). Some of these students confused chromosome number with daughter cells.

The concept of bivalence in relation to meiosis was probed using the question: "In an organism with 4 chromosomes, how many bivalent or homologous pairs would be expected to form during meiosis I?" (Appendix F, question 7).

Twelve percent of the students did not attempt the question (Table 41).

Table 41. Responses given by first year Medical Biology students (151) on the question on bivalent number in relation to meiosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Answers	**Responses (%)**
None	12 (0)
Correct	50 (17)
Incorrect	38 (5)

However, 50% gave the correct answer and 17% were sure of their responses. Examples of some of the incorrect answers given were: 4 bivalents (19%); 8 bivalents (5%); 1 bivalent (9%) and 2 chromosomes (1%). Results imply that the 19% of students who gave the incorrect answer "4 bivalent" may have confused bivalent number for chromosome number. The 13% who gave the incorrect answer "8 bivalent" may have had confusion between bivalent number and chromatid number. Thus, these students confused bivalent number with chromosome number and chromatid number.

Students understanding of the concept chromatid number in relation to meiosis was assessed using the questions: "If a diploid number of a cell is 6, how many chromatids are present in the cell at metaphase I of meiosis?" (Appendix F, question 8) and "If a cell has 3 pairs of chromosomes, how many chromatids are present in the daughter cells at prophase 11 of meiosis? " (Appendix F, question 9). Only, 34% correctly answered question 8 (Table 42).

Table 42. Responses given by first year Medical Biology students (151) on the question on chromatid number in relation to meiosis. [The percentage of students confident of their answers is given in brackets after the responses.]

Questions	Answers	Responses (%)
8	None	19 (0)
	Correct	34 (9)
	Incorrect	47 (3)
9	None	18 (0)
	Correct	34 (3)
	Incorrect	58 (12)

Three chromatids (25%), 6 chromatids (17%), and "no chromatids-chromosomes do not split" (1%) were some of the incorrect answers given for this question. While 34% of the students answered question 9 correctly, 58% gave incorrect answers (Table 42). Examples of some of the incorrect answers given were: 12 chromatids (17%); 3 chromatids (20%) and 6 chromosomes (1%).

Results suggest that majority of the students who gave incorrect answers in this question (8) had no idea of chromosome behaviour at metaphase I and prophase II of meiosis. Students (17%) who gave 6 chromatids as the answer for question 8, may have confused chromosomes for chromatids.

The concept's of defining genes and alleles was assessed using the question: "Define the term genes and alleles." (Appendix F, question 10a). Only 36% of the sample gave the correct definition of the term "gene", with 24% being confident of their responses (Table 43).

Table 43. Responses given by first year Medical Biology students (n=151) on the question on definition of a gene and an allele. [The percentage of students confident their answers is given in brackets after the responses.]

Answers	**Responses (%)**
None	21 (0)
Acceptable explanation of what is a gene	36 (24)
Unacceptable explanation of what is a gene	44 (18)
None	62 (0)
Acceptable explanation of what is an allele	8 (36)
Unacceptable explanation of what is an allele	30 (15)

Forty four percent gave incorrect answers. Some examples of the unacceptable explanations of the term gene were: set of cells containing genetic information; number of genes in a DNA strand; and a substance that carries messages or information. On the concept of defining alleles, 62% gave no answers for this question. Only 8% of the students correctly defined the term allele, and 36% of them were sure of their responses. Results also show that of the 36%, who correctly defined the term gene, only 3% of them could correctly define the term allele.

Examples of some of the unacceptable explanations given were: locus; pairing of genes; natural real outside appearance; a collection of genes; and a point at crossing over of a chromosome. Results may imply that students not defining genes and alleles and those giving incorrect definitions had no understanding of these terms (Table 43).

Students understanding of the concepts of identification of alleles and genes was probed using the question: "Look at the diagrams below. Identify genes and alleles. Write down the letters of all the genes and alleles shown in diagram 4 in the table below. Show or mark on diagram 5 all the genes and alleles after DNA replication."Where students were required to write down the letters from diagrams provided which represented genes and alleles?" (Appendix F, question 10b). There were three genes and three alleles shown in the diagram.

Only 9% gave the correct answer, and 8% of them were sure of their responses, 3% identified two genes and none was sure of their responses, 9% identified one gene, and 8% of them were sure of their responses (Table 44).

Table 44. Responses given by the first year Medical Biology students (n=151) on the question of identifying genes and alleles. [The percentage of students confident of their answers is given in brackets after the response.]

Answers	**Responses (%)**
Genes None	22 (0)
Correct	9 (8)
2 correct	3 (0)
1 correct	9 (8)
Incorrect	58 (5)
Alleles None	26 (0)
Correct	3 (0)
2 correct	3 (0)
1 correct	11 (13)
Incorrect	58 (6)

Some examples of incorrect answers given were: A, a; B, b; D, d (13%); a, b; b, A. (3%); Adbda (4%); AD; ad (7%) and BAD (8%). In the concept of identification of alleles, only 3% gave the correct answer, and none was sure of their answers. Another 3% identified two alleles (none was sure of their answers) and 11% identified one allele (13% of them were sure of their responses). Example of some of the incorrect answers given were: Ad ad (6%); Aa; Bd; Dd (9%); a, b, d (9%); abd, (4%); and A, D, a, d (6%). Results show that these students confused genes for alleles and *vice versa*. Students were also found to confuse non-allelic pairs for genes and alleles and genotypes for genes and alleles.

The concept of chromosome number or ploidy was assessed using question 11, where students were required to give the ploidy and the chromosome number of cells A to D provided (Appendix F, question 11). In diagram A, 65% of the students gave the correct answer, with 16% being confident of their responses (Table 45).

Table 45. Responses given by first year Medical Biology students (n=151) on the item on chromosomes number of diagrams A-D. [The percentage of students confident of their answers is given in brackets after the responses.]

Diagrams	**Answers**	**Responses (%)**
A	None	15 (0)
	Correct	65 (16)
	Incorrect	21 (16)
B	None	13 (0)
	Correct	45 (22)
	Incorrect	42 (11)
C	None	14 (0)
	Correct	42 (24)
	Incorrect	44 (11)
D	None	16 (0)
	Correct	56 (17)
	Incorrect	28 (17)

Examples of the incorrect answers given were: 2 chromosomes (13%); 46 chromosomes (3%); zero chromosomes (2%); and 8 chromosomes (1%). In diagram B, 13% of the students did not attempt the question, 45% of the sample got the correct answer, and 22% of them were sure of their responses. Examples of the incorrect answers given were: 8 chromosomes (34%); zero chromosome (1%) and 2 chromosomes (3%). In diagram C, 42% of the students got the correct answer, and 24% of them were sure of their responses. Examples of incorrect answers given were: 4 chromosomes (29%); 8 chromosomes (8%); and zero chromosomes (1%). In diagram D, 56% of the sample got the correct answer, and 17% of them were sure of their responses. Examples of incorrect answers given were: 8 chromosomes (9%); one chromosome (8%); 4 chromosomes (4%) and zero chromosomes (1%). Results may imply that the 13% of these students who gave chromosome numbers of diagrams A and D as 2 chromosomes, may have paired the unreplicated homologous chromosomes. In diagram D, the 1% who gave the chromosome number as zero, and 8% who gave 1 chromosome, may have held the erroneous idea that chromosomes are double structures. Also in cell B, the 34% who gave the chromosome number as 8 and 8% who gave 8 chromosomes in cell C may have counted all the chromatids to come up with the chromosome number. In diagram C, 29% who gave the chromosome number as 4, may have added up chromosomes in the two cells instead of giving the answer 2 chromosomes in each cell. In diagram D, the 4% who gave the chromosome number as 4 may have grouped or paired similar chromosomes according to size and shape. Moletsane and Sanders (1995) and Sanders *et al.* (1997) found similar results.

The concept of ploidy or chromosome number was assessed using question 11 "Where diagrams showing some steps occurring during meiosis are provided. (Appendix F question 11). Students were to show the ploidy or state whether each of the cells is haploid or diploid and the number of chromosomes in each cell (Cell A to D) (Table 46).

Table 46. Responses given by first year Medical Biology students (n=151) on the question on ploidy. [The percentage of students confident of their answers is given in brackets after the responses.]

Diagrams	Answers	Responses (%)
A	None	16 (0)
	2n (diploid) *	24 (25)
	n(haploid)	60 (13)
B	None	16 (0)
	2n (diploid) *	82 (17)
	n (haploid)	3 (0)
C	None	16 (0)
	n (haploid) *	29 (16)
	2n (diploid)	55 (18)
D	None	16 (0)
	n (haploid) *	76 (17)
	2n (diploid)	8 (0)

* Denotes the correct answers.

Results (Table 46) connote that the ploidy of cells in some diagrams was more problematic than in others. For example, in diagrams A and B, which were both diploid, the percentages of correct answers were higher in diagram B for the three samples (82%) than in diagram A (24%). The only visual difference was that A showed undivided chromosomes whilst B showed chromosomes that had divided to reveal chromatids. The same trend was shown in diagrams C and D, which were haploid. The percentages of correct answers were higher in diagram D (76%) than in diagram C (29%), where the latter showed replicated chromosomes while the former showed unreplicated chromosomes. This may imply that some students perceived ploidy as being dictated by chromosome structure (i.e. if a diagram had showed unreplicated chromosomes, it was considered to be haploid, and if it showed replicated chromosomes it was considered diploid). Results may also imply that the 55% of the students who said that diagram C was diploid, and 8% who wrote diagram D was diploid, may have considered the number of cells, since in diagram C, there were two cells and in diagram D, there were four cells.

Student conception of the concept of DNA replication in relation to meiosis was probed using the questions: "The DNA content of a cell is measured in G1 phase. What is the DNA content of the cell at metaphase I and in each of the daughter cells at metaphase II?" (Appendix F, question 12) and "The DNA content of a cell is measured in the G2 phase. What is the DNA content of each of the daughter cells immediately after telophase I and telophase II?" (Appendix F, question 13). Over half of the students (52% and 54% respectively) did not answer either question 12 or 13 (Table 47).

Table 47. Responses given by first year Medical Biology students (151) on the questions on DNA replication in relation to meiosis. [The percentage of students confident of their answers is given in the brackets after the responses.]

Questions	Answers	Responses (%)
12	None	52 (0)
	Both phases correct	6 (0)
	Metaphase I correct	7 (0)
	Metaphase II correct	1 (0)
	Incorrect	35 (8)
13	None	54 (0)
	Both phases correct	1 (50)
	Telophase I correct	4 (0)
	Telophase II correct	1 (0)
	Incorrect	40 (3)

However, in question 12, 6% of the students gave the correct answer, but none of them was sure of their responses; 4% and 1% got prophase and telophase correct respectively, and none of them were sure of their answers. Some of the incorrect answers given were: 46 chromosomes in both phases; diploid and haploid; DNA content as 1/2 of G1 and same as G1; and DNA content would be same in both phases. In question 13, 1% of the students gave correct answers for both phases, with 50% being confident of their answers. 4% got telophase I correct and 0.7% got telophase II correct, and none was sure of their answer. Examples of incorrect answers given were: diploid and haploid; 46 chromosomes in both phases; genes; DNA content of telophase I and II would be same as that of G2. Results suggest that most of the students had no conception of the concept DNA replication and meiosis process, as 52% and 54% of the students did not attempt questions 12 and 13 respectively. This is further illustrated by the fact that 35% and 40% respectively gave incorrect answers for question 12 and question 13. Students giving incorrect answers appeared to confused DNA replication with ploidy, chromosomes and genes.

Overall results on misconceptions (results not shown) indicate that the first year Medical Biology students, though highly selected, had the same misconceptions as those identified among the Grade 11 and first year Cell Biology students (Table 48).

Table 48. Concepts tested and misconceptions held by Grade 11 students (n=249), first year Cell Biology students (n=142) and first year Medical Biology students (n=151) within specific concepts.

Concepts	**Misconceptions**
Ploidy/chromosome number	Erroneously believing that ploidy is dictated by chromosome structure
Chromosome number/ ploidy	• Adding up chromatids in replicated chromosomes to come up with chromosome number • Erroneously pairing of chromosomes according to size and shape to come up with chromosome number
Identification and definition of genes and alleles	Confusion of genes for alleles and vice versa, non-allelic pairs for genes and alleles, and genotypes for genes and alleles
Identification of whole chromosomes, chromatids and homologous chromosomes	• Confusion among whole chromosomes, chromatids non-homologous and homologous chromosomes • Erroneously believing chromosomes are only single structures (unreplicated) • Erroneously believing that chromosomes exist only as double structures (replicated)
Bivalence in relation to meiosis	Confusion of bivalent number with chromosome number and chromatid number
* Symbolism and mathematical aspects of genetics	• Lack of understanding of how to form symbols, meaning of genotypes, phenotypes, hetrozygoity and homozygoity • Confusion between percentages and proportions
** Gamete formation from dihybrid and trihybrid genotypes	Lack of understanding of how to illustrate gamete formation from dihybrid and trihybrid genotypes or how to show the combination of gametes to get F2 generation
Chromosome number in relation to mitosis	• Confusion of chromosome number with chromatid number • Lack of understanding of importance of mitosis process
Chromatid number in relation to mitosis and meiosis	-Confusion of chromatid number with chromosomes number at metaphase 1 and prophase 11 • Lack of understanding of importance of mitosis and meiosis
** DNA replication in relation to mitosis and meiosis	Confusion of DNA replication with chromosomes, chromatid network, centrioles, genes, nucleus and ploidy

* and ** Denotes concepts tested only among the Grade11 and the first year Cell Biology students

*** Denotes concept tested only among the first year Medical Biology students.

Additionally they confused DNA replication with chromosome, chromatids, ploidy and genes. However, significant difference in performance was found between the first year Cell Biology students and first year Medical Biology students. The first year Medical Biology students performed better than the first year Cell Biology students ($Z=-5.7720$, two-sided $P<0.005$). Further statistical analysis of the performance of first year Medical Biology students who had attended rural and urban high schools found no insignificant difference ($z=-1.0720$, two-tailed $p = 0.2837$). Also, Medical students from rural schools appear to hold more misconceptions than those students from urban schools (Table 49).

Table 49. Percentages of first year Medical Biology students who had attended rural (n=13) and urban high school (n=110) with specific misconceptions in concepts related to Mendelian genetics.

Misconceptions	**Medical rural students (%)**	**Medical urban students (%)**
Confusion among chromosomes, chromatids, homologous and non homologous chromosomes	73	63
Lack of understanding of mitosis process	67	61
Confusion among chromosome number, chromatid number and number of bivalent	33	17
Confusing gene for alleles, alleles for genes, non allelic pairs for genes and alleles, and genotypes for genes and alleles	85	73
Confusion between chromatid number & chromosome number at metaphase I and prophase II	33	33
Ploidy as dictated by chromosome structure	64	37
Erroneously believing chromosomes as only single structures (unreplicated)	49	39
Erroneously believing chromosomes are only double structures (replicated)	39	54
Adding up chromatids to come up with chromosome number	52	31
Confusion of DNA with chromosomes, chromatids, ploidy, and genes	12	21

These results may further suggest that the availability of teaching resources in urban high schools do not seem to be a crucial factor in determining student performance in Mendelian genetics.

The problem of rote learning in genetics and the related mechanisms was noted, as in almost every concept tested, most of the students who gave the correct answers were not sure of their answers. Similar results were reported by Sanders *et al.* (1997).

The same problem was also evident among the teachers surveyed in the identification of the most difficult content areas of genetics.

Analysis of the student marks in each concept was done to determine which concepts were difficult for the students (Table 50).

Table 50. Concepts tested ranked from the most difficult to the least difficult and the percentages of first year Medical Biology students (n=151) confident of their answers is given in the bracket.

Concepts	Correct answers (%)
Identification of whole chromosomes	2 (67)
Identification of alleles	3 (0)
DNA replication in relation to meiosis	6 (0)
Definition of alleles	8 (36)
Identification of genes	9 (8)
Chromatid number in relation to mitosis	19 (8)
Ploidy diagram A	24 (25)
Identification of chromatids	27 (43)
Ploidy diagram C	29 (16)
Chromatid number in relation to meiosis	34 (9)
Definition of genes	36 (24)
Chromosome number in relation to mitosis	37 (16)
Identification of homologous chromosome	37 (25)
Chromosome number diagram C	42 (24)
Chromosome number diagram B	45 (22)
DNA replication in relation to mitosis	46 (29)
Bivalent number and meiosis	50 (17)
Chromosome number Diagram D	56 (17)
Chromosome number diagram A	65 (16)
Ploidy diagram D	76 (17)
Ploidy diagram B	82 (17)

Results indicate that the concept of identification of whole chromosomes was the most difficulty for the students followed by identification of alleles, DNA replication in relation to meiosis, definition of alleles, identification of genes, chromatid number in relation to mitosis, ploidy diagram A, identification of chromatids, ploidy diagram C, chromatid number in relation to meiosis, definition of genes, chromosome number in relation to mitosis, identification of homologous chromosomes, chromosome number diagram C, chromosome number diagram B, DNA replication in relation to mitosis, Bivalent number and meiosis, Chromosome number diagram D, chromosome number diagram A, ploidy diagram A and ploidy diagram B.

Results show that the Medical Biology students had the same misconceptions as those held by the Grade 11 and first year Cell Biology students. These results suggest that most students find the study of genetics, especially the concepts related to Mendelian genetics, difficult to understand.

Identification of Misconception After Traditional Instruction

Misconceptions held by the Medical Biology students after traditional instruction was also determined (Table 51).

Table 51. Percentage of first year Medical Biology students (n=151) with specific misconceptions prior to traditional instruction and after traditional instructions.

Misconceptions	% of students with specific misconceptions	
	Pre-test	**Post-test**
Confusion among chromosomes, chromatids, non-homologous and homologous chromosomes	65	72
Lack of understanding of mitosis process (getting chromosome number in one phase correct and the other phase incorrect)	62	57
Confusion of chromosome number with chromatid number and bivalent number	21	14
Confusion of genes for alleles and vice versa, non-allelic pairs for genes and alleles, and genotypes for genes and alleles	76	74
Confusion of chromatid number with chromosome number in metaphase I and prophase II of meiosis	33	46
Ploidy is dictated by chromosome structure (single structure (haploid) double structure (diploid)	43	38
Chromosomes are single structures	41	3
Chromosomes are double structures	51	73
Adding up number of chromatids of replicated chromosomes to come up with chromosome number	36	20
Confusion of DNA with chromosomes, ploidy, genes and chromatids	19	9

Results of misconceptions held by first year Medical Biology student after traditional instruction show that some of the misconceptions were slightly corrected by the traditional method of teaching (Table 51). Example of misconceptions corrected were: lack of understanding of mitosis process (57%); confusion of chromosome number with chromatid number and bivalent number (14%); confusion of genes and alleles and vice versa, non-allelic pairs for genes and allele, and genotypes for genes and allele (74%); ploidy is dictated by chromosome structure (38%); chromosomes are single structure (3%); adding up number of chromatids of replicated chromosomes to come up with chromosome number (20%) and confusion of DNA with chromosomes, chromatids, ploidy and genes (9%).

Student performance in pre- and post-tests was significantly different ($Z=-10.43$, $p<0.005$). However, 31 students failed the post-test and were invited to attend constructivist tutorials that used learning resources on mitosis and meiosis developed by Professor Kathleen Fisher (San Diego State University, USA). Eighteen of the 31 students elected to attend these tutorials. After completing the tutorial students answered the same questionnaire (post-post-test) as previously used.

Identification of Misconception After Constructivist Instruction

The misconceptions held by these 18 students prior to traditional instruction, after traditional instruction and after using the constructivist methods and resources were determined (Table 52).

Table 52. Percentage of first year Medical Biology students (n=18) with specific misconceptions prior to traditional instructions, after traditional instructions and after learning intervention using the constructivist learning resources and methods used in this study.

Misconceptions	Students with specific misconceptions (%)		
	Pre-test	Post-test	Post-post-test
Confusion among chromosomes, chromatids, non-homologous and homologous chromosomes	94	94	61
Lack of understanding of mitosis process (getting chromosome number correct in one phase and incorrect in the other phase	83	89	33
Confusion of chromosome number with chromatid number and bivalent number	28	44	22
Confusion of genes and alleles and vice versa, non-allelic pairs for genes and allele, and genotypes for genes and alleles	78	78	89
Confusion of chromatid number and chromosome number in metaphase I and prophase II of meiosis	83	83	50
Ploidy is dictated by chromosome structure - single structure (haploid), double structure (diploid)	83	78	17
Chromosomes are single structures	39	11	6
Chromosomes are double structures	50	89	22
Confusion of DNA replication with chromosomes, chromatids, ploidy and genes	22	17	0
Adding up number of chromatids in replicated chromosomes to come up with chromosome number	44	39	17

Use of constructivist learning resources and methods had an impact on the misconceptions held by these students after being instructed using traditional teaching methods. Most of the misconceptions held by these students were reduced and the misconception of confusing DNA replication with chromosomes, chromatids, ploidy and genes eradicated. However, some of the misconceptions were not reduced by these learning resources (e.g. confusion of genes and allele and *vice versa*, non-allelic pairs for genes and allele, and genotypes for genes and allele, confusion among chromosomes, chromatids, homologous and non-homologous chromosomes, and the misconception of erroneously thinking that chromosomes are double structures).

The use of the constructivist learning resources too, significantly improved student performance ($z=-5.13$, two-sided $p<0.0005$). The performance of the whole group improved, as none of the students attained less than 50% in the misconception questionnaire. These results suggest that constructivist learning resources and method of teaching applied in the tutorial appeared to be more effective than the lecture method used earlier to teach these students.

Evaluation of Student Opinions of the Constructivist Teaching Resources and Teaching Method

The 18 students who participated in the learning intervention on mitosis and meiosis completed a questionnaire to determine what they liked or disliked about the materials and methods used. Most of the students (94%) liked both the teaching materials and the teaching method (Table 53).

Table 53. Questions asked and percentage of response given by the Medical Biology students (n=18) on materials and methods used in the mitosis and meiosis learning intervention.

Questions	**Responses (%)**
Those who liked the materials used in the tutorial	94
Those who liked the teaching methods used in the tutorial	94
The tutorial deepened understanding of mitosis and meiosis	94
Not sure if tutorial deepened understanding of mitosis and meiosis	6
Mitosis and meiosis should be taught using the lecture method	11
Mitosis and meiosis should be taught using the tutorial method	61
Both lecture and tutorial methods should be used to teach meiosis and mitosis	28
Suggestions on other appropriate materials for modelling mitosis and meiosis	0
No other comments or suggestions	67
Other comments or suggestion	33

Of these students 22% commented that the materials made concepts like chromosomes and chromatids easy to understand, 6% found the materials confusing, and 6% did not like working in groups (Table 53). Most of the students (94%) reported that the tutorials deepened their understanding of mitosis and meiosis. Of these students 22% stated that the tutorials helped them to understand the importance of mitosis and meiosis and DNA replication; 7% said that the tutorial helped them to understand the basics of the two processes and 2% claimed that the tangible nature of the materials made it easier for them to understand the two process and the concepts related to chromosomes, chromatids, haploid and diploid. More that half of the group (61%) suggested that mitosis and meiosis should in future be taught using the method employed in the tutorial, while 11% said that the lecture method should be used and 28% of the students were of the view that both methods should be used to teach mitosis and meiosis. None of the students provided suggestions on other appropriate materials that could be used to model mitosis and meiosis. However, 33% of the students gave other comments or suggestions pertinent to the tutorials: 17% stated that the tutorial was very beneficial to most of them and that the tutorial should be made available to all students, 11% said that the tutorial was helpful and wished that such tutorials could be conducted in all units of biology and 6% commented that the tutorial was excellent, tutors were very patient and understanding and such tutorials should be run in the future.

Constructivist materials and methods of teaching and learning were also found to be effective in teaching by Hanlon (1996) who found that students from Nerthelands elementary schools, which employed constructivist methods of teaching mathematics, scored well in comparison to students from other countries in an international mathematics and science assessment. The author further asserted that that children from schools that use constructivist methods develop deeper understanding of mathematics and are able to develop enhanced and sophisticated strategies when confronted with new situations or problems. Similar results were found at the Virtual Language Laboratory (New York Bank Street Collage) where technology and construstivist learning was integrated in a course in programming using the Macintosh HyperCard environment (Strommen, 1992). Jonnassen (1994) argues that constructivist methods make teaching and learning more effective as the method provides multiple representation of reality, represents the natural complexity of the real word, focuses on knowledge construction and not reproduction; presents authentic tasks that contextualize rather than abstract instructions, providing real-world case-based learning environments rather than pre-determined instructional sequences; foster reflective practice, enable context and content dependent knowledge construction and supports collaborative construction of knowledge through social negotiation.

Other good examples of Internet-based teaching resources on genetics include the Virtual Fly Library[1], the Cell Biology Project[2] and the Virtual Genetics[3]. While the quality of resources on the Internet varies, it is important to note that very little empirical research exists that identifies factors which make educational software effective (Jolicoeur and Berger, 1988) and software that is effective in one situation may not be useful when used

[1] http://esg.www.mit.edu:8001/bio/mgdir.html
[2] http://www.oise.on.ca/~kdavidson/cons.html

[3] http://www.biology.uc.edu/vgenetic/mitosis/mitosis.html

in a different place, with different students or in a different manner (Cafarella, 1987). However, any teaching resource can be used successfully in the classroom if it is used appropriately within constructivist-like activities. For example, software that is full of logical errors can be evaluated by a group of students to determine the errors and suggest ways in which the software could be improved.

2.5.4. Conclusion

The first year Medical Biology students, though a highly selected group, were found to hold the same misconceptions with respect to Mendelian genetics as do Grade 11 and Cell Biology students. Results also showed that 18 students performed statistically better after receiving instruction using constructivist-learning methods (learning resources) than they did after traditional (lectures) instruction. These students, who attended the constructivist tutorials, also liked the materials and teaching method and commended that they deepened their understanding of the processes of mitosis and meiosis. Thus, the constructivist methods and materials appeared to be more effective in teaching mitosis and meiosis than the lecture method.

CHAPTER 3

General Conclusion and Recommendations

3.1. Introduction

The objective of this study was to identify, in association with teachers, content areas and concepts within the Matric biology syllabus, that teachers find difficult to teach and students difficult to understand. Thereafter, the project attempted to identify misconceptions related to Mendelian genetics and evaluate the use of constructivist materials to overcome such misconceptions. A secondary objective of this study was to introduce teachers and students to modern methods of education and to the use of electronic or digital resources.

The project was therefore divided into five areas: (i) categorisation of teaching theories and materials that high school biology teachers use in their teaching; (ii) Introduction of teachers to the role of computer technology in education and assessment of the state of computer based education in the schools represented; (iii) Identification of biology topics that teachers find hard to teach and students find cognitively difficult to understand; (iv) Identification of difficult content areas and the misconceptions teachers and students have in specific topics and (v) Implementation and evaluation of constructivist learning materials to overcome the identified misconceptions.

3.2. Teaching theories and materials used by high school biology teachers

Many students leave school functionally illiterate due to a number of factors, including the use of out-dated educational practices, poorly qualified teachers and lack of adequate resources (Amory, 1997). Ausubel (1968), Carey (1993), and Sylwester (1994) contend that behaviourism dominates educational thought and practices. Such a system of education emphasises that students should passively accept what they are taught without questioning, learning by memorising and repetition. Teachers are responsible for ensuring that pupils learn and thus their personalities determine how much motivation they give to their pupils. Furthermore the syllabus is rigid and non-negotiable, and subject matter is restrained by textbook content (with teachers providing the main source of information within a specified period of time). Examinations are the main methods of evaluating students and input from parents or the public are unwelcome. Such a system provides learners with isolated pieces of inert knowledge (Hannafin, 1992).

In regard to this, results of investigations done in this study on educational theories, types of motivations and materials teachers use in their teaching identified that the majority of the teachers surveyed relied heavily on behaviourist theories in their teaching and the chalkboard was the most widely used teaching resource. This dominance of teacher centred role methods of teaching may be due to the fact that teachers saw this role modelled throughout most of their own schooling experience and that much of teacher education today prepares them for this type of role, as argued by Cuban (1983). This study also showed that teachers relied heavily on extrinsic motivation that, that Wiggins (1993) argued are not synonymous with educational achievement and do not measure process-oriented problem-solving. In this regard, the progress in identifying the educational practices used nowadays and their weaknesses, is the first step which would make it possible for educators to seek for alternative educational practices that could lead to effective teaching and learning.

Results of the study on learning styles revealed that teachers surveyed had different learning styles, just as their learners do. Teachers, or designers of instructional materials, tend to assume that learners are by and large uniform. In addition, the teaching materials they design may unconsciously reflect their styles and preferences, which may not be congruent with the styles and preferences of at least some of the intended audience Rowtree (1992). Therefore, designers of all instructional materials may need to be aware of the potential impacts of learning styles in learning performance and consider how to accommodate them in instructional design.

In this study, teachers were made aware of the usefulness of computer technology as an educational tool. Results of the questionnaire on the state of computer-based education in the schools represented showed that most of the schools had no computers, and the few that had computers, the computers were not freely accessible to teachers and were mostly used for administration, games or recreation, and are rarely used for teaching and research. Teachers, particularly at the elementary level, more frequently use traditional media than the newer technologies such as computers (Seidman, 1986; Carter and Schmidt, 1985). This may be due to lack of exposure to the potentials of computer technology as a tool for learning and simply, teachers lack of confidence in, and the positive attitudes towards using advanced media technologies in their teaching. Also, majority of the teachers surveyed were computer illiterate. Institutional pressure to integrate computers into instruction is unfortunately minimal (only one of the schools represented had institutional pressure). However, a willingness to integrate computers into instruction was shown by all the teachers. Lack of enough computers to accommodate the large numbers of learners, computer illiteracy of both teachers and learners, safety of the computers in the school and lack of finance for maintaining the computers were some of the problems teachers would contend if they had computers in their classroom. These results are in agreement with findings of Waggoner and Goldberg (1986), Gallo and Horton (1994) and U.S Congress Office of Technology Assessment (1995). In conclusion, these results suggest that willingness to integrate computers into instruction exist among all the teachers surveyed. However, in order to achieve this, teachers retraining, purchase and maintaining and safety of the computers in the schools should be guaranteed.

3.3. Identification of biology topics that teachers find hard to teach and students find cognitively difficult to understand

In this study, an attempt to identify the most difficult topic in high school biology syllabus for teachers to teach and students to understand, showed that genetics is the most difficult topic in the high school biology syllabus. Within genetics, Mendelian genetics is the most difficult topic. These results were similar to those from studies done by Johnstone and Mohmoud (1980), Stewart (1982), Finley *et al.* (1982), Dunn (1986) and Thomas (1988). The progress in identifying the most difficult topic in the high school biology syllabus is the first step in trying to search for the causes of the difficulty and ways of improving the way the topic is taught, in order to enhance understanding. According to Longden (1982) teacher factors such as confidence and competence with genetics, perceived relevance of genetics within the curriculum, coherence and association of the concepts principle in genetics with other parts of the biology course, and student factors such as level of attainment in areas recognised as pre-requisite knowledge to genetics, cognitive styles, ability to integrate new knowledge to existing scheme, student attitudes to learning in general and to genetics in particular, will play some part in how well students have learned genetics. The abstract nature of genetics concepts also makes it difficult to understand.

3.4. Identification of difficult content areas and misconceptions held by teachers and students in concepts related to Mendelian genetics

Research on conception, misconceptions and conceptual change has shown that students bring to instruction, views and explanations of natural phenomena that often differ from the consensus views of scientists (Driver, 1981; Osborne, 1982). Ausubel (1968) asserts that the most important single factor influencing learning is what the learner already knows, and meaningful learning occurs if only the new concept to be learned is consciously related by the learner to relevant concepts which the learner already knows. If this linkage is not successful, rote learning will occur, rather than meaningful learning where concepts are understood. Research indicates that these preconceptions, or alternative frameworks, are not easily extinguished or corrected (Gunstone, Champagne and Klopfer, 1981) as they have been developed through interpretation of personal experiences. Identifying these errors is a vital pre-requisite if the teacher is to provide appropriate feedback to the learner to help them rectify erroneous ideas. However, what is more imperative is that unless erroneous ideas about basic concepts are eradicated, students will have problems understanding new knowledge which depends on the understanding of those more fundamental concepts. Thus, in this part of the study, teacher and student misconceptions and difficult content areas related to Mendelian genetics were elicited. Teachers were found to have various misconceptions on specific concepts, as shown in Table 16. The most difficult content area for the teachers was the concept of DNA replication in relation to meiosis, followed by dihybrid cross, DNA replication in relation to mitosis, symbolism and mathematical aspects of genetics, chromatid number in relation to mitosis, bivalent number in relation to meiosis and chromosome number in relation to mitosis (Table 15).

This study revealed that the majority of the teachers surveyed had problems in understanding the fundamental structures and concepts of mitosis, meiosis and Mendelian genetics, which are essential if genetics is to be fully comprehended and this knowledge applied. The reasons for these difficulties and misconceptions among teachers can partly be attributed to traditional teaching methods used to teach them, which are seldom effective in promoting understanding (Moletsane and Sanders, 1995). Also, majority of the teachers may lack the time to update their knowledge in their field.

In the case of the students, various misconceptions were identified among the Grade 11, first year Cell Biology and the first year Medical Biology students, as shown in Table 48.

For the Grade 11 and first year Cell Biology students, the most difficult content area was the concept of DNA replication in relation to meiosis followed by identification of alleles, identification of whole chromosomes and DNA replication in relation to mitosis (see Table 34). For the first year Medical Biology students the concept of identification of whole chromosomes was the most difficulty concept for the students followed by identification of alleles, DNA replication in relation to meiosis, definition of alleles and identification of genes (see Table 50).

Overall results on student misconceptions revealed that the misconceptions rife among the Grade 11 students who had not taken instructions in mitosis, meiosis and Mendelian genetics are found to persist the First year Cell Biology students and the first year Medical Biology students who are presumed to have learned genetics and cell division at school. These results are in agreement with findings of Champagne *et al.* (1983) and Brown (1992). While the identification of misconceptions is an important part in process of understanding of why students fail to understand Mendelian genetics, the causes of such misconceptions need also to be identified so that appropriate solutions can be developed. It can be contended that misconceptions identified in this study exist partly because of the lack of understanding of the topic by the teachers, the abstract nature of the genetic concepts (Lazarowitz and Penso, 1992), the impact of strong association with previously acquired and in itself correct scientific knowledge which brings about wrong association of concepts (Gilbert *et al.*, 1982) and could also be associated with the sexist attitudes of the society. Also, the careless use of 'easy words' (which are often analogies) by teachers tend to oversimplify the genetic learning situation and lead students to perpetuate myths about genetics (Jungwith, 1975; Cho *et al.*, 1985; Smith and Simmons, 1992). Additionally, the teaching of meiosis separately from genetics may result in a situation in which students can recite the stages of meiosis and draw elaborate diagrams, yet be unaware of the genetic significance of the process (Radford and Bird-Stewart, 1982; Tolman, 1982; Mitchell, 1992; Sanders *et al.*, 1997). Cho *et al.* (1985) argued that since meiosis concerned the tracing of alleles (also called traits) from parents to offspring's and with separation of alleles during sexual reproduction, the two concepts should be related in text (meiosis and genetics). Furthermore, teaching methods applied by teachers (instructivist) could result to these misconceptions. In conclusion, the identification of teacher and student misconceptions and difficult content areas is an essential prerequisite for development of teaching and learning materials that can enhance the understanding of concepts related to Mendelian genetics.

3.5. Implementation and evaluation of constructivist learning materials to overcome the identified misconceptions

Results on educational practices (see 2.1.) indicated that behaviourist (instructivist) methods of teaching and learning dominate educational thought. This method of teaching and learning, does not engage students in the learning process and often fails in developing creative or problem solving skills, and learners who are significantly illiterate (Amory, 1997). Therefore, investigation done in this study on the misconceptions held by 18 first year Medical Biology students after instructions using the traditional method of instruction (instructivist) showed that this method of teaching had minimal effects on the misconceptions held by these students prior to instruction. All these students failed to attain 50% on the misconception questionnaire after instruction using the traditional method. Although there is no research which specifically proves that certain teaching methods will eradicate these misconceptions in genetics and related mechanisms, learning theorists do have ideas about how understanding of science concepts can be improved (Moletsane and Sanders, 1995). They assert that understanding would be improved if: students are made aware of common errors made by scholars of genetics and errors students make, learners are taught about the constructivist theory of learning and how the use of hand-on-mind-on task can promote understanding and teachers to provide such hands-on-mind-on activities, making sure that where possible they use physical models to concretise microscopic structures.

Thus, this part of the study embarked on implementing and evaluating the effectiveness of web-based constructivist materials on mitosis and meiosis, developed by Professor Kathleen Fisher (San Diego State University, U.S.A) on teaching and learning. After the 18 students underwent learning intervention using the constructivist materials and methods significant difference in performance between post-test (taken after traditional instructions) and post-post-test (taken after learning intervention, using the constructivist material and methods) was registered. None of the students attained less than 50% and some of the misconceptions held by these students were eradicated while others were reduced. Ninety four percent of these students liked the materials and methods used in the learning intervention and commented that this materials and methods deepened their understanding of the process of mitosis and meiosis.

Thus, this study shows that use of constructivist materials and methods can eradicate or reduce misconceptions and improve the understanding of concepts related to Mendelian genetics.

The application of constructivist materials and method of teaching Mendelian genetics and other topics, however, also raises certain concerns (see 1.3.1). For example, critics argue that if learning occurs by construction, it is costly in time and when the search is lengthy or unsuccessful, motivation flags. Critics argue that in other cases students remember as well or even better information provided to them than that which they create (Slamecka and Katsaiti, 1987). However, despite these criticisms, constructivist materials and methods of teaching pose risks no different from instructivist materials and methods. Instead, constructivist materials and methods should be viewed as a solution to the potentially detrimental side-effects of the existing instructional practices (see 1.3.1). Whichever strategy of teaching is used, it is therefore imperative that materials are evaluated with students, prior to release for use in the classroom environment.

3.6. Recommendations

Since students will always come into classroom with prior knowledge, misconceptions will inevitably endure. It is therefore important to explore strategies that could overcome, even if this is only partially, misconceptions and thereby help students to integrate what they already know with what they learn in the classroom.

Students need to become more aware of common errors made by scholars of genetics and errors they make themselves. They need to be taught about the constructivist theory of learning and how the use of hands-on-mind-on tasks can promote understanding and teachers to provide hands-on-mind-on activities, making sure that where possible they use physical models to concretise microscopic structures (Moletsane and Sanders, 1995).

Teaching and learning materials should focus upon situations and organisms which are familiar to most of the students outside the classroom, as this may facilitate comprehension and learning (Kinnear, 1983; Smith and Simmons, 1992). This recommendation finds support in Jansen (1990) when the author suggested that "African educational authorities should revise and reform the content of education in the area of curricula, textbooks and methods, so as to take account of the African environment, child development, cultural heritage and the demands of technological progress and economic development."

The aforementioned results may be used for further research focusing on development of teaching materials that will enhance the understanding of Mendelian genetics, mitosis, meiosis and concepts related to genetics.

3.7. Final conclusion

The objectives of this study was to identify, in association with teachers, content areas within the Matric biology syllabus concepts that teachers find difficult to teach and students difficult to understand. Thereafter, the projected attempts to identify misconceptions related to this topic and evaluate the use of constructivist materials to overcome such misconceptions. A secondary objective of this study was to introduce teachers and students to modern methods of education and to the use of electronic or digital resources.

It has been demonstrated that majority of the teachers surveyed relied heavily on behaviourist theories in their teaching and chalkboard was the most widely used teaching resource. Teachers also relied heavily on extrinsic motivation and had different learning styles, just as their learners do. Most of the schools represented by the teachers surveyed had no computers, and the few that had computers, the computers were not freely accessible to teachers and were mostly used for administration, games or recreation, and are rarely used for teaching and research. Majority of the teachers surveyed were computer illiterate. Institutional pressure to integrate computers into instruction is unfortunately minimal (only in one of the schools represented). However, a willingness to integrate computers into instruction was shown by all the teachers.

The study also suggests that genetics is the most difficult topic in the high school biology syllabus, and within it Mendelian genetics is the most difficulty topic. Other difficult topics revealed were protein structure and photosynthesis.

Investigations done in this study also revealed that majority of the teachers surveyed had problems in understanding the fundamental structures and concepts of mitosis, meiosis and Mendelian genetics, which are essential if genetics is to be fully comprehended and this knowledge applied.

The research undertaken in this project has also provided: information on the misconceptions held by Grade 11 students on mitosis, meiosis and genetics, that are found also to persist in the first year Cell Biology and first year Medical Biology undergraduates of University of Natal, Durban. Results on evaluation of the constructivist materials revealed that the constructivist materials appeared more effective in teaching mitosis and meiosis than the lecture method.

The effectiveness of the constructivist materials and methods used to teach mitosis and meiosis further suggests that the hypothesis that the integration of computers into South African science curriculum can provide an invaluable educational resource that can help initiate a change from a didactic to a constructivist philosophy, without threatening or intimidating educational practitioners.

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APPENDIX A

Exercises on Theories, Motivation and Learning Styles

Behaviourist theories

Behaviourist theories hold that the function of the mind is to reflect external reality. In a sense then, reality or knowledge is thought to exist independently of the learner. To them, human mind is an "empty vessel." They hold that learning is a change in the behaviour of an organism and behaviour is influenced by the environment. In simpler terms, learning consists of transferring knowledge from outside to within the learner and the presence of some form of motivation is vital to aid in learning. Examples of these theories are: Classical conditioning by Ivan Pavlov, 1849-1946; Operant conditioning by B.F Skinner, 1938-1953 and Connectionism theory by L. Thorndike, 1874-1949.

Cognitive theories

Cognitive theories are a revolution or a complete change to behaviourism in that they acknowledge the mind and its functions in learning. Their view of learning emphasises insights, thinking, meaningfulness, motivation and organisation of information as being essential for learning to occur. They maintain that a learner is capable of controlling his learning activity and organising his field of operation and has an inherent capacity to learn. But they too appear to assume that knowledge is 'out there' to be transferred to the learner. Examples of these theories are: Discovery learning by Jerome Bruner, 1966; Reception learning by David Ausubel, 1978 and Conditions of learning by Gagner, 1985.

Constructivist theories

Constructivist theories of teaching and learning grew from cognitive theories but differ from them in that they are more concerned with how people construct knowledge. They hold that each learner constructs their own knowledge, based upon the current or new Experiences/past or existing knowledge, and on a unique set of experiences with the world and meanings given to these experiences. Knowledge is constructed by people, it does not have an objective existence outside the human mind waiting to be delivered to and imprinted upon us. They emphasise context learning, where knowledge that is easily applied in relevant situations should be developed. They also emphasis the influence of cultural and social context in learning. That is learners should test their own understanding against those of others. Problem- solving, reasoning, critical thinking and active use of knowledge constitutes the goals of constructivist theories. Examples of these theories are: Discovery learning by Jerome Bruner, 1977; Jean Piaget's stages of cognitive development, 1964; Multiple intelligence theory by Howard Gardener; Cognitive flexibility theory by R. Spiro, P. Feltovich and R. Coulson, and Cognitive apprenticeship theory by Brown, Collins and Duguid.

Activity

Think of the teacher's role, learner's role and examples of motivations/ reinforcements used in behaviourist, cognitive and constructivist theories of teaching and learning.

Write them down in the table provided.

	Behaviourist	Cognitive	Constructivist
Teachers role			
Learners role			
How are students motivated?			

COGNITIVE LEARNING STYLES

Definition

According to Gregorc (1979) cognitive learning styles consist of distinctive behaviours which serve as indicators of how a person learns from, and adapts to, his/ her environment. It gives a clue as to how a person's mind operates. Messick (1970) defines cognitive learning styles as the preferred way an individual process information and describes a person's typical mode of thinking, perceiving, problem- solving and remembering.

James and Blank (1993) defines learning styles as the complex manner in which and under which learners most efficiently and effectively perceive, process, store and recall what they are attempting to learn. Regardless of the definitions given, learning styles are believed to characterise the way a person prefers to learn and studies show that learning styles greatly affect classroom achievements

Activity

When attending teachers' conferences or lectures, in you discipline, how effective and or enjoyable do you find the following activities in terms of learning and developing new ideas? Rank the activities shown below in the order 1-6 considering which best describes how you prefer to learn.

Ranking	Activity
	Attending lectures and examining in great details what the speaker is saying; Reading the lectures summary very carefully; Noting participants names and where they are from.
	Linking ideas learned in one session to another; Asking challenging questions about the content learned; Analysing the impact of new theories on what has gone before; Discovering an overall theme to the conference which may suggest a fine new trend in your field.
	Imagining what your lectures might be like and making it happen; Imagining what is involved in carrying out research; Seeing the visuals (posters, overheads and slides that you would use in your lecture.)
	Buying a summary of the lectures on cassette and listening to these; Thinking about ideas you heard and remembering these in the speaker's own voice; Being aware of the speed and the way the lecturer spoke.
	Learning by trying out new experimental equipment's; Hands-on experimentation
	Learning through social interaction; meetings with colleagues; discussing ideas.

Your ranking of the activities above will help us determine how you learn or your learning style according to Howard seven styles of learning.

Activities in the seven rows represented different learning styles. The different learning styles from the first row to the seventh are; Linguistic; Logical/ mathematical; spartial; musical; kinaesthetic; interpersonal and intrapersonal. The activity ranked 1 by the delegates represented their primary learning style. The delegates after establishing their primary learning style, they where supposed to read the table below very carefully in order to enable them to know what kind of learners they are. This information was provided after the delegates had ranked the activities to make sure that they were sincere in their rankings and not influenced by the characteristics of learners given in the table.

Howard Gardener's seven styles of learning (Multiple Intelligences [Gardner, 1993])

Type of learner	likes to...	is good at...	Learns best by....
Spatial "The visualizer"	Draw, build, design Creating things Look at pictures/ slides; Daydream Watch movies play with machines	Imagining things Sensing changes Doing mazes/puzzles Reading maps/ charts	Visualising Dreaming Using the mind's eye Working with colours diagrams, and pictures
Linguistic The word play	Read Write Tell stories	Memorising names, places, dates and trivia	Saying, hearing and seeing words
Logical/ mathematical "The questioner"	Do experiments Figure things out Work with numbers Ask questions Explore patterns and relationships	Math Reasoning Logic Problem-solving	Categorising Classifying Working with abstract patterns/relationships
Bodily/ Kinaesthetic "The mover	Move around Touch and talk Use body language	Physical activities (sport, dance, acting) Crafts	Touching, moving. Interacting with space Processing knowledge through bodily sensations
Interpersonal "The socializer"	Have lots of friends Talk to people Join groups	Understand people Leading others Organising Communicating Manipulating Mediating conflicts	Sharing Relating Co-operating Interviewing Comparing
Intrapersonal "The socializer"	Work alone Pursue own interests	Understanding self Focusing inwardly on feelings/dreams Following instincts goals. being original	Working alone Individualised Projects Self-paced instruction Having own pace
Musical "The music lover"	Sing, hum tunes Listen to music Play an instrument Respond to music	Picking up sounds Remembering melodies Noticing pitches/ rhythms Keeping time	Rhythm Melody Music

Count the ticks in each section outlined below and write them in table provided.

Section	Total number of ticks
1-12	
13-24	
25-36	
37-48	

Learning style as represented by sessions. This information was provided to the delegates after the exercise.

1-12= Concrete sequential

13-24 = Abstract sequential

25-36 =Concrete random

37-48 = Abstract random

The sessions were they had more ticks showed them their dominant learning styles.

Learning styles according to Gregorc style delineator test

The table below shows four learning styles and learners characteristics in each style. Delegates were supposed to read their dominant learning characteristics after knowing their dominant learning styles

concrete sequential	Abstract Sequential	Concrete Random	Abstract Random
Orderly	Evaluative	Investigative	Sensitive
Perfectionist	Argumentative	Creative	Caring
Reliable	A thinker	Change-oriented	Emotional
Practical	Rational	Inquisitive	Sociable
Organised	Resistant to change	Daring	Flexible
Thorough	Logical	Problem- solver	Colourful
Direct	Analytical	Experimenter	Empathetic
Precise	Intelligent	Inventive	Interpretative
Industrious	Academic	Curious	Understanding
Task- oriented	Structured in thought	Challenger	Subjective

The following literature was provided to the delegates to help them understand some of the terms used above.

Gregorg style delineator

It is a self-scoring battery designed to assess learning styles. Its based on mediation ability theory which states that the human mind has channels through which it reveals and expresses information most effectively and efficiently. The term mediation abilities describe a person's capacity to use these channels. The style delineator focuses on two types of mediation abilities in individuals. Perception (the means in which one is able to grasp information) and ordering (the means in which one arranges, systemize and disposes of information). The two dimensions of ordering are referred to as sequential and random; and the two dimensions of perception are abstractness and concreteness.

Abstractness allows the individual to comprehend that, which is not visible to the senses. Data can be mentally visualised, grasped and conceived through the faculty of reasoning.

Individuals who are strong in concreteness use the physical senses to comprehend and mentally register data. Sequential individuals perceive and organise data in a linear, methodical fashion and can express themselves in a precise manner. Randomness disposes the mind to organise information in a non-linear and multidimensional fashion. This quality enables individuals to deal with and process multiple data simultaneously.

Gregorc combines these abilities to create four mediation channels of mind styles. Concrete sequential (CS), concrete random (CR), abstract sequential (AS) and abstract random (AR). He believes that individuals have to certain degree characteristics of each category, but most individuals tend to show a stronger orientation towards specific channels.

Learner characteristics

People who are dominant concrete sequential are usually practical, thorough, well organised and prefer quiet stable and structured environments. They tend to perceive reality as the concrete world of the physical sense and think in a sequential and orderly fashion. They can detect the minutest details and can work with the exactitude of a machine. A concrete sequential student is a perfectionist and prefers being told what to do. These learners do not like to go against the norm, view work as a job assignment and enjoy being physically involved and active in lessons.

Abstract sequential people consider themselves as evaluative, analytical and logical individuals with a preference for mentally stimulating, orderly and quiet environments.

They have an academic-type mind, which is driven by thirst for knowledge. To them, knowledge is power and the ability to synthesis and relate concepts enables them to transmit ideas (both through the spoken and written word) intelligibly and eloquently. Abstract sequential learners thrive on teachers who are experts in their area of interest, learning well through lecture- style teaching.

Abstract random individuals are highly focused on the world of feeling and emotion and are sensitive, spontaneous, attuned and person- oriented people. Their thought processing tends to be non-linear multidimensional, emotional, perceptive and critical. They prefer active, free and colourful environments. Abstract random people thrive on building relationships with others and as learners, dislike extremely structured assignments.

Concrete random individuals process information in three-dimensional patterns and think intuitively, instinctively, impulsively and independently. They prefer competitive, unrestricted and stimulus- rich environments. They can be risk takers and can easily jump to conclusions. Such individuals are divergent thinkers, thriving in environments, which engender exploration. The concrete random learner does not need many details to solve a problem, instead operate according to personally constructed standards.

According to Gregorc, sequential learners (CS and AS) tend to prefer computer based education because they are able to learn from the computer relatively independent. This is because they do well in self-study. On the other hand random learners (CR and AR) require environments which are flexible and provide opportunities for multidimensional thinking. They may find computer technology adversative. Furthermore, AR learners are inherently social and enjoy learning with others. It is apparent that traditional computer based education does not always provide such an environment for these learners. In an attempt to ensure that all learners can benefit from computer technology, educators should know that random learners may need support and guidance. Hence teachers should not assume every student will automatically benefit from computers in the classroom. There remains the need to interpersonal contact and guidance to ensure that all students attain their learning potentials.

The theme of the above activities was to show the delegates that people have different understanding potentials or intelligence's and different learning styles. All people posses some features of the learning styles mentioned above, yet they all to a degree have a natural 'dominant' style, which accounts, in part, for individual differences among themselves. Understanding their learning styles can help them to improve their learning and can help them interact with others who learn differently from them. Thus teachers should provide a variety of activities that could be planned to accommodate the needs/ interests of diverse learners.

APPENDIX B

Questionnaire Used to Evaluate Teachers Computer Awareness and the State of Computer-Based Education in the Schools Represented

This questionnaire is part of a survey to assess teachers' awareness of the benefits of computer technology in education. Your responses are highly appreciated.

Your name
Name of school

In each of the questions that follow, fill the blank spaces or mark your answers with an x where appropriate.

Are you able to use a computer?

Yes	No

If YES, what programmes can you use?

____

____

____

____

Are there computers in your school?

Yes	No

If Yes, how accessible are they to teachers

Not accessible	Rarely accessible	Frequently accessible	Freely accessible

Are the school computer used for:			
	a. Teaching	Yes	No
	b. Research	Yes	No
	c. Administration	Yes	No
	d. Games/recreation	Yes	No

Is there institutional pressure to use computers in teaching? | Yes | No |

Have you attended any course on computer technology? | Yes | No |

If YES, list the course you have attended.

____

____

Which of the skills that you learned on this course have you passed onto you students?

____

____

____

____

Would you like to use computer software in you classroom? | Yes | No |

What difficulties do you think you will experience if you had computer in your classroom?

____

____

____

____

How did you find the workshop?

Bad	
Fair	
Good	
Excellent	

Would you like to attend more of this workshop?

Yes	No

Please suggest ways of making the next workshop better

____

____

____

____

Thank you for taking the time to participate in this survey.

APPENDIX C

Questionnaire Used by Teachers in Identifying the Most Difficult Biology Topic

The Biology Department of the University of Natal has initiated a project to find out which biological topics students find difficult to understand and teachers /lecturers find difficult to teach. Such information will give us an idea of where to develop teaching materials that may be helpful to both students and teachers/lectures.

This questionnaire is designed to find out which biological topics you find difficult to understand.

Answer the following question. In the space provided on this question paper. Work as quickly as you can. Leave the answer block empty if you do not know how to answer a question.

Please supply the following information:

Date of birth			19
	DD	MM	YY

Institution:	

Gender	Male	Female

Race:

Home Language:

Year of study:

Questions

Section A

In this section we want to find out which sections of the work you find easy or difficult to understand.

Please rank each topic as very easy, easy, difficult or very difficult to understand. Make a cross on your choice if you have studied the subject

Topic	**Rating**			
Genetics	very difficult	difficult	easy	very easy
Biological compounds	very difficult	difficult	easy	very easy
Plant physiology	very difficult	difficult	easy	very easy
Human anatomy	very difficult	difficult	easy	very easy
Population dynamics	very difficult	difficult	easy	very easy
Enzymes	very difficult	difficult	easy	very easy
Animal physiology	very difficult	difficult	easy	very easy
Ecosystem	very difficult	difficult	easy	very easy
Homeostasis	very difficult	difficult	easy	very easy
The cell	very difficult	difficult	easy	very easy
Viruses and bacteria	very difficult	difficult	easy	very easy
Plant types	very difficult	difficult	easy	very easy
Reproduction	very difficult	difficult	easy	very easy
Animal tissues	very difficult	difficult	easy	very easy
Human physiology	very difficult	difficult	easy	very easy
Molecular genetics	very difficult	difficult	easy	very easy
Invertebrates	very difficult	difficult	easy	very easy
Respiration	very difficult	difficult	easy	very easy
Plant tissues	very difficult	difficult	easy	very easy
Vertebrates	very difficult	difficult	easy	very easy

Section B

In this section we wish to find out those concepts within specific topics you find easy or difficult to understand.

Each question consists of four related topics that you must rank from the most difficult to the easiest. Write :

- **most difficult** under the topic you find the most difficult,
- **difficult** under the topic you find difficult,
- **easy** under the easiest topic you find easy, and
- **Easiest** under the topic you find the easiest.

Two or more topics should not be labelled most difficult, difficult, easy or easiest.

Mitosis	Nucleus Structure	Meiosis	Mendelian Genetics

Carbohydrates	Proteins	Lipids	Vitamins

Water Relations	Photosynthesis	Transpiration	Growth & Development

Population Growth	Carrying Capacity	Energy Flow in the Ecosystem	Competition

Enzyme Structure	Enzyme Functions	Proteins Structure	Co-factors

Animal Nutrition	Gaseous Exchange	Excretion	Homeostasis

Protein Synthesis	DNA replication	RNA structure	DNA structure

Section C

We need to identify the topics you find the most difficult.

Question 1.

In the space below write down all the topics you labelled as most difficult from the questions in section B.

Write down the two most difficult topics from this list.

Question 2.

List the two most difficult topics you have experienced while studying biology. (Note: these need not have been mentioned previously in the questionnaire.)

Are their any comments you wish to make?

Thank you for you co-operation.

APPENDIX D

Questionnaire Used by Teachers in Identifying the Difficult Content Areas Related to Mendelian Genetics

This is a survey of high school biology teachers to determine what contents of genetics they find difficult to teach. In order for us to develop appropriate teaching and learning materials.

The questionnaire contains 13 open -ended questions on genetics. Answer all the questions and indicate how confident you are about your answer. Three choices are provided: **sure** (if you are absolutely sure your answer is correct); **think so** (if you think that your answer is correct but you are not absolutely sure) and **guessing** (if you have no idea what the correct answer is and you've merely guessed).

Write your name and name of your school.

NAME:	
NAME OF SCHOOL:	

1. A cell with 52 chromosomes undergoes mitosis. How many chromosomes are present at Prophase and in each of the daughter cells at Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

2. A cell with 52 chromosomes undergoes mitosis. How many chromatids are present at Prophase and in each of the daughter cells at Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

3. The DNA content of a cell is measured in the G1 phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

4. The DNA content of a cell is measured in the G2 phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

5. A cell with 20 pairs of chromosomes undergoes mitosis. How many chromosomes are present at Prophase and in each of the daughter cells at Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

6. The DNA content of a cell is measured in the G1 phase. What is the DNA content of that cell at Metaphase 1 and each of the daughter cells at Metaphase 11?

How sure are you of your answer?

Sure	I think so	Guessing

7. The DNA content of a cell is measured in the G2 phase. What is the DNA content of each of the daughter cells immediately after Telophase 1 and Telophase 11?

How sure are you of your answer?

Sure	I think so	Guessing

8. In an organism with 52 chromosomes, how many bivalents would be expected to form during meiosis 1?

9. If the diploid number of a cell is 20, how many chromatids are present in that cell at Metaphase 1 of meiosis?

How sure are you of your answer?

Sure	I think so	Guessing

10. If a cell has 5 pairs of chromosomes, how many chromatids are present in the daughter cells at Prophase 11 of meiosis?

How sure are you of your answer?

Sure	I think so	Guessing

11. The alleles of a gene are represented by a capital letter if they are dominant, and by a lower case letter if they are recessive. For each of the following cases, work out the gametes produced by each genotype:

AaBb

AaBbCc

AABb

AaBBCc

AABBCc

How sure are you of your answer?

Sure	I think so	Guessing

12. Copy and complete the schemes given to answer each part of the question. In the fruit fly, white eye colour is recessive to red eye colour.

a. Show clearly the phenotype and the genotype of a white -eyed fly and a heterozygous red- eyed fly (use the symbol R to represent the gene giving red-eye colour).

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

b. If a homozygous red and a homozygous white are bred together, what colours appear in the offspring's and in what proportions?

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

c. If the F1 flies are inbred what percentages of offspring's are white-eyed?

What proportion of red-eyed flies are heterozygous (i.e. carriers of white allele)?

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

13. In the mouse, C- animals are pigmented, cc individuals are albinos. Another pair of genes determines the difference between black (B-) and brown (bb). What F2 will be produced as a result of the cross CCBB X ccbb?

How sure are you of your answer?

Sure	I think so	Guessing

Thank you for participating in this survey.

APPENDIX E

Questionnaire Used by Grade 11 Students and the First Year Cell Biology Students

We are currently trying to find out what parts of your biology course you find difficult to understand. This information will help us design better learning materials. This questionnaire has been designed to find out your general knowledge about genetics. This is not a test. It does not matter if you get the answer correct or wrong.

The questionnaire contains 13 open -ended questions on genetics. Answer all the questions. Some questions need you to say how sure, or confident you are about your answer. Here, three choices are provided: **sure** (if you are absolutely sure your answer is correct); **think so** (if you think that your answer is correct but you are not absolutely sure) and **guessing** (if you have no idea what the correct answer is and merely guessed).

Write your age, race and name of your school.

AGE:	
RACE:	
NAME OF SCHOOL:	

1. If a tall man and a short woman have a child and this child is a boy, how tall will he be when he is fully-grown?

____

____

____

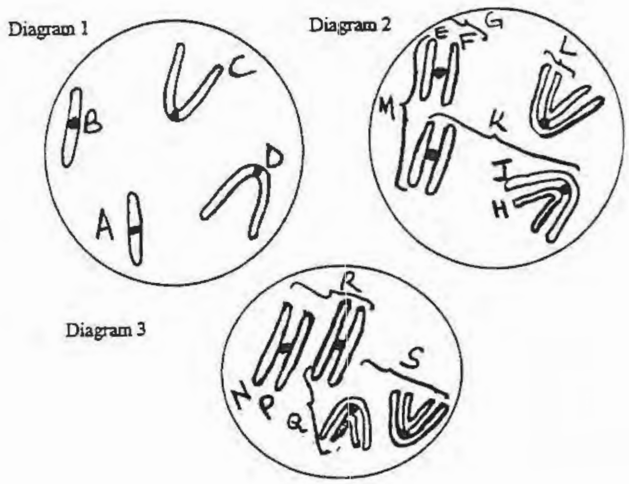
____

Give reasons for your answer.

2. While crossing the road, two female dogs and one male dog were unfortunately hit by a car. The leg of one of the female dogs was broken by the car. As a result, the dog limps after it became well. Will the puppies of this dog be born with a lame leg?

Give reasons for your answer.

3. The following diagrams show a cell in various stages of a meiotic division. The three diagrams show various chromosomes, chromatids and homologous chromosomes labelled with letters from A to S. Write down in the space provided which letters represent chromosomes, chromatids and homologous chromosomes.



	Letters representing
Chromosomes	
Chromatids	
Homologous chromosomes	

How sure are you of our answers?			
Chromosomes	Sure	I think so	Guessing
Chromatids	Sure	I think so	Guessing
Homologous chromosome	Sure	I think so	Guessing

4. A cell with 6 chromosomes undergoes mitosis. How many chromosomes are present at Prophase and in each of the daughter cells at Telophase?

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

5. A cell with 4 chromosomes undergoes mitosis. How many chromatids are present at Prophase and in each of the daughter cells in Telophase?

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

6. A cell with 3 pairs of chromosomes undergoes mitosis. How many chromosomes are present at Prophase and in each of the daughter cells at Telophase?

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

7. In an organism with 4 chromosomes, how many bivalent or homologous pairs would be expected to form during meiosis 1?

How sure are you of your answer?

Sure	I think so	Guessing

8. If a diploid number of a cell is 6, how many chromatids are present in the cell at Metaphase 1 of meiosis?

How sure are you of your answer?

Sure	I think so	Guessing

9. If a cell has 3 pairs of chromosomes, how many chromatids are present in the daughter cells at Prophase 11 of meiosis?

How sure are you of your answer?

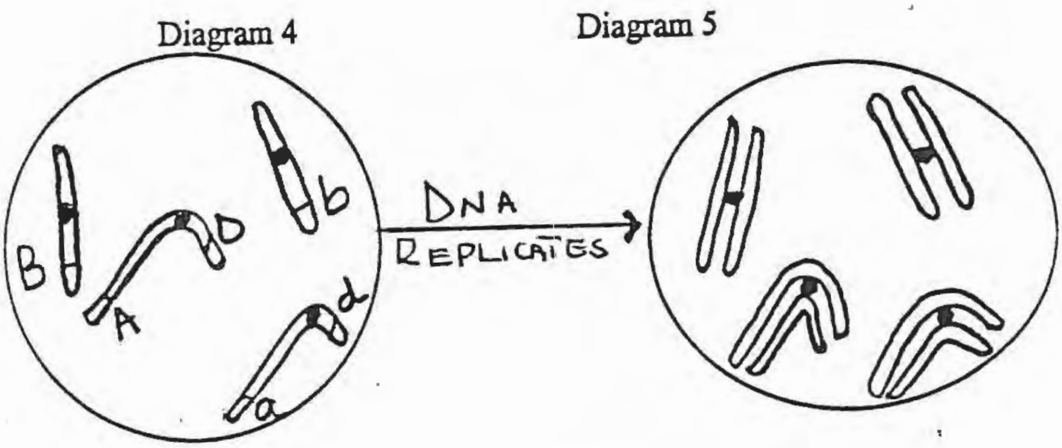
Sure	I think so	Guessing

10. a. Define the term genes and alleles.

How sure are you of your answer

Sure	I think so	Guessing

b. look at the diagrams below. Identify genes and alleles. Write down the letters of all the genes and alleles shown in Diagram 4 in the table below. Show or mark on Diagram 5 all the genes and alleles after DNA replication.



	Letters
Genes	
Alleles	

How sure are you of your answer?

Sure	I think so	Guessing

11. The alleles of a gene are represented by a capital letter (A) if dominant and by a lower case letter (a) if recessive. For each of the following cases, work out the gametes produced by each genotype.

AaBb

AaBbCc

AABb

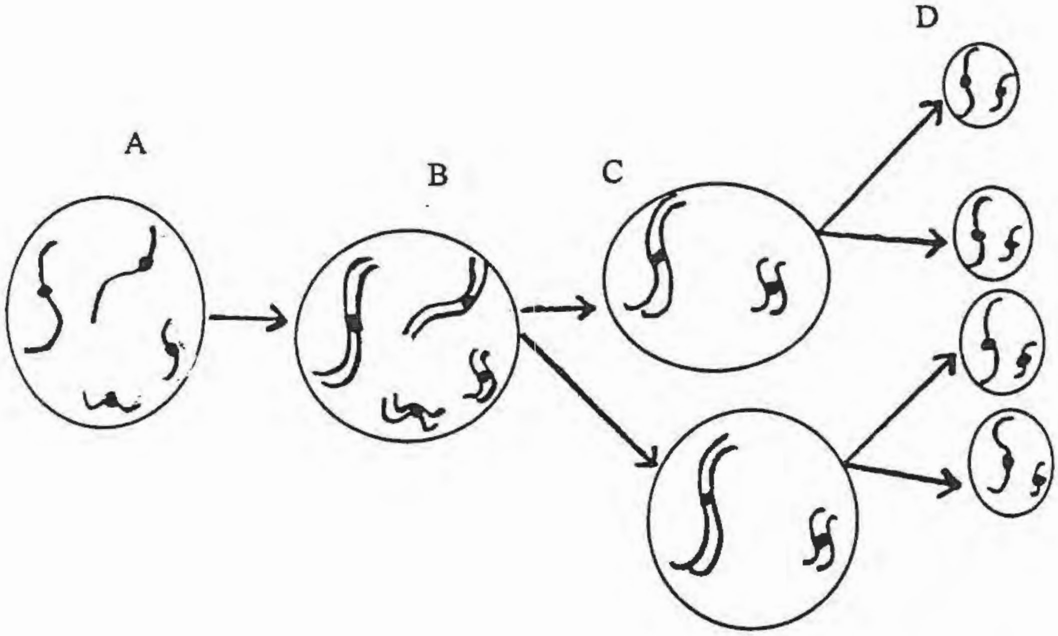
AaBBCc

AABBCc

How sure are you of your answer?

Sure	I think so	Guessing

12. The diagrams below show some of the steps occurring during meiosis. Show the ploidy or state whether each of the following cells is haploid or diploid and the number of chromosomes in each cell. (Cell A to D)



Cells	Haploid	Diploid	Number of chromosomes
A			
B			
C			
D			

How sure are you of your answer?

Sure	I think so	Guessing

13. In the fruitfly, white eye color is recessive to red eye color.

a. Write down the phenotype and the genotype of a white eyed fly and a heterozygous red-eyed fly (use the symbol R to represent the gene giving Red-eye color).

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

b. If a homozygous red fruitfly and a homozygous white are crossed together, what colors appear in the F1 generation and in what proportions?

____

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

c. If the F1 flies are crossed,

(i) What percentages of offspring's will be white eyed?

(ii) What proportions of red-eyed flies are heterozygous (carrier of white allele?)

____

____

____

How sure are you of your answer?

Sure	I think so	Guessing

APPENDIX F

Questionnaire Used by First Year Medical Biology Students

We are currently trying to find out what parts of your biology course you find difficult to understand. This information will help us design better learning materials. This questionnaire has been designed to find out your general knowledge about genetics. This is not a test. It does not matter if you get the answer correct or wrong.

The questionnaire contains 13 open -ended questions on genetics. Answer all the questions. Some questions need you to say how sure, or confident you are about your answer. Here, three choices are provided: **sure** (if you are absolutely sure your answer is correct); **think so** (if you think that your answer is correct but you are not absolutely sure) and **guessing** (if you have no idea what the correct answer is and merely guessed).

Write your age, race and name of your school.

AGE:	
RACE:	
NAME OF SCHOOL:	

Was your school located in a rural or urban area?

Rural	Urban

1. The DNA of a cell is measured in the G 1 phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after Telophase?

How sure are you of your answer?

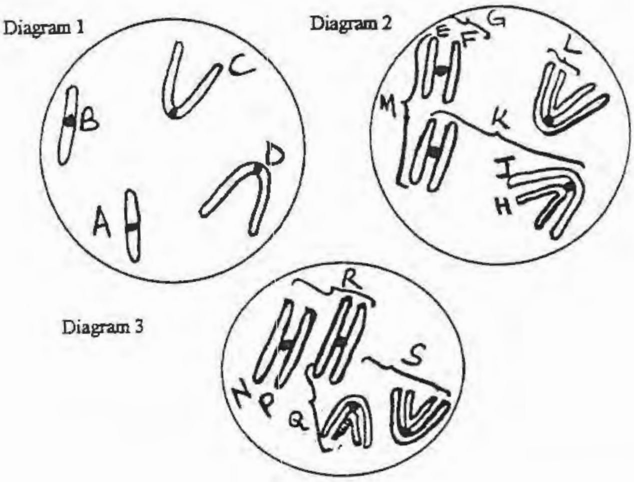
Sure	I think so	Guessing

2. The DNA content of a cell is measured in the G 2 phase. When this cell undergoes mitosis, what is the DNA content of each of the daughter cells immediately after Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

3. The following diagrams show a cell in various stages of a meiotic division. The three diagrams show various chromosomes, chromatids and homologous chromosomes labelled with letters from A to S. Write down in the space provided which letters represent chromosomes, chromatids and homologous chromosomes.



	Letters representing
Chromosomes	
Chromatids	
Homologous chromosomes	

How sure are you of our answers?			
Chromosomes	Sure	I think so	Guessing
Chromatids	Sure	I think so	Guessing
Homologous chromosome	Sure	I think so	Guessing

4. A cell with 6 chromosomes undergoes mitosis. How many chromosomes are present at Prophase and in each of the daughter cells at Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

5. cell with 4 chromosomes undergoes mitosis. How many chromatids are present at Prophase and in each of the daughter cells in Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

6. A cell with 3 pairs of chromosomes undergoes mitosis. How many chromosomes are present at Prophase and in each of the daughter cells at Telophase?

How sure are you of your answer?

Sure	I think so	Guessing

7. In an organism with 4 chromosomes, how many bivalent or homologous pairs would be expected to form during meiosis 1?

How sure are you of your answer?

Sure	I think so	Guessing

8. If a diploid number of a cell is 6, how many chromatids are present in the cell at Metaphase 1 of meiosis?

How sure are you of your answer?

Sure	I think so	Guessing

9. If a cell has 3 pairs of chromosomes, how many chromatids are present in the daughter cells at Prophase 11 of meiosis?

How sure are you of your answer?

Sure	I think so	Guessing

10. a. Define the term genes and alleles.

____

____

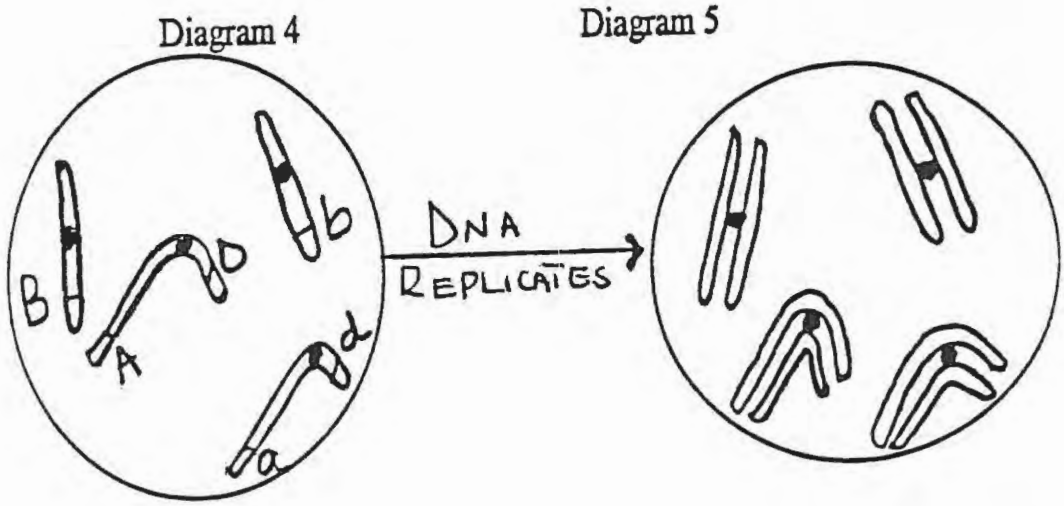
____

____

How sure are you of your answer

Sure	I think so	Guessing

b. Look at the diagrams below. Identify genes and alleles. Write down the letters of all the genes and alleles shown in Diagram 4 in the table below. Show or mark on Diagram 5 all the genes and alleles after DNA replication.

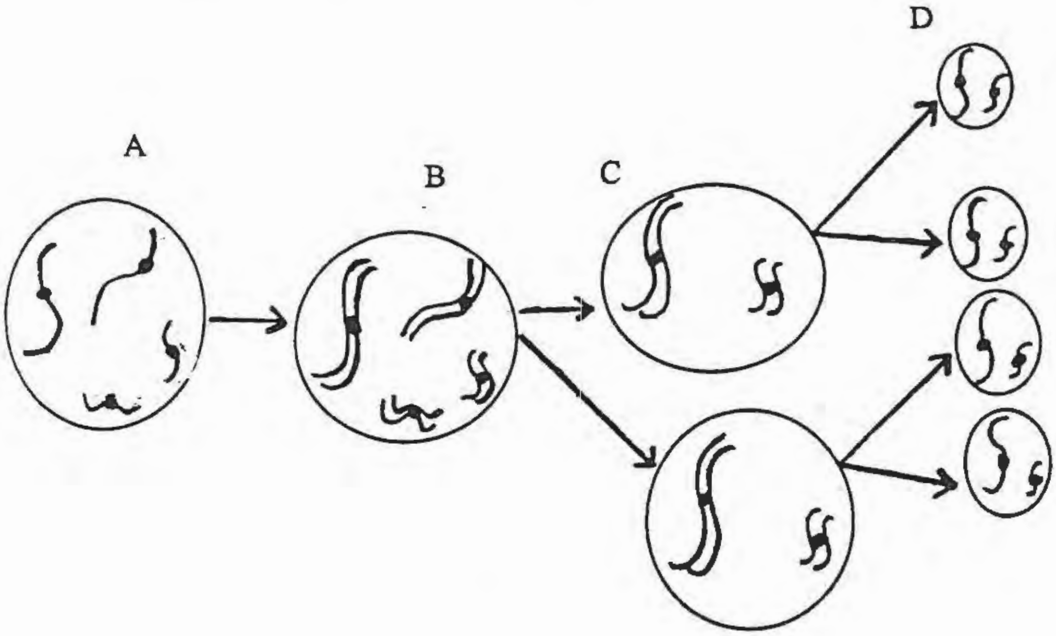


	Letters
Genes	
Alleles	

How sure are you of your answer?

Sure	I think so	Guessing

11. The diagrams below show some of the steps occurring during meiosis. Show the ploidy or state whether each of the following cells is haploid or diploid and the number of chromosomes in each cell. (Cell A to D).



Cells	Haploid	Diploid	Number of chromosomes
A			
B			
C			
D			

How sure are you of your answer?

Sure	I think so	Guessing

12: The DNA content of a cell is measured in the G 1 phase. What is the DNA content of the cell at Metaphase 1 and each of the daughter cells at Metaphase II?

How sure are you of your answer?	Sure	I think so	Guessing

13: The DNA content of a cell is measured in the G 2 phase. What is the DNA content of each of the daughter cells immediately after Telophase 1 and Telophase II?

How sure are you of your answer?	Sure	I think so	Guessing

Thank you for participating in this survey

APPENDIX G

Constructivist Teaching Resources and Methods Used

Mitosis: Chromosome Replication & Division

Prospective and Practicing K-8 Teachers; may be adapted for use in elementary classes.

Exercises 1 & 2 take approximately 2 1/2 hours.

To ponder	1.	How does a human being grow from a single fertilized cell into an individual containing billions of cells?
	2.	Do all the cells of the body look like one another? Do they perform the same jobs?
	3.	Do all the cells of the body contain the same genetic information?
	4.	How is the genetic blueprint that makes you who you are transmitted faithfully from one cell to the next?
	5.	How long does it take for one parent cell to become two **daughter cells**?
	6.	Are cells alive?
	7.	What is a cell, anyway?
Supplies		2 sets of white and 2 sets of red plastic knives, forks and spoons per group for **chromosomes**

1 large (3 ft) length and two smaller lengths (1.5 ft) of yarn for

nuclear membrane

white or brown paper per group

scissors

string for **spindle fibers**

small rubber bands for **centromeres**

yarn that is longer and a different color to represent cell membrane

Once you have completed these exercises you should be able to:

Objectives

1. Describe how cells reproduce themselves.
2. Explain how **chromosomes** are copied and distributed to each **daughter cell** in a precise way.
3. Describe the need for, and the mechanism of, conservation of **hereditary material**.
4. Be able to define and correctly use the following terms: **allele**, **anaphase**, **chromosome replication**, **cytokinesis**, **diploid**, **DNA synthesis**, **gene**, **homologous chromosome**, **interphase**, **life cycle**, **metaphase**, **mitosis**, **prometaphase**, **prophase**, **replicated chromosomes**, **sister chromatids**, **spindle fibers**, **telophase**, **unreplicated chromosomes**.

Cell Division

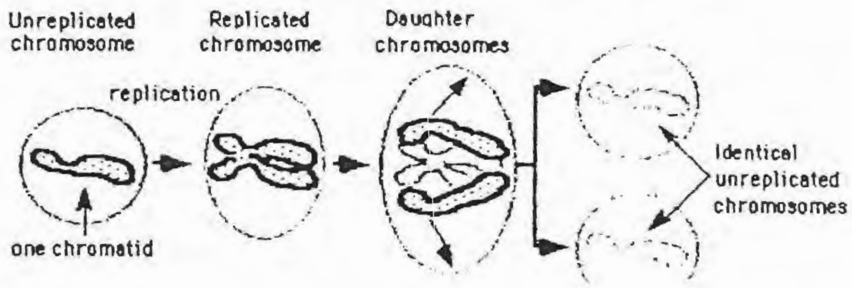
Your body is composed of more than a billion cells. Cells are continually dying, and new cells are continually being formed. An identical copy of your **hereditary material** is found in the **nucleus** of each and every **somatic cell**. A **somatic cell** is any cell in the body except for the reproductive cells in the reproductive system.

This genetic blueprint is organized into 46 3chapters2 or parts known as **chromosomes**. It is estimated that, on average, each **chromosome** contains between one and two thousand **genes**. A **gene** contains the information for making a single **protein** or **RNA product**.

Background information

Every time a cell divides, each **chromosome** must be carefully replicated (copied) and then distributed to assure that each **daughter cell** gets a complete and accurate set of information. Thus, nuclear division includes successive processes of **chromosome replication**, separation, and distribution (Figure 1).

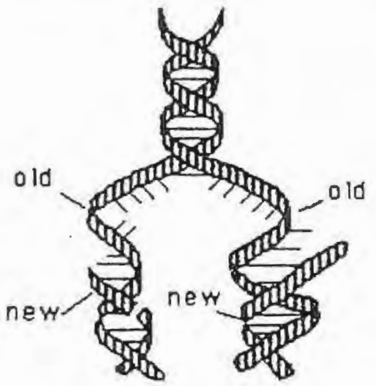
Figure 1: Chromosome Replication & Division



DNA synthesis occurs in the nucleus, producing an exact replica of every chromosome. A chromosome can be thought of as a very long

DNA double helix. During replication, the double helix opens up and a new complementary strand is synthesized along each parent strand (Figure 2). This results in two identical DNA helices, each containing one original parent strand and one newly synthesized trand.

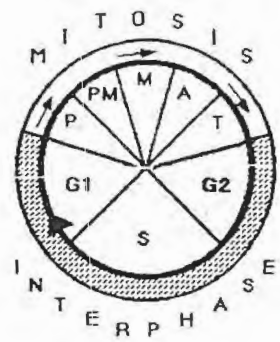
Figure 2: DNA Replicating



DNA synthesis occurs during the S phase of interphase. Each cell goes through a regular life cycle, similar to the cycle of life in humans. Where we might call our stages infancy, childhood, adolescence, young adult, adult, and senior, the major cell stages are interphase, mitosis, and cytokinesis is subdivided into G 1 (growth 1), S (synthesis), and G 2 (growth 2), and mitosis is divided into P (prophase), PM (prometaphase), M (metaphase), A (anaphase), and T (telophase).

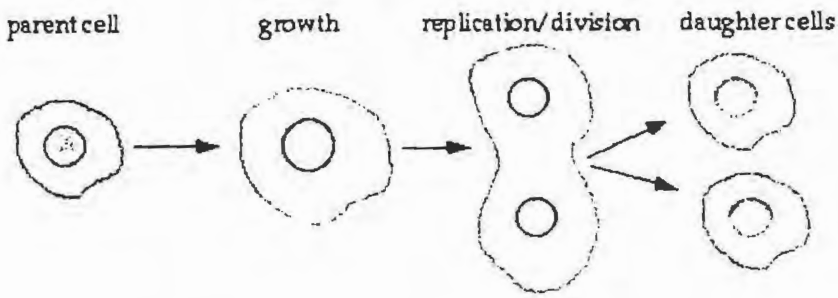
This is shown in Figure 3.

Figure 3: Cell Cycle



Another way to illustrate this cycle is shown in Figure 4.

Figure 4: Cell Division



Exploring the Process of Mitotic Cell Division

1.1 Introduction

You will study **<u>mitosis</u>** in the Triffle, a mythical creature with six **<u>chromosomes</u>** that look like knives, forks, and spoons. You will

To Do 1.

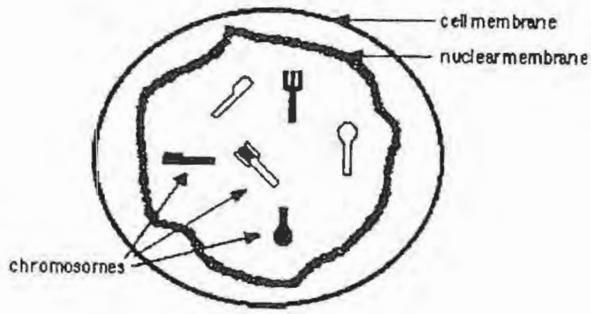
work out each step of the process using paper for **cells**, yarn for **membranes**, string for **<u>spindle fibers</u>**, and plastic knives, forks and spoons for **<u>chromosomes</u>**.

Go through the entire process (1.1 through 1.8) several times, with each group member taking a turn as the "explainer". Follow along with the procedure below for the first one or two turns, and perform the subsequent repetitions from
2. memory. Answer the questions about **each** stage as you go along, and answer them each time you go through the process. Explain your answers in your own words and your own way don't recite them by rote memory.

Take one large piece of paper for your cell, and use one color yarn to show the **nuclear**
3. **membrane** and a different color yarn to show the **cell membrane**.

Begin with a cell and **nucleus** containing six **chromosomes** represented by two forks (one red & one white), two knives (one red & one
4. white), and two spoons (one red & one white). This represents a **diploid cell** with three pairs of **chromosomes** (Figure 5).

Figure 5. Triffle Diploid Chromosome Set



a. What does diploid mean?

b. Are most human cells diploid?

c. How many pairs of homologous chromosomes are present in the picture of a Triffle cell above?

d. Draw a circle around each homologous pair of chromosomes in the picture above?

e. Are the homologues , (a short name for homologous chromosomes) above paired with one another in the cell, or are they independent from one another?

f. What is the best description of homologous chromosomes?

(choose the best response)

(1) they are the same size and shape

(2) they contain the same types of genes in the same order

(3) they generally contain different versions

(alleles) of many of their genes

(4) all of the above

g. Define homologous chromosomes.

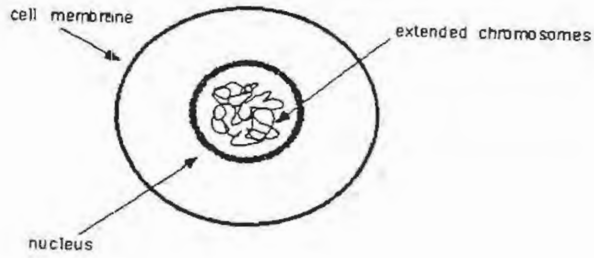
h. Contrast gene and allele.

1.2 Interphase and Chromosome Replication

Throughout **interphase**, the **chromosomes** are **extended** and are not visible in the light microscope (Figure 6). That is, the **DNA** is uncoiled. We cannot simulate this extended condition with the knives, forks, and spoons, so please imagine it. Replicate each of the **chromosomes** in your Triffle **nucleus**,

1. pretending they are extended at the time. Do this by obtaining six more **chromosomes** that match the set you already have. Attach a red fork to your red fork, a white fork to your white fork, and so on with an elastic band (which will represent the **centromere**). In this process, each chromosome has essentially made an identical copy of itself.

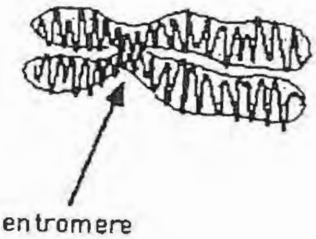
Figure 6: Interphase



Your **nucleus** initially contained six **unreplicated chromosomes**, and now it contains six **replicated chromosomes**. The two identical copies of each chromosome, **sister chromatids**, remain attached at a point called the **centromere** (Figure 7).

2.

Figure 7: Chromosome Centromere

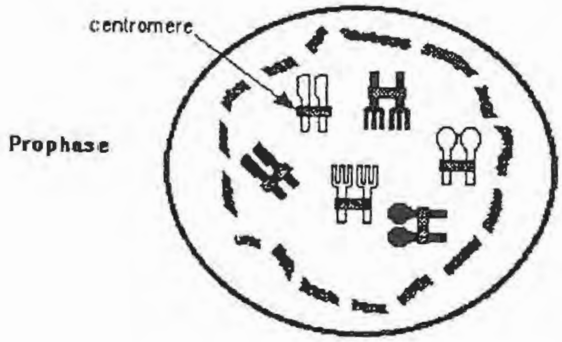


1.3. Prophase of Mitosis

1.

In **prophase**, the **replicated chromosomes** condense and become visible (Figure 8). This is the first stage of **mitosis**.

Figure 8: Prophase



a. Are the two sister chromatids that are connected by a centromere identical to one another or do they contain different alleles? Explain.

b. As noted above, these structures are called replicated chromosomes (or, in many books, simply chromosomes). Replicated chromosomes are quite different from unreplicated chromosomes seen earlier. Compare replicated chromosomes to unreplicated ones (by filling in the blanks below).

(1) the amount of DNA in the replicated chromosome is times the amount of DNA in an unreplicated chromosomes

(2) the number of copies of each gene in a

replicated chromosome is   times the amount of copies in an unreplicated chromosome

(3) each replicated chromosome contains   (insert number) complete copies of genetic information

(4) the copies of genetic information in each chromosome are   (identical, homologous, or complementary)

c. Do you think that the homologous replicated chromosomes (the two pairs of knives, the two pairs of forks, and the two pairs of spoons) will pair with one another during mitosis? Explain.
d. How many sister chromatids are in your Triffle nucleus in prophase?
e. A diploid human cell contains 46 unreplicated chromosomes in early interphase. How many sister chromatids will be present in the human cell during prophase of mitosis?

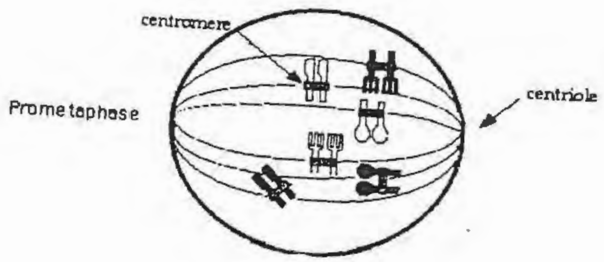
1.4. Prometaphase of Mitosis

To Do 1. In **prometaphase**, the **nuclear membrane** literally "disappears", which allows the rest of the mitotic events to occur. Remove the **nuclear membrane** from around the **chromosomes** in the **nucleus** of your cell. **Spindle fibers** form, emanating from two structures called **centrioles** that have migrated to opposite poles (ends) of the cell. **Spindle**

2. **fibers** are assembled from **protein** microtubules. Put **spindle fibers** in your cell using pieces of string and draw the **centrioles** on the paper at the appropriate points.

Some of the **spindle fibers** attach to the **replicated chromosomes** at their **centromeres** (Figure 9).

3.

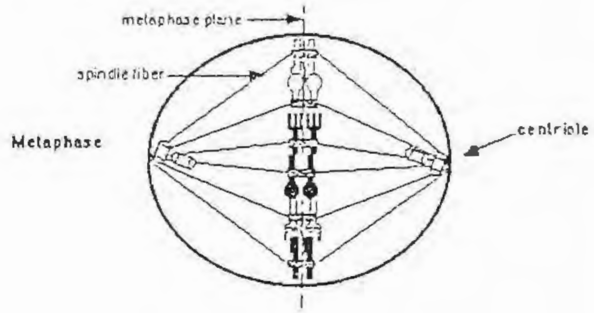


1.5. Metaphase of Mitosis

In **metaphase**, **replicated chromosomes** are

1. lined up on the **metaphase plane** (across the center of the cell) by the **spindle fibers** (Figure

10). **Homologous chromosomes** are independent of one another. That is, **homologous replicated chromosomes** such as the two sets of replicated spoons ARE NOT PAIRED.



Arrange your Triffle **chromosomes** across the center of the cell. The specific order of **chromosomes** and their orientation (right side up, upside down) is completely random.

How many replicated **chromosomes** are on **metaphase** plane in the Triffle?

To Do 2.

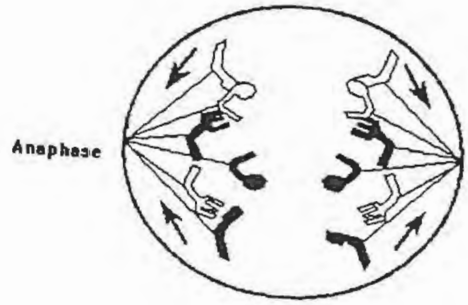
How many replicated **chromosomes** would be on the **metaphase** plane in a human cell undergoing mitosis?

1.6. Anaphase of Mitosis

In **anaphase**, **sister chromatids** separate to become **daughter chromosomes** (Figure 11).

1. Separate your **sister chromatids** to form **daughter chromosomes**.

Figure 11. Anaphase



Daughter chromosomes are moved toward opposite poles by the **spindle fibers**. **Chromatids** are flexible. They do not remain rigid, but rather bend on each side of the **centromere** as they are dragged through the **cytoplasm**.

2. Are the **daughter chromosomes** replicated or unreplicated?

Are the two sets of **daughter chromosomes**, the one moving toward the left and the other towards the right, identical or non-identical?

Are the two sets of **daughter chromosomes** identical to those in the parent cell?

what is accomplished by this process?

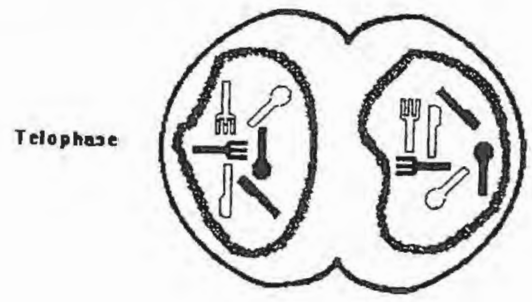
1.7. Telophase of Mitosis

1. **Daughter chromosomes** reach the poles of the cell and become extended (relaxed). The

spindle fibers disappear - actually, the **microtubulin subunits** are disassembled. You can remove your **spindle fibers** from your cells and pretend your **chromosomes** are going into the extended state.

Two new **nuclear membranes** form, one around each set of **daughter chromosomes**. Use the **nuclear membrane** yarn to create two new **nuclear membranes** in your cell (Figure 12). Pinch in the yarn representing the **cell membrane**.

2. Figure 12: Telophase



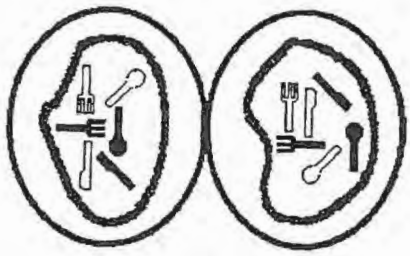
1.8. Cytokinesis

1. An animal cell pinches in half at the center (Figure 12), from the outside in, until it has produced two separate **daughter cells** (Figure 13). Divide your cell in half in this manner by

replacing the long yarn representing the parent **cell membrane** with two shorter pieces of yarn representing the membranes of the two **daughter cells**.

Figure 13. Cytokinesis Completed

Cytokinesis



These **daughter cells** are now entering the early **interphase** stage. Pretend that your Triffle **chromosomes** are becoming extended. The cells will grow to full size and, if continuing to divide, will replicate their **chromosomes**, and repeat the cycle again.

2. Does the parent cell still exist?

How are these **daughter cells** related to one one another?

How are these **daughter cells** related to the parent cell?

Overall, what has been accomplished by

mitosis?

you have used your materials to model mitosis (nuclear division) and cellular division Explain some ways in which a model differs from the actual things and processes it represents.

1.9. Practice through Repetition

1. As noted above, you can go through the entire process several times, with each group member taking a turn as the "explainer". Follow along with the procedures outlined above for the first one or two turns, and then perform the subsequent repetitions from memory. You may refer to Table 1 for a rough guide, and your team-mates can assist you by asking questions and giving hints.

Meiosis (production of haploid sex cells)

Supplies

Sixteen sets of the following: (that is, 2 sets per group so students may work in pairs)

2 sets of white and 2 sets of red plastic knives, forks and spoons

1 large oval and four smaller ovals of white paper

1 scissors

1 2.5-ft. length thick brown yarn

4 1-ft. lengths thick brown yarn

12 small rubber bands

1 1-ft. white string

Background

In an earlier lab, you explored the process of mitotic cell division, by which most of the cells in an organism are produced-these are called *somatic* cells. An alternative specialized process, *meiotic cell division* produces the sex cells or *gametes*, (sperm and egg in humans and other animals, pollen and egg in plants). Meiotic cell divisions occur in specialized cells in the reproductive structures of plants and animals, and other sexually reproducing organisms.

Recall that chromosomes are composed of DNA and contains the genetic blueprint for organism. Each species ha its own unique chromosome set, and all individuals in a particular species typically have the same number of chromosomes. The domestic dog has 78 chromosomes, the domestic cat has 38 chromosomes, and the mouse that it chases has 40 chromosomes. In some animals the sexes differ by one chromosome. In the kangaroo rat (potorous tridactylus apicalis), for example, the male has 13 chromosomes while the female has 12, and in the big fruit-eating bat (Artibeus lituratus), the male has 31 chromosomes and the female 30

Within each individual in a species, every somatic cell contains the same number of chromosomes as every other. However, each gamete cell in a sexually reproducing organism has only half the number of chromosomes carried in a somatic cell. The term ploidy refers to the number of complete sets of chromosomes a cell contains. Humans (and most other animals) are haploid (2N) meaning that each cell contains 2 complete sets (where did they come from?). Human gametes are haploid (N), meaning that they have only one complete set of chromosomes within them. All normal human beings, male and female, have 46 chromosomes in every somatic cell in their bodies (except in the red blood cells). However, a human gamete (sperm or egg) contains one-half the somatic number, or 23 chromosomes. When fertilization occurs the haploid sperm and egg unite, producing (i.e., restoring) the diploid chromosome number of 46.

Meiotic cell divisions occur only in cells that have an even (for our purposes, diploid) chromosome number. The result of meiotic cell divisions is to produce four daughter cells, each with a haploid chromosome number. Thus, each daughter cell is different from the parent cell by virtue of having:

(a) half the chromosome number, and

(b) chromosomes that are no longer like those in the parent cell (the genes are reshuffled during meiosis by a process called *recombination*).

Recall that mitotic cell division, in contrast, produces two daughter cells from one parent cell. The daughter cells are identical to the parent cell and to each other in terms of both chromosome number and chromosome type. Mitotic cell division can occur in haploid as well as in diploid cells.

The process of meiosis is similar to mitosis in that both involve one round of

DNA replication (chromosome doubling).

The process of meiosis is <u>different</u> from mitosis in that:

(1) similar (homologous) chromosomes pair in meiosis (but not in mitosis)

(2) homologous chromosomes exchange parts in meiosis (but not in mitosis)

(3) meiosis involves two cell divisions (whereas mitosis involves one)

Exercise 1: Self-Test on Meiosis

Circle the letters of all correct statements.

1. What is the specialized cell division called meiosis?

a. it is the process by which gametes are formed

b. it is the process by which gametes divide

c. it is involved in egg and pollen production

d. it occurs in the anther of a flower

e. it is how sperms multiply

2. The primary purpose (s) of meiosis is/ are to

a. separate larger from smaller chromosomes

b. reduce the chromosome number

c. allow union of cells from different parents without an increase in chromosome number

d. sort the chromosomes by type

e. produce genetic variation through reshuffling of genes

3. Meiosis occurs in

a. all organisms

b. diploid organisms

c. plants and animals

d. the reproductive structures of higher organisms in which gamete are produced

e. haploid organisms

f. the gametes

g. the ovaries

Experiment 2: Modelling Meiosis

You are going to work through meiosis step by step. You will be working with the chromosomes of a *'Triffle'*, a mythical organism in which we earlier examined mitosis. Recall that the Triffle has a <u>diploid chromosome number of six.</u> You and a team-mate are to complete the following steps, and then repeat the process until you can go through it without using these instructions.

1. Let a complete set of three haploid chromosomes be represented by a knife, a fork, and a spoon. Create a diploid nucleus containing two similar but not identical chromosomes of each type- that is

- two knives (one red and the other white)
- two forks (one red and the other white), and
- two spoons (one red and the other white)

The chromosomes in each pair (that is, the two knives, two forks, and two spoons) are said to be *homologous,* meaning similar but not necessarily identical.

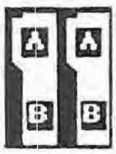
2. Label one gene at each end of each chromosome, using masking tape. We'll assume that some of the traits we find in humans (and their corresponding genes) are also found in the Triffle

Traits and location	Red Cutlery	White Cutlery
Genes on knives (Hair color) (Hair type)	 A (brown, black or red B (naturally curly)	 a (blond) b (naturally straight)
Genes on the forks (Tongue curling) (Mid-digital hair)	 C (can curl) D (hair present)	 c (cannot curl) d (hair absent)
Genes on the spoons (pigmented iris) (widow's peak)	 E (eyes not blue) F (peak)	 e (blue eyes) f (no peak)

*To keep things simple in this exercise, all dominant alleles are on one chromosome and all recessive alleles are on its homologue. This is not what you would expect in real life-they could be distributed any which way.

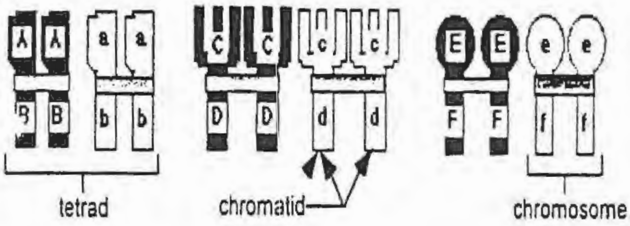
*Also note that we are looking at only two genes (two pairs of alleles) on each chromosome (while ignoring hundreds)

3. Each chromosome replicated by DNA replication. Simulate replication by adding a matching chromosome (same shape and color) for each of the six chromosomes in your nucleus. Label each chromatid with taped genes so they are exact copies.



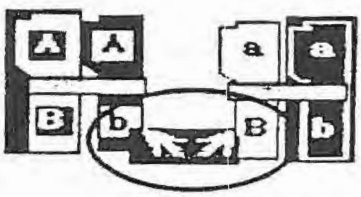
Connect sister chromatids together with rubber bands. This gives you <u>six replicated chromosomes each containing 2 'sister' chromatids</u>.

4. Each replicated chromosome then pairs with its homologous replicated chromosomes. That is, the replicated knife pairs with the replicated knife, the replicated fork pairs with the replicated fork, and so on. This pairing will produce three <u>tetrads</u> containing 4 sister chromatids each or a total of 12 chromatids.

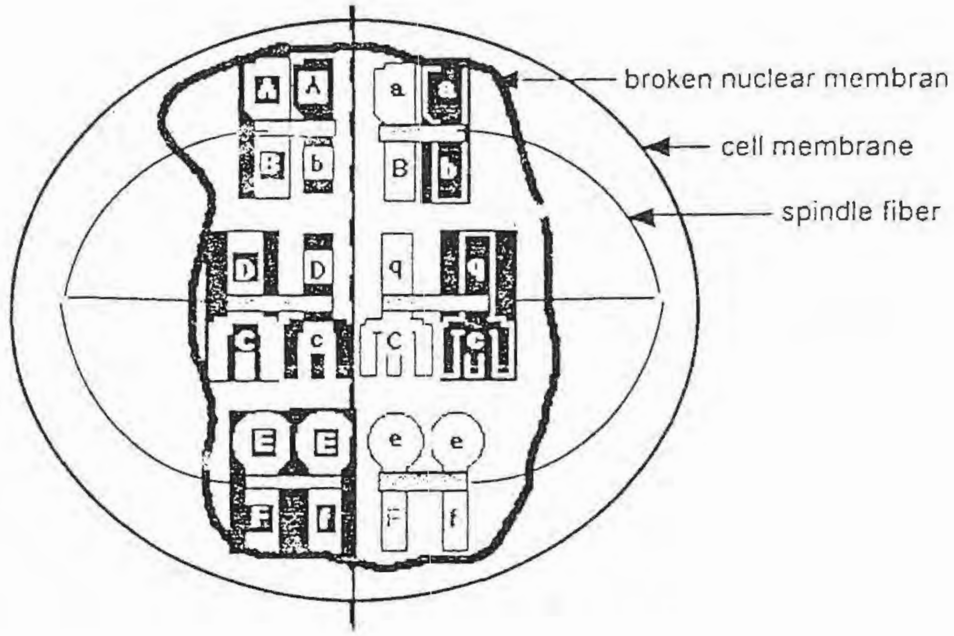


There are 4 copies of each type of chromosome at this point.

5. Next, crossing over and exchange of parts occurs. In each tetrad, switch one pair of genes between two non-sister (or non-identical) chromatids, by swapping pieces of tape. For example, swap an allele from a red knife with an allele, in the corresponding position on a white knife.

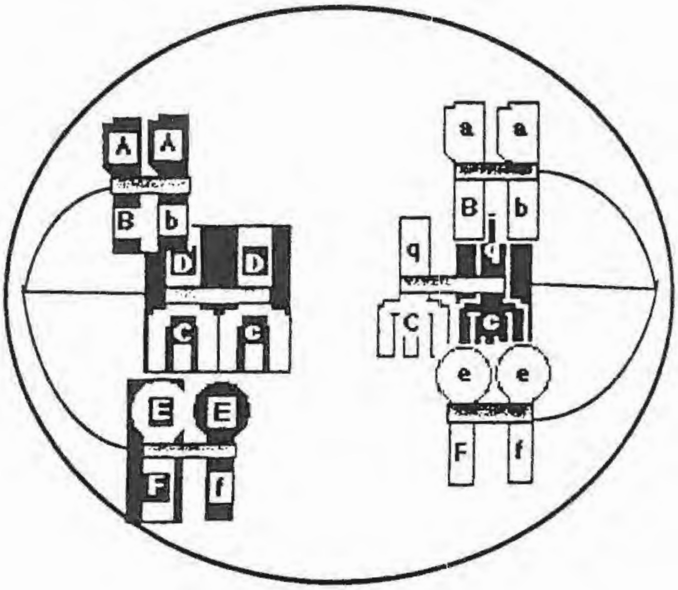


6. Line the tetrads end to end across the center of the cell. (The nuclear membrane has broken up.)

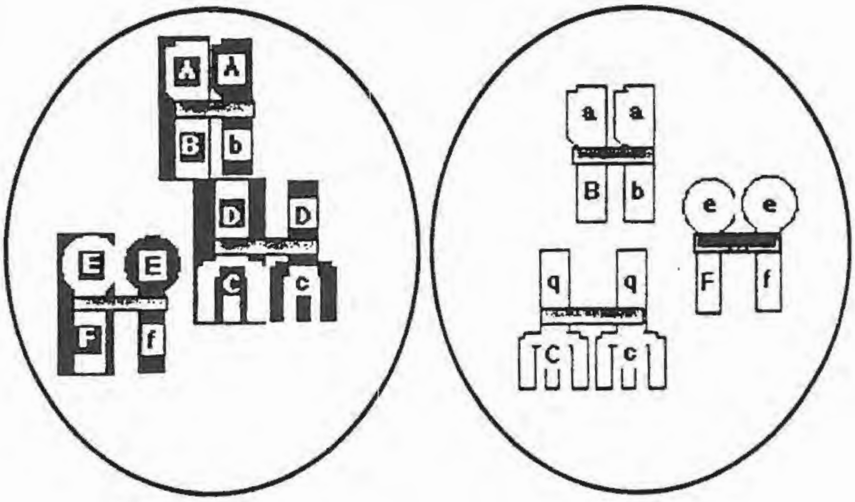


In this picture, for simplicity, all red chromosomes are on the left and all white chromosomes are on the right. However, in real life the tetrads orient themselves randomly, so that there will likely be some red chromosomes on the left and some on the right, with white on the opposite sides.

7. Each tetrad separates, with the replicated chromosomes going to opposite poles.



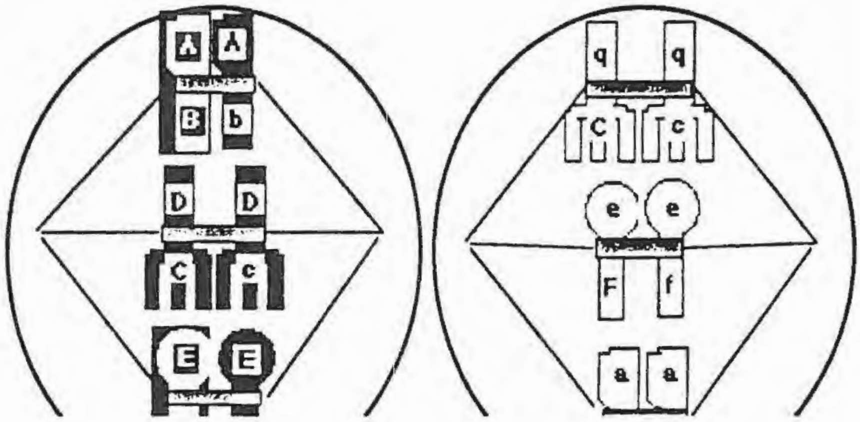
8. Division 1 cytokinesis (cell division) occurs to form two daughter cells.



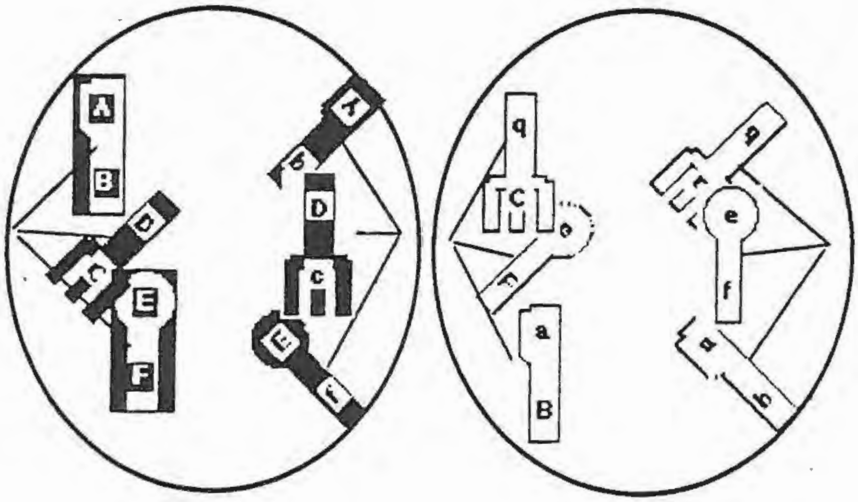
Remember, it is not necessary for all 'red' chromosomes to be together as shown here- they will be randomly distributed.

Will DNA replication occur prior to the next division? Explain.

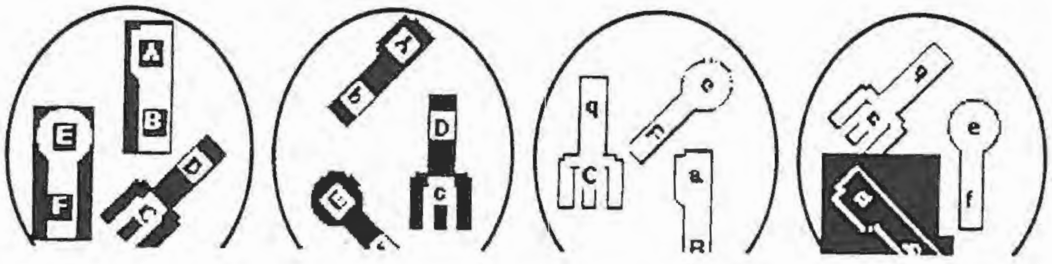
9. The replicated chromosomes line up end to end in the center of the two cells.



10. The two chromatids in each homologous pair separate and go opposite poles.



11. Division 2 cytokinesis occurs again, producing two cells each. Thus, a total of four daughter cells are produced from a single parent cell by two successive divisions.



ABCDEF (genotype) AbcDEf aBCdeF abcdef

Each daughter cell contains a haploid set of chromosomes (that is, in the Triffle, 3 chromosomes - a knife, a fork, and a spoon). Note that each cell has a different genotype (combination of alleles). As a result of gene swapping, each daughter cell contains one or more chromosomes that is different from both those in the parent cell and those in other daughter cells.

APPENDIX H

Questionnaire Used to Evaluate Students Opinions of the Constructivist Teaching Resources and Teaching Methods

Your valuable contribution will be used to evaluate and modify the tutorial and determine its need for the future.

1. Which part/s, if any, of the tutorial, materials or methods used did you like?

____

____

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2. Which part/s, if any, of the tutorial, materials or methods used did you not like?

____

____

____

3. Did the tutorial deepen your understanding of mitosis and meiosis? | Yes | No |

If yes, please explain:

____

____

____

4. How should mitosis and meiosis be taught in the future?

   A. The method used during the tutorial

   B. The traditional lecturing method

5. Please feel free to make suggestions on the use of other appropriate materials that could be used to model mitosis and meiosis.

6. Any other comments/ suggestions.

Thank you.