A CASE STUDY OF PRACTICAL WORK IN A CELL BIOLOGY COURSE AT THE EDUARDO MONDLANE UNIVERSITY IN MOZAMBIQUE

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor Philosophiae, in the Department of Didactics, University of the Western Cape.

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KEYWORDS

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ABSTRACT

A Case Study of Practical Work in a Cell Biology Course at the Eduardo Mondlane University in Mozambique

This study was carried out with the assumption that practical work does contribute to the teaching and learning of cell biology at Eduardo Mondlane University in Mozambique. In this regard, the main purpose of this study was to investigate the impact of practical work in the teaching and learning of cell biology concepts, specifically focussing on cell divisions concepts. It also aimed at determining the students' perceptions of the role of practical work in the learning of cell biology. On the other hand, the study sought also to understand the lecturers' practical work teaching experiences and views regarding the cell biology practical work.

The sample of this study consisted of 41 first-year biology students and eleven biology lecturers. To get a holistic picture of the answers to the research questions, the study employed both quantitative and qualitative approaches. The data yielded in this study were from pre-and post-tests, interviews, classroom observations and questionnaire. The analysis was performed using both descriptive statistics and qualitative analytical approaches. A qualitative analytical model was employed to determine the students' level of understanding of cell division before and after laboratory instruction.

The results of this study suggest that the cell biology practical work improved substantially the students' level of understanding of cell division on the four themes: (1) events in the cell cycle; (2) sequence of mitotic phases; (3) sequence of meiotic events meiosis; (4) differences between mitosis and meiosis. Even though, similar to other studies carried out in this area, the students continued demonstrating a poor knowledge of the basic concepts (e.g. chromosome structure, chromosome number, specific events in prophase I of meiosis, DNA replication) important to understand the whole process of mitosis and meiosis even after laboratory instruction. Furthermore, practical difficulties experienced by most students to use

the light microscope during the laboratory sessions influenced negatively the envisaged aims of practical work in cell division. Despite this, the students shared a common understanding that practical work in cell biology improved their level of learning in that they gained the necessary manipulative skills required to observe, understand and explain well the mitotic and meiotic events by linking theory and practice as well positive attitudes towards practical work.

The lecturers seemed convinced of the benefits of a constructivism instructional approach to guide laboratory activities. They regarded this approach as providing students with ample opportunities to interact with one another and the learning materials and thus, enhance their conceptual understanding of cell division. However, they seemed to not fully grasp the importance of problem-solving activities, open-inquiry or project work in the development of critical scientific attitudes and values. Similar to other studies, the lecturers and students agreed that the inadequacy of the laboratory materials critically required to perform practical work in cell biology impacted negatively the effective implementation of the envisaged aims of cell biology practical work.

The study provided useful insight to the need to carry out laboratory activities to provide students with opportunities to develop valid understanding of cell biology concepts. The study suggested a need to explore the students' backgrounds before introducing them to new learning materials or equipment. The complexity of the cell division topic requires that new teaching strategies and learning aids be established at all educational levels. Thus, a professional development program for secondary school staff and university staff in this regard would be required.

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DEDICATION

In memory of my eldest sister "MANA BERTA" who taught me throughout her life that the best way to triumph over difficulties is going to school and showing your faith through your deeds.

"We please God by what we do and not only by what we believe"
(James 2, 24).

"If you have good instruction it will help you to have even better sense and to live right. Education will help you to know even better"
(Proverb 9, 9).

DECLARATION

I declare that "A Case Study of Practical work in a Cell Biology Course at the Eduardo Mondlane University in Mozambique" is my own work, that it has not been submitted before for any examinations in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Eugenia Flora Rosa Cossa March, 2007

Signed:…………………………………………..

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

CHAPTER 2: LITERATURE REVIEW

CHAPTER 3: RESEARCH METHOLOGY

CHAPTER 4: RESULTS AND DISCUSSION

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BSD	Biological Science Department
BUSC	Basic University Science Course
CBT	Cell Biology Test
ADC	Academic Development Centre
ISP	Instituto Superior Pedagógico
KAS	Knowledge, Attitudes and Skills
LEQ	Lecturer Experience Questionnaire
PLI	Post-Laboratory Interviews
PCI	Post-Course Interviews
SPQ	Student Perception Questionnaire
Stadep	Staff Development Program
EMU	Eduardo Mondlane University
PU	Pedagogical University

CHAPTER 1: INTRODUCTION

The study described in this thesis was concerned about understanding the role of practical work in the teaching and learning of cell biology in the Biological Science Department (BSD) of the Eduardo Mondlane University (EMU) in Mozambique. Thus, the main challenge was to investigate the nature of practical work in cell biology and its function in the improvement of the students' conceptual understanding of cell division concepts (mitosis and meiosis). The study was based on the premise that practical work plays a great role in improving the acquisition of specific process skills (planning and design of experiment, execution of experiment, observing and classifying objects and events, analysis and interpretation of data and application of results) as well as positive attitudes towards science. The present chapter provides an introduction to the background of the study. It first focuses on the establishment of the Eduardo Mondlane University including some aspects of the educational system in Mozambique and the status of practical work in Mozambican schools and, particularly, at the Eduardo Mondlane University. It also includes the rationale for the study; a preliminary literature review; the conceptual framework; aims, research questions and definition of the terms used in this study.

For the purpose of this study, the term 'practical work' is used to refer classroom laboratory activities that include teacher demonstrations, discussions, simulations, exercises, observations or manipulations of real objects and materials by students and fieldwork.

1.1 Background of the study

1.1.1 Establishment of the Eduardo Mondlane University

The Eduardo Mondlane University was established in 1962 as a major higher and public educational institution in Mozambique. This University was firstly named 'General University Studies of Mozambique' and was renamed 'Lourenço Marques University' in 1968.

In 1975, when Mozambique became independent from the colonial power (Portugal), the EMU restructured itself around a new political and cultural dynamic. In this context, a new educational system according to the actual demands of Mozambique was developed. The highest priority was to renovate and democratise the structure of the University as well as introduce gradual changes in the already existing *curricula.* From 1975 onwards the primary objective of the courses offered by the University was to provide a general education, multifaceted in nature so that in the short-term it would produce a qualified body of trained lecturers and technicians capable of assuming positions of administration and management essential for the growth and development of human resources in the various economic and social sectors of the country.

In 1980, due to the expansion of the educational system, a growing need for trained teachers for the secondary education sector led to the establishment of the Faculty of Education. The policy of the new Faculty was to train teachers for a period of two years in acquiring pedagogical skills for teaching and running laboratory classes. Parallel to the Faculty of Education, a new Pedagogical University (PU) was established. In 1989 the Faculty of Education was closed and the task of training secondary school teachers has since 1986 gradually been transferred to the Instituto Superior Pedagógico (ISP) now called the Pedagogical University (PU).

In 1985, a Basic University Science Course (BUSC) commenced for all first year students involved in technical or life science related disciplines. The main reason for the establishment of this course was the deterioration of the secondary education school system right after independence. Because of the poor infrastructure and few qualified teachers there were not many possibilities for doing practical work. In this regard, the principal aim of the BUSC course was to develop a range of practical skills among science students linking theory to daily practice and using a student oriented learning approach. Because the policy of EMU is to stimulate academic staff development and provide career opportunities, BUSC had a role to play in the training of Mozambican staff for mathematics and science education research.

Parallel to BUSC another educational initiative named the Staff Development Program (Stadep) was established in 1988. In the ambit of this program, courses were developed on writing of student materials, teaching methods, evaluation, how to conduct research, how to conduct laboratory classes as well as workshops and seminars on educational research. Recently, due to the curriculum reforms at the EMU, the Stadep is now known as the Academic Development Centre (ADC) and is incorporated into the new Faculty of Education of the EMU. It reopened in 2000 without changing its function. Also, the Basic science courses that were taught at BUSC were transferred to the respective Faculties and Departments of the EMU where the students will continue to be prepared in the courses-oriented laboratory science activities. In addition, within the various programmes offered by the University in the Life Sciences, science laboratory classes are often not well developed. The reason for this is linked to the various constraints described later in section 1.1.2.

In 2006 the EMU offered about 30 degrees programmes in 10 Faculties and three Technical Schools. The duration of the programmes is four years for Honours (except Medicine which is seven years), three years for the Bachelors degree and an additional two years for Masters. Presently, about 1160 full-time and part-time lecturers are employed by EMU. Among those, 65% lecturers are young academics with Honours; about 20% have a Masters degree and about 15% hold a PhD. The student population of the University is approximately 8000 students coming from different parts of the country with mixed abilities and knowledge. Despite this improvement there is still only a limited number of lecturers with post-graduate degree at the PhD level and the Mozambican staff mainly consists of young lecturers mostly with Honours and a considerable number with Master level. Now, the University is facing the pressure of equipping its staff with better skills to respond to the challenge of increased number of the candidates wanting to study at the tertiary level.

1.1.2 Practical work at Eduardo Mondlane University

The Eduardo Mondlane University recognizes the importance of course-oriented laboratorial work in the teaching and learning of the sciences (namely, Agronomy, Veterinary, Chemistry, Physics, Medicine, and Biology). The current curriculum of the Biological Science Department emphasizes the use of practical work to develop conceptual knowledge, process skills and positive attitudes towards science. These knowledge and skills are critical to the sustainable development of the biological resources in Mozambique. However, as in many developing countries effective implementation of practical work is a general problem at the Eduardo Mondlane University (Allsop, 1991) as there are so many constraints. For instance, lack of laboratories and equipment for teaching practical science, poor preparation of teachers, poor implementation of procedures, an overwhelming number of activities demanded by the new curricula and lack of qualified teachers are some of problems confronting the process of science teaching in Africa (Ogunniyi, 1986 cited in Fessehatsion, 2003).

This study assumes that the current situation of practical work at Eduardo Mondlane University do not differ significantly from that reported in the literature. It is characterized by poor conditions in the running of laboratory sessions. The material provision is widely different, but often poor, with lack of equipment, maintenance of equipment, chemicals, water, properly printed manuals being problematic. Assessment methods traditionally used to test practical work are basically written laboratory reports and/or (part of) written examinations. The framework for designing practical work seems to be quite mechanical: during lectures the lecturer presents the theory. Some training of the concepts taught take place in the tutorials and during the laboratory classes related experiments or exercises are performed. Often different lecturers, sometimes with very little coordination, teach the different types of lessons. Many lecturers themselves have been educated along the same lines. Both young and experienced staff may lack sufficient background on how to design practical work in order to enhance students' learning of life science subjects.

Furthermore, in this study, it is assumed that the lack of an educational research (science education) tradition at EMU can contribute to staff not having a well-developed view on the goals to be attained through practical work. Using the framework of 'cookbook practicals', that is, 'recipe-style' practicals, some lecturers perform very well while others do a rather poor job, due the lack of training, experience, effort, available resources, support, and so on. Students simply follow a set of instructions to do experiments or to perform skills training. Hence, the practicals are mostly performed to obtain a preset result (Langa, Cossa, Frencken, & Groosjohan, 1995).

According to Hodson (1996) the use of 'cookbook practicals' and verificationistic practical work has been criticized for it distortion of what science really is and its encouragement of rote learning rather than meaningful inquiry oriented learning. In addition, the use of 'cookbook practicals' has been criticized for its failure to provide students with opportunities to plan investigations and perform their own experiments enabling them to construct their own knowledge of the scientific phenomena (Domin, 1999; Shiland, 1999). Furthermore, the results of a study conducted by Cossa (1998) which sought to evaluate the extent to which the goals of a practical component of the cytology section of the basic biology course at BUSC were achieved, revealed that the instruments traditionally used at EMU to assess students' practical work (written laboratory reports and paper-and-pencil tests) were inappropriate.

The kind of assessment mentioned early, has been criticized as inadequate (e.g. Johnstone & Wham, 1982; Solomon, 1988) as it fails to assess such students' skills as abilities to manipulate equipment, perform observations and plan and perform investigations. For instance, in a study conducted by Cossa (1998), students when asked to prepare a wet mount slide of the onion epidermal cells and required to observe it using a light microscope, were inept to perform certain skills in a logical sequence and most of them were unable to explain the meaning of what they were doing in terms of understanding the concepts and skills needed to prepare a wet mount slide or to operate correctly a light microscope. Most laboratory experiments and activities are performed using so-called 'cookbook practicals' or 'recipe-style' (Hodson, 1996) during which students demonstrate and verify already known scientific knowledge.

In attempting to minimize some of the problems affecting the current practices of practical work taking place at EUM, Langa *et al*. (1995) in collaboration with the Staff development programme proposed a possible framework for the development and design of a practical work at EMU as illustrated in Figure 1.1 below. On the Xaxis the 'sophistication' of practical work design is indicated. The 'mechanical form of doing practical work' represents the format of the most current practices taking place at EMU as was already explained. The 'practicals as part of an educational design' would imply a much wider range on types of practical work or methods, depending on its objectives. This could imply 'open-ended' practicals, projects, skill training practicals, research techniques training practicals, inductive or deductive approaches, and so on. The Y-axis indicates the teaching skills related to 'doing practicals' as a teacher. The teaching skills involved in practicals depend much on the type of practical work activities performed. For instance, if only 'cookbook practicals' are done, the lecturer does not necessarily need to conduct open-ended practicals. However, it would be difficult to develop skills on the lower part of the Y-axis ('many developed teaching skills') without the actual existence of other than cookbook practicals. In other words, a relationship should be assumed between the possible teaching skills which can be acquired and the diversity of methods used for practical work as indicated by the tilted line.

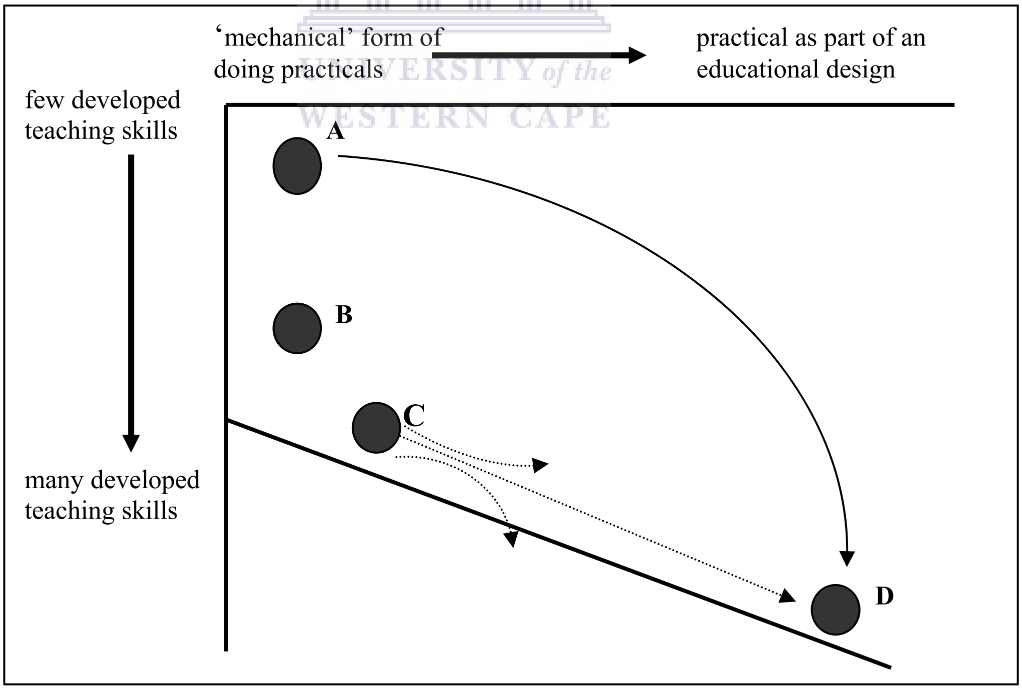

Figure 1.1: A Possible framework for developing practical work at EMU

For the reasons mentioned above, most of the staff at EMU is supposed to be in the range between A and B in the Figure 1.1. From an 'idealistic' point of view of staff development, in proposing this framework, the expectation was to see teachers changing from A / B to D (Langa *et al*., 1995). It means that teachers would change from staff with little experience and a narrow, poorly developed arsenal of teaching skills to experienced teachers, exploring and exploiting a wide range of methods and techniques. This would contribute to the development of their teaching skills to perform better in their laboratory classes as well as provide students with an optimal learning environment. Furthermore and according to the framework, teachers should try to introduce changes within the existing *curricula*, for instance, use of better assessment procedures (moving from A to C) and develop more explicit research skills training in educational area (moving from A to D) as indicated by the dotted arrow in Figure 1.1 (ibid.). In general, this framework provided the researcher with some important cues to understand the problem that the EMU is faced with in terms of the teaching skills, methods and techniques needed to conduct practical work. Based on this framework and descriptions above on the current practices at EMU, the rationale of the study is explained in the next section.

1.1.3 The rationale of the study

As a Biology lecturer at the EMU and also as teacher at secondary schools for many years prior to lecturing, the researcher felt that it was pertinent to carry out research to investigate the nature of practical work in the teaching and learning of cell biology at EMU as well as the students' perceptions and lecturers' experiences and views on the aims of practical work in the cell biology course. In general, the problem addressed in this study took into account the factors affecting the current status of the practical work at EMU with a particular interest for the Biological Science Department. It was also expected that this study would help to understand the students' learning difficulties of cell biology concepts (mitosis and meiosis) and therefore, improve the quality of teaching and students' understanding level.

On the other hand, it was also hoped, that the results of this study would assist in the enhancement of the interrelationships between all the laboratory-oriented courses (viz., Physics, Chemistry, Biology, Medicine, Agronomy and Veterinary Science) in terms of understanding the functions of laboratory activities in improving students' investigative skills. In this regard, the researcher suspected that the problem addressed in this study could be linked to the ways laboratory classes are used to teach and learn cell biology topic or; could be linked to the lack of understanding of the objectives for doing practical work in order to enhance students' learning and understanding of cell biology concepts in a meaningful way.

Research evidence into previous biological ideas and concepts revealed that teachers have been challenged with difficulties when teaching cell biology concepts (e.g. genetic and cell division processes in living organisms) and that practical work can be helpful in assisting teachers as well as students to overcome such difficulties when integrated with theories (e.g.: Lewis and Wood-Robinson, 2000; Yip, 1998; Jones and Eichinger, 1998; Woolnough, 1991). In the next section, a preliminary overview from the literature on practical work is given

1.2 Preliminary literature study

The above descriptions of the current status of the practical work at EMU are also an issue for several other authors (Cossa, 2002; Bekalo & Welford, 1999; Hodson, 1990; Kapenda, Marenga-Kandejeo, Kasanda, & Lubben.; 2001;; Lazarowitz & Tamir, 1994; Tamir, 1991; Watson, 2000). They share the same conceptions arguing that the way practical work is conducted in many schools, is ill-conceived, confusing and unproductive resulting in little understanding of what goes on in the laboratory classes and consequently, contributing little to the students' learning or understanding of science in a meaningful way. For instance, during laboratory sessions students regularly perform 'cookbook' experiments following step-by-step procedures already written in practical manuals, and consequently engage in predominantly lower-order cognitive activities (Lazarowitz & Tamir, 1994). In addition, Hodson (1992) cautions that the poor conditions of designing an experiment, for example, small group size, lack of an adequate control of relevant variables and the use of inappropriate test instruments have contributed to the inefficiency of practical work. He points out that such difficulties can contribute negatively to learning outcomes, particularly to comprehension of scientific concepts and the acquisition of positive attitudes towards science.

Beside these negative aspects mentioned above, several other authors reported that practical work has been playing an important role and central part of the science programmes schools in many countries (Woolnough, 1991). Practical work often assumes the dominant role and involves a vast amount of teachers' time and expense. He goes further to suggest that practical science, by which he means doing experiments or practical exercises with scientific apparatus, usually in science laboratory, has established a large and influential place in the science teaching of many countries.

Several authors have reported the importance of meaningful learning and how practical work can contribute to promote meaningful learning in terms of conceptual growth (Sanders, 1988; Kirschner, 1988; Hodson & Reid, 1988; Tobin, 1990; Gunstone, 1991; Aho, Huopio, & Huttunen, 1993). Lowe (1993) believes on the theory described by Ausubel (1968) which emphasises that the process of learning will only be meaningful if a new concept or material to be learned is connected with success by the learner into existing system of knowledge that the learners already have. Piaget (1974) and other psychologists believe that the learner must be active to be engaged in real learning and the process of learning becomes active when students are able to connect new knowledge with their prior understanding. In addition, Thanasoulas (2001) argues that if a learner is able to perform in a problem-solving situation, a meaningful learning should then occur because he has constructed an interpretation of how things work using pre-existing structures. A personal interpretation of external ideas and experiences allows the learner to construct their own understanding about how these ideas can be related to each other and pre-existing knowledge.

According to Sanders (1988) an inquiry-based practical work can help the learner make a linkage between a new concept or idea and the existing prior knowledge. If this linkage does not occur, the learning process will result in rote learning and memorization of the concepts. Similarly, Hodson and Reid (1988) argue in favour of a learning experience in which the consideration of the prior theories and the exploration of the existing ideas can contribute for the effectiveness of practical investigation. The same authors suggest that a learner needs to be equipped with an adequate theoretical understanding (real understanding of ideas, and the development of physical manipulative skills). Only in that way he/she will be able to makes appropriate observations and practical work can contribute to promote meaningful learning. In addition, and according to Calloids, Göttelmann-Duret, & Lewin (1997) others authors refer to the need to stress the importance of direct experience and 'personal response' to science that may result from practical work. In doing so, practical work arranged carefully can create the conditions for meaningful rather than rote learning (Head, 1985) and shift the balance from reception of information to interact and manipulation of ideas (Novak, 1984).

The theories referred to above can be elaborated to give a better understanding of the students' conceptions of the cell biology. Several studies on students' biological concepts caution that a particular attention should be paid to the teaching of structure of cells and cellular phenomena, including cell division, protein synthesis, respiration, and photosynthesis. For instance, the notion that green plants synthesize their own intracellular substances seems to be an unsolvable problem for many students. When they are asked about plant nutrition, most of them, including those who have taken several biology courses, insist that plants obtain food from the soil (Wandersee, Mintzes, & Novak, 1994). In that way, teachers are required to pay particular attention to students' conceptions which students take to the classroom as this will help to guide the conceptual development of students. In addition and according to, van den Berg (2002), by doing laboratory activities students have the opportunity to use the concepts, processes and psychomotor skills in an integrated manner.

Others studies in biology education report that cell biology concepts are both difficult to learn and to teach at different educational levels. According to Flores, Tovar, & Gallegos (2003), conceptual problems range from the understanding of the cell as an autonomous organism and the functions it performs to difficulties in spatial and material representations resulting in confusions between cells, atoms and molecules. The same authors caution that the lack of ability to integrate the ideas about different topics in cell biology into overall picture does not facilitate students' understanding of such processes as respiration, reproduction, nutrition or genetic regulation mechanisms and organelle composition. Similarly, Driver, Squires, Rushworth, & Wood-Robinson (1994) and Kindfield, (1994) identify two aspects that make it difficult for students to understand the complex and microscopic nature of the cells: (i) difficulty in differentiating between cells and their molecular components, such as proteins, carbohydrates, and water and; (ii) lack of ability to integrate their knowledge of cell structures with an understanding of corresponding function in cell division.

In studying the models of mitosis and meiosis held by novices and experts a range of misunderstandings at all levels was found, particularly for the novices (Kindfield, 1994). For instance, it was found that students experience difficulties in understanding both cell division processes. The most salient difficulties are coupled to the poorly developed understanding of chromosome structure, specific events that occur, for example, during meiosis crossing-over, (called "event-specific process misunderstanding"), the importance of the order and timing of events (called "whole-process misunderstanding"). In the same line, Lewis and Wood-Robinson (2000) investigated the knowledge and understanding of genetics among 482 students nearing the end of compulsory education in England. The findings of this study revealed that students have poor understanding of the processes by which genetic information is transferred coupled with the lack of the basic knowledge about the structures involved (e.g. gene, chromosome, cell). In face of this, Kindfield (1994) identifies two implications for the understanding of mitosis and meiosis:

- Appreciating the function of cellular structures important for cell division is necessary for full understanding of the processes of cell division;
- Recognizing that both mitosis and meiosis are dynamic processes, with a specific order of events, is critical for coherent models of cell division. It is assumed that the failure of understanding the order of events can hamper the understanding of cell division as a whole.

Based on this and other findings reported in the literature on students' conceptual understanding of the cell biology and the role of practical work to promote a meaningful learning of scientific concepts, the researcher felt motivated to investigate the students' conceptions of cell division before and after undertaking practical work in cell biology course as well as the contribution of laboratory activities in enhancing the students' understanding of cell division at the Eduardo Mondlane University in Mozambique. In addition, the evidences reported in the preliminary literature regarding the students' difficulties in relating the functions of cellular structures and cell division as well as see mitosis and meiosis as dynamic processes provided the researcher a deep insight to investigate the way practical work can be conducted to improve the students' understanding of mitotic and meiotic concepts. Before presenting the aims and research questions, the conceptual framework underpinning this study is given.

1.3 Conceptual framework

The framework used in this study took the form of a systemic model, which enabled me to ascertain the degree to which the cell biology practical work accomplished or failed to attain the intended goal of the cell biology course taking into consideration the context in which the cell biology course had been implemented (Stake, 1967; Ogunniyi, 1984; Easton, 1996). The model, which comprises a process of teaching and learning, is summarized later in Figure 1.2. This process includes interactions between students and lecturers through laboratory activities and cognitive course (tutorials), headmaster and lecturer, lecturer and laboratory materials and so on. In this model, input represents any conditions in terms of the knowledge, attitudes and skills (KAS) existing prior to teaching and learning process through tutorials and practical work, which may relate to outputs. Output refers to the students' conceptions acquired after the process of transaction through practical work and tutorials. It includes the acquired knowledge, attitudes and skills of students resulting from an educational experience (Stake, 1967; Easton, 1996). Laboratory activities refer to activities which students are required to perform during laboratory sessions (e.g.: observe, analyse and interpret events or phenomena occurring to objects or events, collect data, apply concepts, measure, explain or make decisions about experimental techniques, compare and contrast results, predict results, formulate hypotheses, apply experimental techniques) guided by the lecturer or technician (van den Berg and Giddings, 1992 & Dekkers, 1997). The laboratory materials and facilities are the supplementary instructional elements that are supplied by the institution or Department needed to help lecturer as teaching agent to conduct laboratory activities. Figure 1.2 below illustrates a summary of the conceptual framework used in this study.

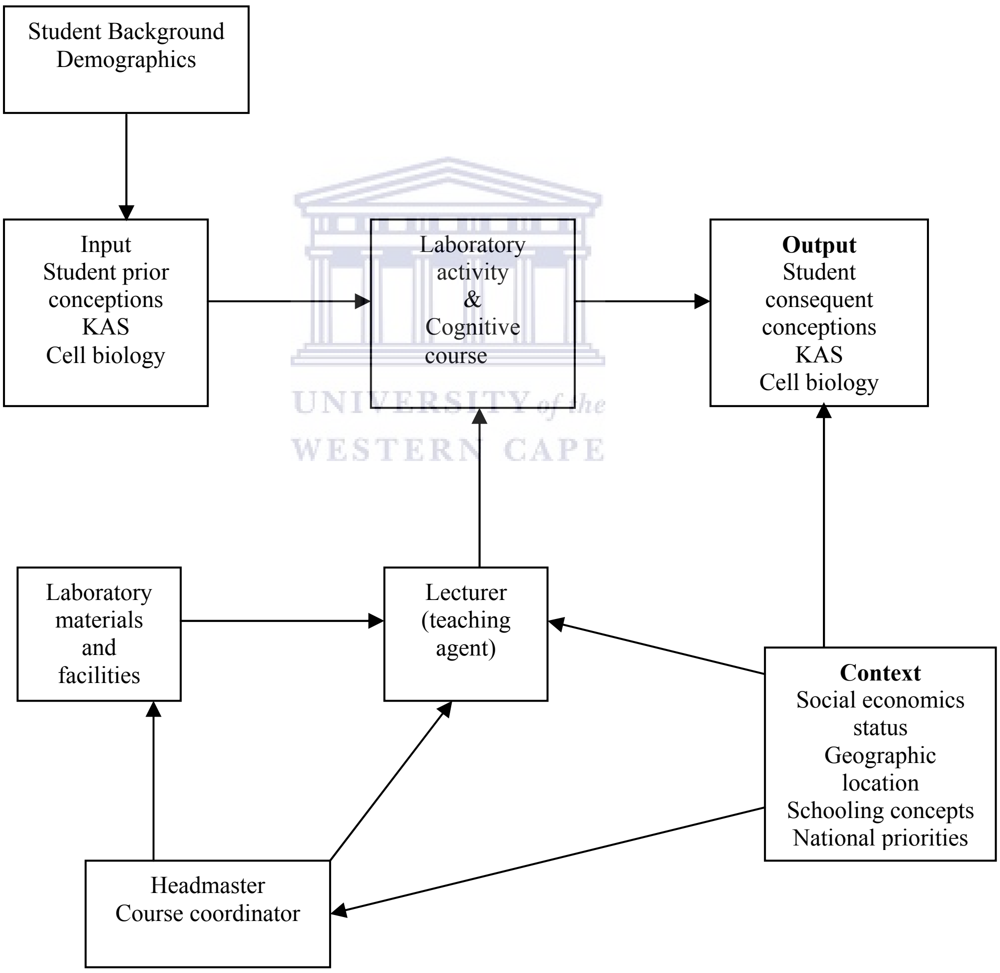

Figure 1.2: A model to investigate the impact of practical work at EMU

Adapted from Easton, (1996).

The model also presents the context in which the process of teaching and learning cell biology through practical work might take place. As can be seen in the Figure 1.2 the context can influence the way lecturers plans or design laboratory activities as well as the way the Headmaster or Course coordinator support lecturer and/or provide laboratory materials and facilities that the lecturer might need to plan or design laboratory activities. On the other hand, the context can also determine the way students interact with lecturer during the laboratory sessions in order to construct their own knowledge. Important to highlight here is that the active process of knowledge construction in the laboratory sessions can occur through social interactions between the learner with peers and with the teacher who acts at the students' zone of proximal development (Firenze, 1997; Tsaparlis & Gorezi, 2005). For instance, it was found that small group practical work can be useful when adopted as a teaching approach. However, this might depend on the kind of the activities that students are required to perform (Shiland, 1999). According to Firenze (1997) small group activities can contribute to students enhance their understanding of the scientific concepts in that students are asked to explain and/or defend their thinking to their peers, and compare and contrast their ideas with their own constructions.

The conceptual framework of this study was also based on the view of social constructivism. This view emphasizes that the process of changing misconceptions will only occur if the students' mind have an active cognitive involvement in the processes that allow for the accommodation of new knowledge (Saunders, 1992). In other words, in a constructivist perspective it is assumed that learning is a process of knowledge construction in the mind of the learner (Taber, 2001). In this process learners actively construct their own knowledge using their existing knowledge to make sense of their new experiences. The making-sense process results from the social interactions that occur within a socio-cultural context. It is in this context where learners agree and construct knowledge in ways that are coherent and useful to them hence producing relatively stable patterns of belief (Hewson, 1993). In this study, it is assumed that minds-on or hands-on laboratory activities, developing alternative hypotheses, designing experiments, and arguing about phenomena under study can facilitate learners' active involvement in the process of knowledge construction (Saunders, 1992).

Considering the framework above, the broad focus of this study was concentrated on how practical work affects the students' conceptual understanding of the cell division concepts (mitosis and meiosis). It was also focused on how lecturers and students perceived the role of practical work in the teaching and learning of cell biology. Thus, the research questions are formulated in the light of the broad focus of this study as indicated in the next section.

1.4 Aims and research questions of the study

The main purpose of this study was to investigate the nature of the impact of practical work in the teaching and learning of cell biology at Eduardo Mondlane University in Mozambique in order to implement possible changes in the way laboratory classes are used to teach and learn cell biology. Specifically the study, using a case study approach, sought answers to the following research questions:

1. What are the students' conceptions of cell division before and after undertaking practical work in cell biology?
2. How do the laboratories activities enhance the students' understanding of cell division?
3. What are the students' perceptions of the role of practical work in the learning of cell biology?

4. What are the lecturers' laboratory work teaching experiences and views about the cell biology practical work?

In the next section, an overview of the key terms used throughout this study is provided.

1.5 Definitions of terms used in this study

Affective domain refers to motivating students and influencing their attitudes towards science.

Alternative conceptions refer to experience based explanations by which a learners makes a range of natural phenomena and objects intelligible.

Alternative framework refers to students' conceptions which are valuable in many everyday contexts, and are not just wrong and hindrances to learning.

Basic process skills refer to intellectual skills which pertain to the process of generating and validating knowledge experimentally.

Cell division refers to a process occurring in living organisms that consists of mitosis and meiosis divisions.

Cognitive domain includes the development of conceptual understanding and intellectual skills such as problem-solving, creative thinking and increased understanding of the methods of science.

Conceptual change refers to meaningful learning occurring when a learner accepts new conceptions on the grounds that they intelligible, plausible and fruitful. The parts of the existing conceptual network are reorganized.

Conceptual framework in this study was used as a formal way of thinking or conceptualise about the problem under study which formed the basis for structuring the research questions and seeking for possible results of the study.

Conceptual growth refers to enlargements of the conceptual network in such a way that one's previous knowledge and its connections, for the most part, remain intact.

Conceptual knowledge/understanding is used in this study to include the ideas and concepts of cell biology such as cell cycle and cell division mechanisms.

Constructivist view refers to a perspective in science which draws attention to the active role of the learner and the interplay between existing and 'new' knowledge.

Inquiry methods refer to those activities which contributes to the students' progress by engaging them in scientific investigations and problem-solving (students construct scientific knowledge though processes such as developing questions, empirically testing hypothesis, designing experiment, gathering data and synthesizing information about problems).

Laboratory activities refer to activities which students are required to perform during laboratory sessions (e.g.: observe, analyse and interpret events or phenomena occurring to objects or events, collect data, apply concepts, measure, explain or make decisions about experimental techniques, compare and contrast results, predict results, formulate hypotheses, apply experimental techniques).

Meaningful learning in this study is described as a theory which emphasises that the process of learning will only be significant if a new concept or idea to be learned is connected with success by the learner into existing system of prior knowledge that the learners already have.

Meiosis refers to a nuclear division mechanism by which the parental number of chromosomes is reduced by two half (to the haploid number) for the forthcoming gametes.

Misconception refers to a conception that is wrong from the science point of view**.**

Mitosis refers to a nuclear division mechanism that maintains the parental chromosomal number in daughter cells.

Phenomenological analytic approach refers to a research specialized in describing the ways of experiencing phenomena. It characterizes the qualitatively different ways that phenomena may be experienced (i.e. conceptualized, viewed, perceived, understood, etc.).

Practical domain consists of manipulative skills, development of intellectual skills and strategies in performing scientific investigations, including the students' scientific attitude communicative and cooperative skills.

Practical work refers to practical activities that include demonstrations, discussions, simulations, exercises, observations or manipulations of real objects and materials by students and fieldwork. The students working in pairs or small groups of three or four are guided by the teachers and the teaching materials to observe and interpret events or phenomena occurring to objects.

Procedural knowledge/understanding refers to the procedures of experimental, investigational work (e.g. observe, analysis and interpret events or phenomena occurring to objects or events, collect data, apply concepts, measure, explain or make decisions about experimental techniques, compare and contrast results, predict results, formulate hypotheses, apply experimental techniques) taking place during laboratory classes.

1.6 Overview of the following chapters

This section describes the overview of the chapters in terms of the outcomes and activities conducted in the different stages of this study, as follows:

Chapter one details the rationale for the study, the research questions, definitions used in the study and the conceptual framework underpinning the study.

Chapter two presents the theoretical background (literature review) used for exploring the influence of practical work to teach and learn cell biology concepts.

Chapter three reports on the methodology, approaches and processes employed to carry out the study.

Chapter four presents and discusses the findings of the study in the light of the extant literature review and the conceptual framework underpinning this study.

Finally, Chapter five synthesises the main findings of the study and presents some conclusions. It also includes some recommendations for teaching natural science courses, particularly, cell biology through practical work, and for incentive further research in science education in Mozambique.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A literature review enables one to deal with many aspects concerning the problem to be investigated. It is crucial that researchers are aware of what kind of research has been carried out in the same field and what kinds of methods have been used to investigate the research problem at hand. The main objective of this chapter was to gain some insight into the potential role of practical work in science curriculum. It is hoped that these insights will expand our knowledge of the use of practical work to improve students' conceptions, as well as to enhance the students' understanding of cell biology concepts. Thus, the literature review aimed to:

- explore the role of practical work in the science curriculum;
- discuss the importance of the inquiry methods in teaching laboratory activities;
- identify the contribution of the meaningful learning in the process of learning;
- examine the issues concerning the constructivism and conceptual change to learning and knowing processes;
- illustrate some of the factors influencing the current practices in practical work.

2.2 The role of practical work

Many curriculum development projects undertaken in science during the 1960s and 1970s indicated that practical work had gradually acquired an increasingly prominent place in the school science curriculum and was accepted worldwide as an integral part of science education at all levels. However, evidence to show its prominence remain less clear (Kempa, 1987; Tamir, 1991; Hodson, 1998; Watson, 2000). The lack of clarity of its objectives – what the students are required to learn from their experiences in practical work, its effectiveness in developing what it intends to obtain, its use for teaching conceptual aims and the strategies for the development of practical procedural knowledge and its use in investigations is seen as a major hindrance in achieving the educational aims of science (Kahn, 1990; Osborne, 1996; Watson, 2000).

Although most scientists share the same ideas about the functions of the laboratory sessions in the teaching and learning processes, opinions concerning the role of practical work are divergent (Tamir, Doran & Bathory, 1992). According to Hofstein & Lunetta (1982), laboratory activities are important in promoting practical comprehension of certain aspects of the nature of science. Also they improve intellectual and conceptual development, as well as contribute to the development of positive attitudes towards science. The same authors see the process of developing abilities in problem-solving for being a crucial element of the laboratory activities. Kaptein (1987) and Tamir *et al*. (1992) regard practical work as the study of natural phenomena through observations and experiences to be carried out carried on in the laboratory or in the field.

Meanwhile, Tamir *et al*. (1992) caution that the role of practical work during curriculum reforms of the 1960s did not only centre on verification and demonstration, but also, on the science learning process. This process includes: formulating hypotheses, collecting and recording data, organising and interpreting the findings and formulating conclusions and generalisations. In that way practical work must be seen as a means for acquiring direct experiences.

Mech (1990) believes that practical work consists of physical and intellectual skills, which differ to some extent from those used in non-practical work activities. According to her practical skills cannot be acquired through symbolically coded media or even through observation. They require active involvement of the learner in the actual performance because these skills cannot be acquired passively through observation and teacher demonstration. In the same line of thought, Tamir *et al*. (1992) name this process which involves the acquisition of practical skills in the context of actual laboratory investigation of field setting, the 'practical mode'. That is, practical work must be seen as a particular mode of thought and action in which reasoning, planning, problem-solving and explaining, interacting with manipulations, observations and other psychomotor activities. In addition, Tamir *et al*. (1992) point out three fundamental reasons for doing practical work: (i) the practical work is important in providing concrete, direct experience; (ii) the practical work promotes the use of scientific methods; and (iii) the laboratory is a means for promoting positive attitudes towards science.

Millar, Le Marechal & Tiberghien (1999) define practical work as those teaching and learning activities in science which involve students at some point in handling or observing real objects or materials they are studying. In this definition, there is no restriction on where the work is carried out. Practical work might be carried out in a laboratory or outside in the field or in an ordinary classroom. This Profile Form allows differentiating the intended learning outcomes of a practical task as well as describing the different aspects of the task design, that is, what learners are to do with the physical objects and science ideas, how open or closed the task is, and the nature of the learners' involvement in the task. Also, the context of the task is identified, that is, the duration the people with whom the learner interacts, the way instructions are provided, and the type of apparatus used. Lastly, the characteristics of the practical reported are documented in terms of its nature, purpose and audience.

Other studies conducted on the role of practical work show that the main reasons usually given to justify practical work in science could be summarized in various ways (van den Berg & Giddings, 1992; Hodson, 1993; Caillods, Göttelmann-Duret, & Lewin (1997). Haddad and Za'rour (cited by Calloids *et al.*, 1997) consider four assumptions related to practical activities: (i) it fulfils the stated objectives of science teaching, especially those related to inquiry and discovery; (ii) it is necessary because science is essentially experimental; (iii) it is justified on psychological and pedagogical grounds; (iv) it has positive effects on educational outcomes that can be empirically verified. These four assumptions can be described as follows:

- The *first* assumption assumes an unrealistically wide exposure to practical work, which can be achieved through alternative (and less costly) teaching methods. From this assumption one can expect students to acquire most of the skills in order to become a professional scientist in short time (e.g., 2 or 3 hours per week when they are exposed to practical activities).
- The *second* assumption risks the devaluation of the non-experimental aspects of science – conceptualising, modelling, theoretical analysis – in favour of what some have labelled "privileging the practical".

- The *third* assumption rejects the position that "adolescents who have moved well into the stage of formal operations should be able to think abstractly without the need of referral to objects to aid in conceptualising or abstracting". It means that most adolescent studying science have reached the Piagetian formal operations stage (thinking), which is not correct.

- The *fourth* assumption is not at all easy to demonstrate. As noted earlier, higher levels of practical activity and provision are generally not associated with higher levels of achievement on conventional assessments, as the outcomes of practical work may sometimes not be assessed.

2.3 Aims of practical work

In order to understand the reasons for carrying out practical work in science education several studies have been conducted on teachers' views about the aims of practical work. In this regard, Kerry (1963) reported on 10 aims of practical work in secondary science education. The aims resulted from a survey of 701 science teachers from 151 schools in England and Wales. The survey was conducted to investigate the nature, purposes, assessment, and views about practical work teachers had encountered in schools. In this study teachers shared a common understanding on the significance of practical work for the development of educational values. However, they showed inconsistency between the kinds of experiments they performed. Teachers used more frequently verification experiments neglecting demonstration work. Theory and practices were not adequately integrated. The study showed also that although teachers were doing plenty of practical work, the educational value often claimed for it was not archived. The failure to accomplish it was linked to the poor conditions for practical activities coupled with the class size, laboratories facilities and technicians. In addition to this, Kerry (1963) proposed the need to concentrate on the development of practical skills rather than meeting examinations requirements as well as the need for greater integration between stated objectives and actual practice.

Based on Kerr's (1963) study others surveys were initiated, such as by Beatty & Woolnough (1982), and by Swain, Monk, & Johnson (1999). Beatty and Woolnough (1982) added 10 aims to Kerrs' list to form 20 aims for their study. The produced 20 aims were further used in the study by Swain *et al*. The 20 aims produced by Beatty and Woolnough (1982) including the 10 aims compiled by Kerr (1963) are outlined bellow in Table 2.1. The aims marked with * are the 10 originally used by Kerr. These aims were used in the study conducted by Swain *et al*. (1999) comparing teachers' attitudes to practical work in science education in Egypt, Korea and the UK.

The results of the Swain *et al*. (1999) study revealed that the three groups of science teachers regarded the importance of the aims of practical work to teach science differently. The Korean teachers value practical work more highly than their UK teachers in being able to use the following aims of practical work: (i) for finding facts and arriving at new principles; (ii) as a creative activity; (iii) to verify facts and principles already taught; (iv) to elucidate theoretical work as an aid to comprehension and; (v) to help remember facts and principles. The aims indicated by the Korean teachers are more content focused while the UK science teachers appear to be offering a view that is more investigation oriented. For instance, amongst this set of aims, 'elucidating theoretical work as an aid to comprehension' shows the smallest difference with UK teachers while the aim on 'creative activity' shows the largest difference from the UK teachers. For the Egyptian science teachers, they rated the following more highly than did the Korean science teachers: (i) to develop self-reliance and (ii) to develop specific manipulative skills. The Egyptian science teachers showed a combination of aims as compared to the UK teachers as for example, 'creativity' and self-reliance' together with 'following standard techniques', which appears as an unworkable combination. The Korean science teachers show a strong tendency towards a positivistic approach to science comparing to their counterparts UK teachers. Furthermore, as with the comparison between the Egyptian and UK science teachers the Egyptian teachers were distinguished as not having included the aims on 'making phenomena more real, or 'arousing and maintaining interest'. According to Swain *et al*. (1999) the inclusion of these aims might only become self-evident when teachers do indeed plan and use practical work in their science teaching. Because the Egyptian science teachers generally do very little practical work with their students this might be one of the reasons of why they did not include from the sets developed in the analysis.

However, Watson (2000) contends that despite changes in the kinds of practical work done over time, in all the three studies, four main aims remained such as: (i) to encourage observation and description; (ii) to make the phenomena more real; (iii) to arouse and maintain interest and (iv) to promote logical and reasoning method of thought. On the other hand, Parkinson (1994) considers that beside these four aims there are a whole host of reasons for carrying out practical work adding the following aims: (i) motivates and promotes interest to do science; (ii) teaches skills to make accurate observations; (iii) teaches manipulative skills; (iv) helps promote logical thinking; (v) helps to understand or accept theory; (vi) provides opportunity to develop communication skills and (vii) provides opportunity to learn through group discussion and to work as a team.

Table 2.1: The 20 aims from Beatty and Woolnough (1982).

Aims of practical work	
1	As creative activity
2*	To make phenomena more real
3	To help remember facts and principles
4*	To practice seeing problems and seeking ways of solving them
5	To indicate the industrial aspects of science
6*	To promote a logical reasoning method of thought
7*	To encourage accurate observation and description
8*	For finding facts and arriving at new principles
9	To be able to comprehend and carry out instructions
10*	To elucidate theoretical work as an aid to comprehension
11	To develop self-reliance
12*	To arouse and maintain interest
13	To develop an ability to communicate
14	To develop ability to cooperate
15	To develop certain disciplined attitudes
16*	To develop specific manipulative skills
17*	To verify facts and principles already taught
18	To develop a critical attitude
19	To give experience in standard techniques
20*	To prepare students for the practical examinations

Source: Swain *et al.* (2000)

Furthermore, relative to the implementation of the Kerr's (1963) aims of practical work, examples of two studies conducted in African context are to be mentioned. These are from Ghebremariam (2000) in physics and Fessehatsion (2003) in chemistry. Both studies were conducted in Eritrea with secondary school teachers. In the Ghebremariam (2000) study the physics teachers rated the aims of practical work in order of importance as follows: (i) to verify facts and principles already taught or to determine cause and effect; (ii) to make physical phenomena more real through actual experience; (iii) to encourage accurate observation and careful recording; (iv) to arouse and maintain interest in the subject and; (v) to promote the understanding of scientific methods or techniques. In the Fessehatsion (2003) study the chemistry teachers rated the most frequent aims as follows: (i) to verify facts and principles already taught; (ii) to make biological, chemical and physical phenomena more real through actual experience; (iii) to arouse and maintain interest in the subject; (iv) to give training in problem-solving and; (v) to develop manipulative skills.

In order to elucidate the magnitude of the practical work in developing conceptual knowledge, procedural knowledge and positive attitudes towards practical work Guzman (2000) categorizes the goals of the science laboratory instructions into five categories as follows:

- **Conceptualisation and illustrative goals:** practical work illustrating reactions, principles, and theories discussed in lecture, illustrating mechanism of reactions, and makes abstract concepts more concrete.
- **Cognitive Goals:** during practical work students learn how to develop systemic and critical ways of thinking and problem-solving abilities, opportunities to diagnose and dispel their misconceptions, apply knowledge and skills to new and unfamiliar situations as well as to remember the central idea of an experiment over a significantly long period of time.
- **Psychomotor Goals:** practical work teaches manipulative skills and provides experience using equipment and instrumentation.
- **Processing Goals:** practical work helps students to develop scientific inquiry skills, such as observation, description, and estimation of measurements, data manipulation, and evaluation of results. It also helps students understand science as a process of scientific inquiry and hypothesis generation.
- **Affective Goals:** practical work provides a model of scientific inquiry and fosters a sense of success, motivation and control. It also promotes positive attitudes towards science.

Moreover and according to Dekkers (1997) quoting (Kempa, 1988 and van den Berg, 1992), various authors categorize the aims of practical work in the process of developing knowledge, skills and attitudes into three domains: affective, practical and cognitive domain. Affective domains refer to motivating students and influencing their attitude towards science. The practical domain comprises manipulative skills, development of intellectual skills and cognitive strategies in performing scientific investigations, including the students' scientific attitude communicative and cooperative skills. The cognitive domain includes the development of conceptual understanding and intellectual skills such as problem- solving and creative thinking.

Similarly, Hofstein & Walberg (1995) point out that the laboratory activities traditionally have been used for a wide variety of cognitive, practical, and affective goals. Their descriptions of these three goals do not differ from those provided by Dekkers (1997). The only difference is Dekkers naming goals as domains. On the other hand, Griffin (1998) classifies the goals of practical work in school science into three main categories: (i) deepen understanding of scientific ideas (practical work can provide experiences that reinforce theoretical ideas); (ii) experience scientific processes (practical tasks provide opportunities for the students to develop competencies in learning to investigate and solve problems), and (iii) acquire scientific research skills (practical work contributes in developing the skills of manipulation, scientific procedures and problem-solving. In this list, Griffin (1998) adds a set of sub-goals such as: self-motivation, simulation of creativity, recognition of relevance of scientific understanding, and simulation of thought.

Based on the literature (Woolnough, 1991) proposed a taxonomy of aims and objectives of practical work structured under five main headings: (i) understandings concepts (declarative knowledge); (ii) acquiring habits and capacities; (iii) gaining skills (procedural knowledge), including planning and designing, performance, organization, analysis and interpretation of data, and application to new situations, (iv) appreciating the nature of science, and (v) developing attitudes. But, the same author cautions that the outcomes of these aims and objectives can be accomplished only if the students are provided with opportunity to be involved in the necessary experiences.

For Tamir (1991) there are five main reasons which form the rational for the school science laboratory:

- Science involves highly, complex and abstract subject matter. Many students would fail to comprehend such concepts without the concrete props and opportunities for manipulation afforded in the laboratory. Practical experiences contribute effectively in inducing conceptual development.
- Students' participation in actual investigations, employing and developing procedural knowledge often referred to as skills, is an essential component of learning science as inquiry. On the other hand, science laboratory activities give students an opportunity to appreciate the spirit of science and promotes problem-solving, analytic, second generalizing ability as well as it allows the student to develop scientific attitudes.
- Practical experiences independently of being manipulative or intellectual, are qualitatively different from non-practical experiences and are essential for the development of skills and strategies with a wide range of generalizable effects.
- Laboratory has been found as offering the unique opportunities conducive to the identification, diagnosis and remediation of students' misconceptions.
- Students usually enjoy activities and practical work, and when they are offered and given a chance to experience meaningful and non-trial experiences they become motivated and interested in science.

However, the implementation of the above rationale in the school science laboratory depends on how the research supports its effectiveness. In the light of this, Tamir (1991) provides some reasons which contributed to the failure of the effectiveness of laboratory. For instance, the reviewers of the literature up to the beginning of the 1980s indicate that the reason for this failure might be that past research studies generally examined a relatively narrow range of teaching techniques, teacher and student characteristics and students outcomes. Another reason is coupled with the way practical work is used in science courses at all school academic levels. There is a misuse of the time during laboratory sessions in that students spend many valuable hours collecting and manipulating empirical data which, at the very best, help them rediscover or exemplify principles that the instructor could present verbally and demonstrate visually in a matter of minutes (Tamir, 1991, pp. 14-15).

Hofstein & Lunetta (2003) point out that among several reasons mentioned in the literature the one prominent is that teachers lack as a whole the perception that laboratory activities can be the main vehicle in enabling students to achieve science knowledge in a meaningful way by engaging the students in laboratory activities in such a way that development of science concepts can be promoted. In addition, the same author refers that many teachers do not understand that helping students understand how scientific knowledge is developed and used in a scientific community is an especially important goal of laboratory activities for their students behave or conduct laboratory activities.

A study conducted by Bekalo & Welford (1999) in Ethiopia points out that the secondary school pre-service teachers conceptualise practical work in different ways. For instance, in the teacher training for physical science the planning and carrying out practical work and the assessment of abilities in practical work were completely neglected. Teacher educators did not recognize practical as being other than routine procedures involving the following of instructions to arrive at predetermined problem solutions. This situation can be linked to the lack of the necessary practical skills to organize, carry out and evaluate investigative science activities by the tutors themselves. This leads to teachers not seeing practical work as an important tool to teach science at schools even when the laboratory conditions and resources are available.

Hodson (1998) in trying to explore and develop personal understanding through practical work he points out that the teachers see often practical work as a means of obtaining factual information and data from which conclusions are later drawn. He goes further by stating that: "it has usually been assumed that these data are 'pure' and 'unaffected' by students' exiting ideas and, therefore, students have not only usually been involved in the design and planning of experimental investigations" (p. 146). This kind of teaching approach does not contribute to students construct their personal meaning of the scientific knowledge in a meaningful way it that it fails to engage them in the thinking that precedes and experimental investigation (ibid.).

There are many other factors influencing the current practices in practical work, for instance, interrelationship between practical work and curricula, resources availability, assessment strategies, classroom environment, large number of students, laboratory instructions, subject content orientation, and time allocated for laboratory activities (Hodson, 1992; Lazorowitz & Tamir, 1994; Calloids *et al*. 1997). Adding to these factors, theoretical argument and research evidence from several other authors have reinforced the claim that the way practical work is conducted in many schools, is ill-conceived, confusing and unproductive resulting in little understanding of what goes on in the laboratory classes and consequently, contributing little to the students' learning or understanding of science in a meaningful way (Watson, 2000; Lazorowitz & Tamir, 1994; Hodson, 1990).

In the same line of thought, Woolnough (1991) contests the excessive practice of standard-exercises in which the student is expected to follow the 'cookbook' instructions, that is, 'recipe-style' during laboratory. He cautions that this kind of practical work does little to enhance students' understanding of the concepts of science and nothing to enhance their appreciation of the methods of science. He continues to say that despite its centrality in the science programmes schools in many countries it involves a vast amount of teachers' time, efforts and expenses which might contribute to the ineffectiveness of practical work.

Hodson (1993) quoted in Watson (2000:58) carried out a study seeking to understand the effectiveness of practical work under four headings: motivation, acquisition of skills, learning scientific knowledge and scientific attitudes. He found that, in each of these four areas, school practical work leaves much to be desired. For instance, on the whole, pupils enjoy practical work and develop positive attitudes to it. However, a significant number of pupils express a dislike for practical work and consequently, the enthusiasm for practical work often declines with age. A concern here is not the participation of the pupils in practical work but the kinds of practical work used. Exemplifying, teachers regard open props (or tasks) of practical work as very motivating as motivation is improved if pupils feel a sense of ownership of investigations and greater control is given to pupils. Several studies on the acquisition of skills revealed that there is a variable success in performing such tasks. For instance, a great variability between countries, with grade eight students in Singapore and England performed significantly better than students in other countries, on practical tasks designed to test skills such: measuring the use of simple experimental and mathematical procedures; designing and implementing approaches to solve problems or investigate phenomena and synthesizing knowledge, application, and personal experience into an interpretation of the data.

According to the studies, there is also variability between different skills and process. An example of that is reported in the APU study (1985). In asking 15-year-olds to read pre-set values on several simple measuring instruments they performed differently. For instance, fewer than one in five correctly read an ammeter and only about half correctly read the value on a rule. The performance was better in reading a thermometer and a force meter. However, only about 50% of pupils performed simple observations successfully. It means that the planning of investigations can support pupils in the acquisition of skills.

Little evidences have been reported in the research literature regarding the effectiveness of practical work in helping students to learn scientific knowledge and methods of science (Hodson quoted in Watson, 2000). However, a recent study conducted by Watson, Prieto & Dillon (1995) comparing the understanding of two groups of 150 fifteen-year-old pupils exposed into different curriculum, namely: curriculum with a high practical content in England and curriculum with a low practical content in Spain gave typical results. In spite of having substantially more practical experience with combustion, the English sample showed few differences from the Spanish in either their scientific or naïve conceptions about combustion. These results show that the amount of students exposure to practical experiences does not necessarily implies improving their scientific knowledge. What counts is how practical work is used to help students develop the understanding of scientific concepts and capability to carry out scientific investigations. In the next section different types of practical are described as well as its contribution to the attainment of the practical work objectives.

2.4 Types of practical work

Research on practical work issues and approaches indicate that various attempts have been made to classify different types practical work activities as a way of defining their respective roles. Wellington (1994:132) considers that different types of practical activities can be appropriate for different aims of practical work as indicated in Table 2.1 above. In this regard, he points out that there are at least six possibilities for organizing and carrying out practical work in the average school situation with its usual constraints: (i) demonstrations (used to illustrate events or phenomena); (ii) class experiment (small group activities performing similar task) ; (iii) circus of experiments (small groups on different activities in a 'carousel', spread over chunks of a lesson or over several lessons); (iv) simulations and role-play (activities based on simulations with real events); (v) investigations and; (vi) problem-solving activities.

For Parkinson (1994: 105) the nature of the type of practical tasks undertaken varies from classroom to classroom. He classifies the types of practical work into four categories:

- **Learning basic skills**: pupils will develop these skills as their carry out practical activities.
- **Illustrating a theory or concept**: pupils will have a better understanding of a scientific idea if they have observed an experiment to illustrate that idea.
- **Providing a theory**: pupils are required to generate the 'correct' scientific answer by carrying out experiments.

- **Investigative work**: pupils are required to plan their own experiments, carry out and draw their own conclusions about the experiments.

Furthermore, Woolnough (1991) based on the research literature characterizes practical science as a holistic activity and as consisting of three types; namely: investigation, exercises and experiences. These three types are similar to those suggested by Woolnough & Allsop (1985). According to Woolnough (1991) the first type of practical, *investigation* constitutes the heart of the scientific activity and no matter what kind of investigation is or how long it will last. He goes further asserting that "the process of planning, performing, interpreting and communicating, with its continual modification through feedback is fundamental to the way scientists work" (p. 186). The second type, *exercises* is important when the scientific activity requires the development of a particular skill and, the third type, *experience* is designed specifically to give the students a feel for the phenomena under investigation. It also allows the scientists to build up personal experiences and tacit knowledge important to form the basis for the subsequent action and understanding as links are formed during investigations. However, Woolnough & Allsop (1985) on their discussion about the varieties and aims of practical work pointed out that practical work is abused when laboratory activities do not match to its aims.

Tomlinson (1991) in discussing the methods used to achieve the aims of practical work, added one type of practical work to the four major types used by science teachers for his discussion: (i) standard exercises; (ii) discovery experiments; (iii) demonstrations; (iv) projects and; (v) 'book' experiments (his addition). In adding the fifth type, Tomlinson (1991) makes the following argument "many experiments cannot be performed as practical exercises or as demonstrations for a variety of reasons such as the lack of time, the excessive cost of apparatus, possible dangers of the experiment or the time it takes to complete the work" (p. 9). He sees this kind of practical work as being an important technique as it can encourage critical thinking as well as provide students with opportunity to be exposed to scientific papers. In this way their analytical framework in terms of results of experiments and observations during investigations could be improved.

Domin (1999) in his review found four distinct styles of laboratory instruction that have been prevalent throughout the history of chemistry education, namely: expository, inquiry, discovery, and problem-based activities. He differentiated these styles by three descriptors: *outcome*, *approach* and *procedure* as indicated in Table 2.2. According to him the outcome of any laboratory activity is either 'predetermined' or 'underdetermined', the approach can been 'deductive' or 'inductive'. The Procedure to be followed for any laboratory activity is either designed by the students or provided to them from an external source (e.g. Instructor, laboratorial manual, or a handout).

Table 2.2: Descriptors of the laboratory instruction styles

	Descriptor		
Style	**Outcome**	**Approach**	**Procedure**
Expositor	Predetermined	Deductive	Given
Inquiry	Undermined	Inductive	Student generated
Discovery	Predetermined	Inductive	Given
Problem-based	Predetermined	Deductive	Student generated

Gott & Dugan (1995) emphasize that several attempts have been made in trying to classify the kinds of practical in order to define their respective roles. Based on the classification developed by Gott *et al*. (1988), they summarize the types of practical work into five broad categories as displayed in the Table 2.3.

Table 2.3: Summary of different types of practical work

Type of practical work	Aims of practical work
Skills	To acquire a particular skill
Observation	To provide opportunities for pupils to use their conceptual framework in relating real objects and events to scientific ideas
Enquiry	To discover or acquire a concept, law or principle
Illustration	To 'prove' or verify a particular concept, law or principle
Investigation	To provide opportunities for pupils to use concepts, cognitive processes and skills to solve a problem

The five types of practical work developed by Gott *et al.* (1988) and described by Gott & Dugan (1995) were further elaborated by Bekalo and Welford (1999) in their survey with the secondary pre-service teacher education in Ethiopia as follows:

- **Basic skills**: measurement, selecting and use of appropriate instruments, following instructions and the constructions of tables, charts and graphs from data generated from students' experiments or drawn from other sources.
- **Observation**: observing similarities or differences and changes between objects and/or events, generating classifications of patterns.
- **Illustration**: showing (often through teachers' demonstration) given phenomena, concepts, laws or principles in action.
- **Enquiry**: 'discovery' a concept in a series of more or less structured activities, usually designed for students to carry out investigations following instructions to find out, confirm or 'see' a concept in action.
- **Investigation**: designing and carrying out an entire investigation, which includes examining the data of the investigation and drawing conclusions from them.

However, Gott & Dugan (1995) caution that in order for the various types of practical work listed by several authors be implemented professionally it is important that teachers be precise about the required learning outcome of the lesson and according to this decide whether practical work is the best way of achieving that goal

2.5 Practical work and meaningful learning

In attempting to explain the importance of meaningful learning several classification schemes of practical work have been reported in the literature. Many authors have reported on the importance of meaningful learning and how practical work can contribute to promote meaningful learning. Lowe (1993) promotes Ausbelian learning theory which emphasises that the process of learning will only be meaningful if a new concept or material to be learned is connected with success by the learner into existing system of knowledge that the learners already have. Piaget (1974) and other psychologists assert that the learner must be active to be engaged in real learning and the process of learning becomes active when students are able to connect new knowledge with their prior understanding. In addition, Thanasoulas (2001) argues that if a learner is able to perform in a problem-solving situation, meaningful learning should then occur because he has constructed an interpretation of how things work using pre-existing structures. A personal interpretation of external ideas and experiences allows the learner to construct their own understanding about how these ideas can be related to each other and pre-existing knowledge.

According to Sanders (1988) inquiry-based practical work can help the learner make a linkage between a new concept or idea and the existing prior knowledge. If this linkage does not occur, the learning process will result in rote learning and memorization of the concepts. Similarly, Hodson & Reid (1988) argue in favour of a learning experience in which the consideration of prior theories and the exploration of existing ideas can contribute to the effectiveness of practical investigations. The same authors suggest that a learner needs to be equipped with an adequate theoretical understanding (real understanding of ideas, and the development of physical manipulative skills). Only in that way will he/she be able to make appropriate observations and practical work can contribute to promote meaningful learning.

In addition, and according to Calloids *et al*. (1997) other authors refer to the need of stressing the importance of direct experience and 'personal response' to science that may result from practical work. In doing so, practical work carefully arranged can create the conditions for meaningful rather than rote learning (Head, 1985) and shift the balance from reception of information to interaction and manipulation of ideas (Novak, 1984). Similarly, Tsaparlis & Gorezi (2005) consider that for meaningful learning to occur, students have to be given sufficient time and opportunities for interaction and reflection in the laboratory. This will force them to take control of their own learning in the search for understanding.

2.6 Practical work and inquiry methods

According to Tamir *et al*. (1992), German, Haskins, & Auls (1996) and Crawford (1998), inquiry-based laboratory activities can contribute to the students' progress in science. In inquiry-based learning teachers engage their students in scientific investigations and problem-solving. From this point of view, practical work promotes students' construction of scientific knowledge through processes such as developing questions, empirically testing hypotheses, designing experiment, gathering data and synthesizing information about problems. Also, students are required to use their knowledge of concepts, principles, theories, and laws together to construct new explanations concerning the natural objects and events (Rutherford & Ahlgren, 1990).

Trowbrigde, Bybee, & Powell (2000) support the idea that by giving students the freedom to inquire, they are able to create and discover new information in order to solve novel problems. An inquiry based science laboratory can be helpful in providing more cognitive involvement and improving thinking ability as opposed to traditional laboratory activities. In addition, linking inquiry methods and constructivist views of learning (nature of scientific knowledge, inquiry and problem-based learning, generative learning, exploratory learning, cooperative learning, active construction of meanings, validation procedures of the acquired knowledge) can be useful to construct laboratory classes. However, according to Crawford (1998) inquiry-based instruction requires the most expert teachers. Crawford (1998) cautions that to create this kind of instruction, there is a need to prepare inexperienced (novice) teachers in several domains of teaching, including pedagogical content knowledge, knowledge of students, and knowledge of the classroom.

Similarly, Zion, Shapira, Slezak, Link & Mendelovici (2004) caution that in spite of all the benefits of using inquiry methods to teach science, inquiry has not gained prominence in most science classrooms in recent years. They point out some examples of studies, in which it was found that teaching through inquiry has a limited influence in high schools. For instance, the results of a study conducted in Israel revealed that students who carried out inquiry work in a conservatory acquired declarative and procedural knowledge of inquiry skills, and did not necessarily gain the conceptual or logical knowledge they might be expected to acquire during problem-solving process. It was also observed that students experienced difficulty in understanding the role of control and the proper planning of an experiment in order to solve a biology problem in laboratory classes resulting in a misunderstanding of the nature of science.

Tamir (1983) points out some evidence of the effects of the inquiry methods on students' learning and attitudes in the U.S. He states that some studies reported positive benefits while others reported that the inquiry method is not an adequate way of teaching science. For instance, the new curricula illustrated positive impacts on the student performance in the U.S. for 17 out of 18 performance criteria (e.g. general achievement, attitudes towards science, process skills, problem-solving and creativity). He indicates that the effects of the inquiry were great for biology, and medium and poor for earth science and chemistry respectively.

2.7 Constructivist views of learning

The above descriptions on the meaningful learning and inquiry methods can be viewed as being important in that they involve students in an active learning process, in which students are supposed to develop critical and logical thinking skills (Lawson, 1994; Zion, *et al.*, 2004). According to the same authors, this active learning process is consistent with the constructivist teaching approach and the idea that the knowledge is actively built up by the learner who is responsible for his or her own learning. This view of a learner as an active agent in constructing his own reality is at the core of Piaget's genetic epistemology, with its notion of an internal principle of organization that determines all living processes and changes, that is the actions form the basis on which the underlying structure of reality is constructed (Mutimucuio, 1998).

Similarly, Hewson (1993) and Sadeck (2000) denotes that constructivism is based on the belief that humans construct their knowledge, more particularly scientific knowledge, personally and/or socially, on the basis of what they already know. This view is largely based on the work of Ausubel (1968), who emphasizes the active role of the learner and the interplay between exiting and 'new' knowledge (Leach & Scott, 2000). In other words, Ausubel emphasizes the importance of the children's prior knowledge by suggesting that the meaningful learning will only occur if some connection is made with what already exists in the mind of the child. Because of this view, the process of learning is understood as the construction of knowledge by the individuals through a process that occurs as sensory data are assigned meaning in relation to prior knowledge (Ogunniyi & Mikalsen, 2004, p. 153). This means that the students do not enter into the learning situation with blank minds, that is as '*tabula rasa'* or receive instruction in a neutral way. Contrary, they approach experiences presented in the science classroom with previously acquired ideas or notions that influence what they learn. Among others, previous ideas include observations made of events within and outside the classroom, interpretations offered for such observations and strategies or process skills that are used to acquire new knowledge, including reading from texts and practical activities (ibid).

According to Akkus, Kadayiçi & Atasoy (2003) the constructivist view is regarded as a very powerful and influential perspective to many science educations research studies. In this view, the most important ingredient in the process of learning is the interaction between new knowledge and existing knowledge. Because of its importance in the process of teaching, Hodson (1996) quoted in Akkus *et al*. (2003) has summarized the main four steps of the constructivism approach as follows: (i) identify students' ideas and views; (ii) create opportunities for students to explore their ideas; (iii) provide stimuli for students to develop, modify and where necessary, change their ideas and views; and (iv) support their attempts to re-think and reconstruct their ideas and views. In this case, the teacher will act as a facilitator to provide support to help students find information or break down problems. Since meaningful learning or understanding is constructed in the internal world of the learner as a result of his/her sensory experiences with the world, more effective learning activities should be developed to help students acquire meaningful learning in place of rote learning. This will enable students to construct and organize their knowledge in a way that can direct them to the use of required information accurately.

The theory of constructivism can modify the way practical work is used in the teaching of science. However, this depends on the kind of the activities that the learners are required to perform. In this regard, Shiland (1999) in examining the implications of constructivism for practical work has suggested many ways in which laboratory activities can be changed such as: open-ended activities, guided discovery approach, scientific reasoning activities and research projects to study industrial problems. He summarizes some of the implications of constructivism for modifying practical work as follows:

- Learning requires mental activities; therefore modify laboratory activities to increase the cognitive activity of the learner;
- Naïve theories affect learning; therefore design laboratory activities to learn what these are;
- Learners must be dissatisfied with their present knowledge: therefore design laboratory activities as problems to challenge their present knowledge;
- Learning has a social component: therefore design laboratory activities to include group and whole class activities;
- Learning needs application: therefore design laboratory activities to require students to find or demonstrate applications.

Based on these implications, Shiland (1999) regards the articulation of the theory of constructivism with respect to laboratory practice as a road map for the classroom teacher in designing laboratory activities, and consequently as a road map to increased learning. He goes further by stating that laboratory practice with respect to constructivism is perceived as being more than the acquisition of process skills; it is an essential ingredient in the understanding of science itself (ibid).

For Tsaparlis & Gorezi (2005) experiences in the laboratory can provide opportunities for constructing knowledge by engaging students intellectually with meaningful investigative experiences. This statement emerges by the fact that the educational constructivism has nowadays assumed two forms: (i) personal constructivism, which is associated with Piaget; and (ii) social-culture constructivism, which is linked to Vygotsky. In the latter form of constructivism, the learner constructs actively his/her knowledge, but this process is greatly assisted by interactions with peers and with the teacher who acts at the students' zone of proximal development. A social constructivist framework has special potential for guiding teaching in the laboratory. It may enhance positive attitudes and cognitive growth. In addition, the extended, reflective investigations can promote the construction of more meaningful scientific concepts based upon the unique brought to the science classroom by individual learners in dialogue with peer investigators (ibid).

2.8 Conceptual change views

The constructivist approach can be reinforced by conceptual change instruction which lets students activate and modify their existing knowledge or misconceptions

(Akkus *et al*., 2003, p. 211). On the other hand, conceptual research is regarded as important to constructivists because learning is viewed as a process of deconstructing misconceptions and reconstructing valid scientific conceptions in their place (Tobin, 1993, p. 54). Since the process of knowledge construction is regarded as a result of personal experiences, these two views requires that the instructors take into account students' prior knowledge and support students in integrating new knowledge with their existing ideas (Tanner & Allen, 2005). In this regard, Tobin (1993) asserts that "in the personal constructivist view, conceptual change occurs when a student personally find that science conceptions are more intelligible, plausible, and fruitful than her previously held conceptions (p. 54). This statement is consistent with the conceptual change theory, based on Piagets' notions of assimilation, accommodation, and disequilibrium which focus on the conditions where students' existing conceptions are modified by new conceptions (Alparslan, Tekkaya & Geban 2003). According to the conceptual change theory (Posner *et al*., 1982) when the learner is confronted with a new concept concerning, for example, evolution and genetic phenomena in biology, the new concept might be rejected, or incorporated into the cognitive structure. The later process could occur as rote memorization (weak links with existing knowledge); conceptual capture or assimilation (the new conception is assimilated into existing conceptions); and conceptual exchange or accommodation (the old conception is replaced with new one). In the case of conceptual exchange or accommodation, the new conception is reconciled with remaining conceptions. Reconciliation involves making sense of the new conception and giving it meaning by contextualizing it with existing knowledge and understanding (Holtman, 2000; Alparslan *et al*., 2003). Teaching toward conceptual change, however, requires that students consider new information in the context of their prior knowledge and their own worldviews, and often a confrontation between these existing and new ideas must occur and be resolved for understanding to be achieved, that is conceptual change can often be seen to first take place in a particular context (Gunstone & Mitchell, 1997; Tanner & Allen, 2005).

Based on Posner *et al.*'s theory, Duit & Treagust (1995); Firenze (1997); Venville & Treagust (1998); Holtman (2000); Geelaan (2000) and Alparslan *et al*. (2003) describe four basic conditions needed before conceptual exchange can occur:

- If the learners are to change their ideas they must first experience dissatisfaction with their existing conceptions;
- The learner must have a meaningful understanding of the intelligibility of the new concepts presented to him/her, that is the explanation of the new concept must be understandable; the learners knows what it means and can find a way of representing conceptions;
- The learner must be able to identify the new concepts as plausible, that is the new concepts must appear to propose solutions to problems generated by its predecessors and must be believable and consistent with other conceptions accepted by the learner;
- The learner must be able to use the new conception in fruitful ways; the new concepts must guide the learners to new insights and have potential for new discovery, that is suggest new possibilities, directions and ideas.

These four basic conditions for conceptual exchange are in accordance with the personal constructivist view (Tobin, 1994) in that they describe the process by which the learner acquires new concepts, restructures existing concepts, or exchanges concepts from one set to another. However and according to Venville & Treagust (1998) the changes in students' knowledge can be examined from more than one perspective (epistemological). They justify their position by stating that: "students can hold more than one conception at the same time and the status of these conceptions is raised or lowered depending on the context in which the learner is using them" (p.1032). Based on this argument Venville & Treagust (1998) developed a multidimensional model interpretive framework for conceptual change. They have employed this framework in their study aimed at examining changes in Grade ten students' conceptions of genes during a genetic course. The authors argue that in the view of this framework a holistic picture of conceptual change is generated by considering not only the changes in the knowledge structures that the student use to construct a scientific idea of a concept, but also the ontological, social/affective, and epistemological aspects of change (ibid). The ontological perspective can be described as a process in which students develop their conceptual understanding by changing from the ontological category to which the concepts belong. This change can be from an erroneous category to the scientifically category. For instance, in biology, the teaching sequence about the fluid mosaic model for cell membranes is done with the purpose of changing the students' ontological view of cell membranes from a static, structural view to a more process-oriented one. The social/affective perspective takes into account factors such as motivation, classroom contexts, the nature of the intervention between students and the teacher, individual students' goals for knowledge learning, and for classroom life in general which can influence the process of conceptual change. An epistemological perspective is concerned with the nature and forms of knowledge; how the knowledge is acquired and communicated to other human beings. This perspective is in consonance with the Posner *et al.*'s theory as it does not simply consider the students' knowledge about a concept but explicitly includes each student's judgement and opinion about his own conception that is, the status of the conception in the student's mind (ibid). This implies that the students must judge their opinions in terms of understand the new conception, then accept it and see that it is useful for him/her.

Jones & Eichinger (1998) in their study about conceptual change in the undergraduate biology teaching laboratory, inspired by science education research ideas from several sources, for instance, the three dimensional framework for conceptual change proposed by Tyson, Venville, Harrison & Treagust (1997) have also proposed they model the "Learning hypercycle Model”. The authors proposed this model because they were interested in investigating the phenomenon of small group laboratory learning using a social constructivist framework. For the kind of the study this model was regarded as being methodologically most appropriate for interpreting interactive learning as in the case of a biology laboratory learning group. In substantiating these arguments, Jones & Eichinger (1998) make the following claim:

> We not view conceptual change as a multidimensional; we also view collaborative laboratory learning as multinodal. At any point in a question-answer cycle, feedback may arrive from peers, laboratory objects, instructor or lab text. Such input may lead to a new question, or may affect the way the original question is processed by a learner. Because we identified multinodal as well as multidimensional processing, we name our framework the Learning Hypercycle Model (p.10).

The above descriptions on conceptual change can be applied in teaching toward understanding of major concepts in biology and achieving conceptual change for students. However, according to Tanner & Allen (2005) there is a need to first understand students’ prior knowledge, examine, identify confusions, and then provide opportunities for old and new ideas to collide. On the other hand, the same authors caution that in teaching toward conceptual change, it is counterproductive to simply cover more material and present an extensive list of few ideas without engaging students in their own metacognitive analysis. They go further by suggesting that an inquiry-based science teaching can be a useful strategy for teaching toward a conceptual change if the students are provided with opportunities to engage themselves into scientific investigations and problem-solving investigations.

2.9 Students' conceptions in Biology

Research on students' biological concepts has expanded significantly (Wandersee, Mintzes & Novak, 1994). A content analysis through mid-1986 listed more than 100 studies and a recent count suggests that the number has doubled since that time. Studies in biology have been categorized into five topical areas: students' concepts of life, animals and plants, the human body, continuity (including reproduction, genetics, and evolution), and other biological phenomena (ranging from cells to food webs). According to Cynthia, Stewart, & Passmore, (2001) in the biological sciences, students' problem-solving has been extensively studied in classical genetics. The results of these studies were consistent in revealing that frequently students do not bring knowledge of meiosis to bear when solving genetics problems. In that way, it is required that teachers pay particular attention to students' conceptions which can cause cognitive dissonance among students as this will help to guide the conceptual development of students (Wandersee *et al*., 1994). Because this study is about students' conceptions of cell division (mitosis and meiosis), some examples of the studies carried out in this subject area showing students and teachers conceptual difficulties are given below.

A study by Lewis & Wood-Robinson (2000) of 482 students showed that most students have a poor understanding of the nature of the difference between mitosis and meiosis, chromosomes and genetic information. For instance, while two thirds of the sample made some distinction between the two types of cell division only one fifth correctly recognized that chromosome numbers would halve and genetic information would vary. Regarding the general functions of mitosis and meiosis, 33% of the sample noted that mitosis was important for growth, repair and replacement of cells and 15% noted that meiosis is a preparation for reproduction. Even fewer (11%) understood the significance of these differences and could correctly locate mitotic division in somatic cells and meiotic division in germ cells. 15% noted that meiosis results in an increased variation in the next generation and 8% stated that meiosis results in a reduction in the number of chromosomes, ready for fertilization.

Similarly, Chattopadhyay (2005) conducted a study to examine the Indian higher secondary students' understanding of genetic information related to cells and transmission of genetic information during reproduction. In this study it was found that the Indian students have fragmented knowledge, which was incomplete and inconsistent in nature. They showed incoherent views of cells, chromosomes, and genetic information within cells of the same individual.

As stated by Chinnici, Yue & Torres (2004) the two kinds of cell division which form the object of the present study are often regarded as challenging for many students to understand, particularly those who are not science majors. The possibly reasons for this include the students inability to differentiate between doubling (replication), pairing (synapsis), and separating (disjunction), as well as determining whether these processes occur in mitosis, meiosis, or both. The nature of these misconceptions is coupled to the lack of understanding of the basic terms. For instance, students often confound chromatids with chromosomes, or replicated chromosomes with unreplicated chromosomes (ibid.)

In order to minimize the students' misconceptions various attempts have been by several authors develop models and/or strategies as learning aids for mitosis and meiosis (e.g. Kindfield, 1991; Kindfield, 1994; Chinnici *et al*.; 2004; Stavroulakis, 2005). Below some of the strategies developed in this regard are exemplified.

Kindfield (1991) found in his study that the most prevalent misconception showed by the participants was related with the chromosomes. The participants viewed chromosome structure as a function of chromosome number. In doing so, he suggests as implications the need of the development of an instruction that clearly defines the origin of two-DNA-molecule entities and distinguishes between chromosome structure and chromosome number in the context of eukaryotic cell cycle and representative eukaryotic life cycles as key elements for the understanding of both cell division processes.

Kindfield (1994) carried out a study on the meiosis models utilized by individuals at varying levels of expertise (expert and novices) while reasoning about the process of meiosis. The study consisted of three levels of expertises: expert, experienced novices and inexperienced novices. The *expert group* consisted of one university professor, lecturers, and two advanced graduate students from research university genetics departments. The *experienced novices* were five senior undergraduate genetics honour students at the same. The *inexperienced novices* were five undergraduate biology majors at the same university and concurrently enrolled in an introductory genetics course.

In general, the results the Kindfield (1994) study revealed the existence of meiosis misunderstanding of the kind: 'chromosome misunderstanding: structure of the chromosomes'; "event-specific misunderstanding: replication of chromosomes, crossing-over, alignment/segregation' and 'whole-process: processes of meiosis as whole' among the expertises. For instance, the expert participant' alternate models contained fewest flaws with misunderstandings related to various aspects of the one variable of meiotic event 'crossing-over', and no chromosome misunderstanding. Both groups of novice participants' alternate models contained flaws about one or more of the necessary events: replication, pairing, alignment I and II, segregation II, and crossing-over. Chromosomes misunderstanding were rare among the experienced novices and common to all inexperienced novices. Process misunderstanding about all events occurred among those novices who also showed chromosome misunderstandings. In some cases, the participants shared certain individual event misunderstandings at all three levels of expertise. Overall, the most deviant meiosis models were displayed by inexperienced novice participants (ibid.).

Öztas, Özay & Öztas (2003) in examining the difficulties biology teachers face when teaching cell division in the secondary schools of central part of the Erzurum province in Turkey they found that 42% out of 36 biology teachers perceived cell division as one of the most difficult subjects. Their findings indicated also that meiosis was particularly difficult to teach, compared to other areas of cell division. Kindfield (1994) and Yip (1998) reported similar findings. In these studies, it has been shown that the first part of meiotic division, especially chromosome movements during prophase, was the hardest part of meiotic division to explain to students. Öztas *et al*. (2003) make some speculation by stating that during the teachers' higher education, subjects such as cell division and the DNA-chromosome relationship were not well-taught to the students and therefore their understanding of the topics or confusion about the topics were reflected in their subsequent teaching. They go further by suggesting that a review of the teaching methodology of subjects such as cell division at higher education may be required in order to provide teachers with adequate level of knowledge for their teaching (ibid).

Meanwhile, the results of a study conducting by Lewis, Leach & Wood-Robinson (2000) on the processes of cell division and fertilization with 482 young people aged 14-16 showed some positive aspects. For instance, the rate of the response on the set of questions about mitosis and meiosis ranged from 79-93% and 69-86% suggesting that students felt reasonable comfortable with, and confident about, the concept of cell division. However, Lewis *et al*. (2000) caution that these results do not imply that students have no difficulties in some of the aspects of the cell division processes. A comparison of the students' responses to mitosis and meiosis showed that only 18% out of 482 students correctly distinguishing between mitosis and meiosis on the basis of chromosome number, while 22% correctly distinguish on the basis of genetic information. Overall, students showed a very limited understanding of the most basic ideas to correctly relate function, structure and location of genes. According to the same authors the actual understanding of cell division among the sample appeared to be limited, confused and inconsistent across the questions. This suggests that students lacked a coherent conceptual framework which could explain the whole set of processes.

In order to accommodate the students' difficulties in learning cell division Chinnici *et al*. (2004) suggest the use of varied materials to simulate chromosomes in various stages of cell division rather than paper and pencils strategies as learning aids. In this regard, they have developed a "Human Chromosomes Role-playing Mitosis and Meiosis" method. It is a cheap method in that only baseball and shirt tags to represent genes on chromosomes are employed. This method helps to model crossing-over during meiosis and demonstrates how genetic variability among gametes occurs as a consequence of meiosis. By wearing baseball and shirt tags students themselves act as "human chromosomes." In trying out this method, it was found that students acting as "human chromosomes" through role-playing mitosis and meiosis are proved to be an effective method to enhance learning of these important processes for non biology student in a college setting. This suggests that the role-playing of this sort would mostly likely be effective in high biology classes, as well.

Similarly, Stavroulakis (2005) suggests the use of paired-socks method to illustrate homogonously paired chromosomes. Sock modelling are seen as advantageous in that it permits classroom discussion of many important concepts in nuclear division and cytogenetics as well engages the students in the lesson, enriches and improves their understanding of both nuclear divisions. Further, socks modelling provide a hands-on method of instruction for both the students and instructor. It provides the students with opportunities to examine the meiotic process in a more dynamic way than by traditional methodologies of presenting meiotic events. In so doing, it is assumed that this approach is a stimulating alternative to a passive learning process where the instructor using textbook illustrations simply describes the origin and behaviour of homologous chromosomes during the meiotic division (Stavroulakis, 2000).

2.10 Obstacles to practical work in science

The current practice in practical work has been influenced by many factors, for instance, interrelationships between practical work and curricula, resources availability, assessment strategies, classroom environments, teacher preparedness, laboratory instructions, teaching effectiveness (Hodson, 1992; Calloids *et al*., 1997).

There are different conceptions on how curricula are perceived and how science laboratory instructions are effectively used in many science schools. According to Guzman (2000) and Lazarowitz & Tamir (1994) the nature of classroom transactions is strongly dependent on how the curriculum materials are used. The same authors argue that the curriculum materials such as the laboratory manual or the worksheets or a textbook that includes exercises determine to a large extent the opportunities to learn. However, the way teachers design the laboratory exercises or experiments may suffer from low quality because teachers often do not have time and resources available to write textbooks and laboratory manuals.

Resource availability is another crucial factor that can contribute to the success of teaching and learning science. Without adequate laboratory facilities and materials, space to store the materials, instructional materials, qualified and well-motivated and confident staff (teachers and technicians), and most students cannot learn biology in any meaningful way (Lazarowitz & Tamir, 1994). Studies have shown that adequate supply of materials makes teaching more convenient and more effective, increases the amount of students' experimental work and enables teachers to broaden the science curriculum. In addition, it improves the correlation between the extent of available assistance and frequency of laboratory experiences, and students' achievements (Lazarowitz & Tamir, 1994; Lunetta, 1998).

Assessing practical work remains problematic because it is expensive in terms of equipment, facilities and teacher time. Nevertheless, most science teachers regard it as essential for improving students' understanding of science concepts, their manipulative skills and their appreciation of the way that scientific knowledge is generated and validated (van den Berg & Giddings, 1992). Several limitations in designing an assessment procedure for practical work, for instance, apparatus available, space requirements, task grading and the procedures to be used in administrating the test, test reliability, amount of time to be scheduled for the assessment, were reported by different authors (Quisenberry, 1982; van den Berg & Giddings, 1992; Lazarowitz & Tamir 1994; Calloids *et al.*1997; Cossa, 2002). A development of an assessment model that matches the nature inquiry of a subject and not merely the curricula materials may be useful to assess the students' ability to apply science process skills (Mech, 1990).

According to Lazarowitz & Tamir (1994) and Crawford, (1998) teachers' attitudes, knowledge, skills, and behaviours are factors that can also affect the attainment of the laboratory objectives. Teaching in the laboratory requires a high level of skill proficiency, domains in the subject matter knowledge, specific pedagogical knowledge, certain specific attitudes and a readiness for risk taking. Despite many factors that influence the nature of learning in the students' practical work, the teacher is regarded as being the single factor that makes the greatest impact in the process of teaching and learning science. Several studies attempting to illustrate the way practical work is currently conducted in schools show various weaknesses and inadequacies. A description by Tobin (cited by Lazarowitz & Tamir, 1994) summarizes the general findings as follows:

> Although teachers appeared to value laboratory activities they did not implement in the manner that facilitate the type of learning that was planned…. For a variety of reasons most teachers appear to avoid laboratory investigations, particularly in classes containing low ability students. When laboratory investigations are implemented they rarely comprise an integral part of the science program. In most cases the laboratory investigations is intended to confirm something that has already been dealt with in an expository type lesson. Students are usually required to follow a recipe in order to arrive at a predetermined conclusion. As a consequence the cognitive demand of the laboratory tends to be low (p. 115).

Based on the above description, it was assumed in this study, that the interrelationships between practical work and curriculum, resource availability, learning environments, teaching effectiveness, and assessment strategies are factors that can facilitate success in science laboratory instructions.

2.11 Summary

The literature review was conducted with the purpose of understanding the potential role of practical work in science curriculum. The expectations in carrying out the literature review is to expand our knowledge of the use of practical work in improving students' conceptions, in general, as well as in enhancing students' understanding of cell biology concepts. In this regard, the literature review focused on the definitions and importance of practical work in science teaching, aims and types of practical work, importance of inquiry methods in teaching laboratory activities, contribution of the meaningful learning in the process of learning, constructivism and conceptual change views in the teaching and learning process of science and its implications for practical work, and obstacles which can affect the accomplishment of the objectives of practical work. In addition, throughout the literature review, empirical evidences of the advantages and some criticisms in using practical work to teach and learn science are described.

Several authors cited in this literature review (e.g. Kempa, 1987; Tamir, 1991; Hodson, 1998a; Watson, 2000) agree that laboratory work occupies a prominent place in the school science curriculum and that also forms an integral part of science education at all levels. Overall, there is a common understanding that practical work helps students to develop their conceptual and intellectual skills promoting the use of scientific methods; enhances the psychomotor abilities teaching manipulative skills as well as provides students with opportunities to use laboratory equipment. In addition, practical work is regarded as being important in promoting positive attitudes towards science (Tamir, *et al.*, 1992; Lazarowitz & Tamir, 1994; Millar, *et al.*, 1999; Guzman, 2000). However, some authors show some shortcomings concerning the effectiveness of practical work to teach science. For instance, Kahn (1990); Osborne (1996) and Watson (2000) caution that there is a need to clarify the objectives of practical work, its use for teaching conceptual aims and strategies for the development of practical procedural knowledge as well as investigations skills. The literature review cites the misuse of the time during laboratory sessions; excessive use of standard-exercises in the form of 'cookbook' instructions, that is, 'recipe styles' during practical work; lack of correlation between aims and types of practical work; lack of interrelationship between practical work and curricula, resource availability, assessment strategies, teacher preparedness, teaching effectiveness, etc. as factors that contribute to someone sees practical work as doing little or nothing to enhance students' understanding of the concepts and appreciation of scientific methods (Tamir, 1991; Woolnough, 1991; Hodson, 1990, Hodson, 1992; Lazarowitz & Tamir, 1994, Calloids, *et al*., 1997; Watson, 2000).

Many authors regard practical work as an important mean to promote meaningful learning rather than rote learning (e.g. Ausubel, 1968; Lowe, 1993; Thasasoulas, 2001). An emphasis is given on the need of providing students with opportunities to connect new concept with their existing prior knowledge as well as sufficient time for interactions and reflection in the laboratory. Learning experience in which the consideration of the prior theories and the exploration of the existing ideas have been regarded as contributing for the effectiveness of practical investigation (Hodson and Reid, 1988, Tsaparlis & Gorezi, 2005). The inquiry-based laboratory activities are regarded also as being important in that they can contribute to the students' progress in science by helping them to make linkage between a new concept or idea and the existing prior knowledge (Sanders, 1988).

The articulation of the constructivism theory reinforced with conceptual change instruction which lets students activate and modify their existing knowledge or misconceptions can modify the way practical work is used in the teaching of science. But this depends on the kind of the activities that the learners are required to perform (Shiland, 1999; Akkus *et al*., 2003).

The application of the conceptual change theory in the teaching towards the major concepts in biology (e.g. evolution, genetics, reproduction, cell division) can help teachers to pay attention to students' conceptions which can cause cognitive dissonance among the students. However, it is important to consider the context in which the process of conceptual change takes place, that is, the context in which the learner acquires new concepts, restructures existing concepts, or exchanges concepts (Tobin, 1993; Gunstone & Mitchell, 1998). Further research in cell biology practical work can provide us with more insights into the potential role of practical work to improve or enhance the students' understanding of the cell biology concepts as well as their investigative skills. In the next chapter, the research methodology employed in this study is described.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The purpose of this study was to investigate the nature of the impact of practical work in the teaching and learning of cell biology at Eduardo Mondlane University in Mozambique. It was hoped that findings from the study would prove to be informative and useful in the teaching and learning of cell biology at the university. As indicated in chapter 1, the study sought answers to the following questions below:

1. What are the students' conceptions of cell division before and after undertaking practical work in cell biology?
2. How do the laboratory activities enhance the students' understanding of cell division?
3. What are the students' perceptions of the role of practical work in the learning of cell biology?
4. What are the lecturers' laboratory work teaching experiences and views about the cell biology practical work?

This chapter describes the methodology used in the study and comprises the research design; sampling; development of the research instruments including piloting of the instruments; issues of validity and reliability; data collection procedures; methods of data analysis and interpretation and ethical issues.

3.2 Research methods

In order to investigate the nature of impact of practical work in cell biology course both quantitative and qualitative data were collected using a case study approach. Four different instruments (tests, questionnaires, semi-structured interviews, classroom observations) were employed to collect the data. Figure 3.1 below summarizes the research design followed in this study.

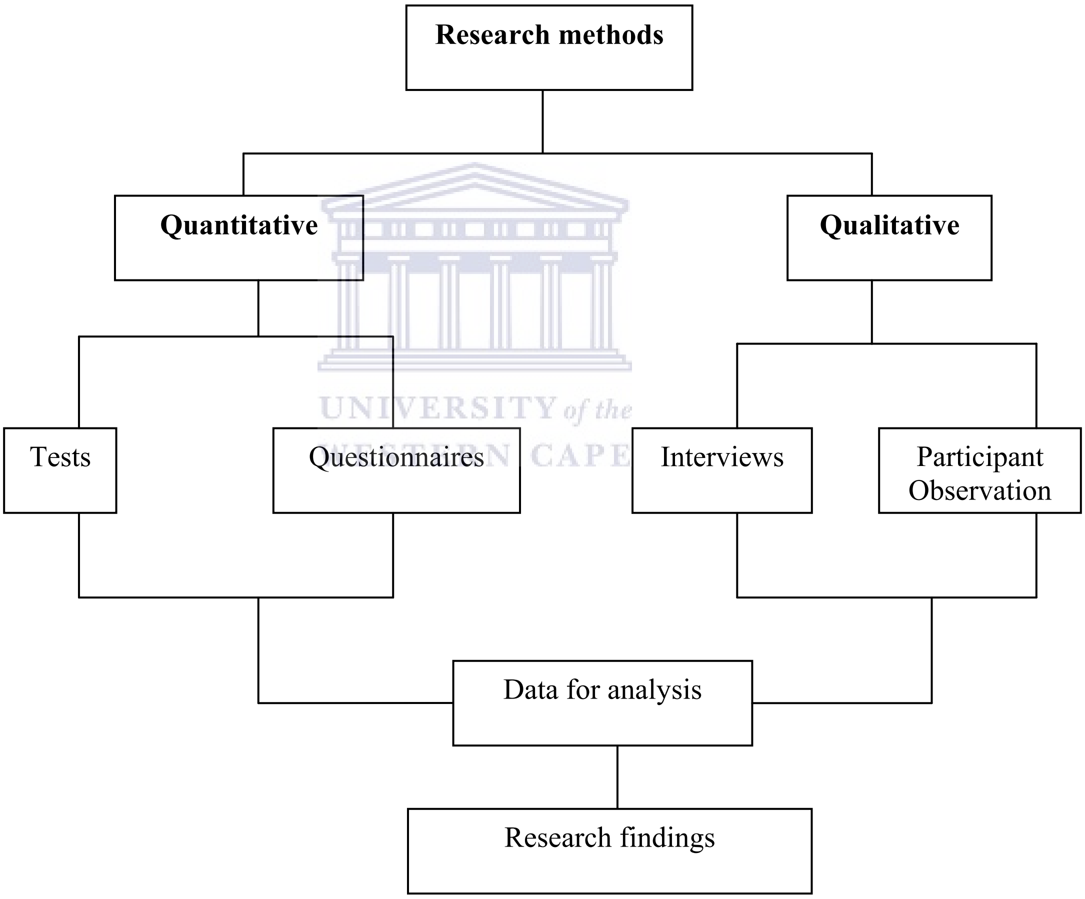

Figure 3.1: Research design

The use of multiple sources of data enabled me to get a more holistic picture of the answers to the research questions, as well as to gain a deeper insight into the nature of practical cell biology at Eduardo Mondlane University. Patton (1990) supports the use of multiple sources of data because he argues that such an approach allows strengths to be combined to correct the deficiencies of any single source or method.

According to Neumann (2003) the combination of quantitative and qualitative data gathering techniques is advantageous and good research practice in that it "often combines the features of each" enabling a confirmation or corroboration of each other through triangulation. Yet, the key features of the qualitative methods can be seen when contrasted with quantitative methods. Qualitative methods as opposed to quantitative methods are best understood as data enhancing. They allow the researcher to see key aspects of cases more clearly. In addition, authors like Miles & Huberman (1994) and Patton (1990) laid down several reasons for combining qualitative and quantitative methods for data collection such as: (a) enables confirmation or corroboration of the gathered-data; (b) makes possible an elaboration or development of analysis by providing richer details; (c) quantitative methods makes it possible to measure the reactions of a great many people to a limited set of questions while qualitative methods produce a wealth of detailed information about a much smaller number of people and cases; (d) qualitative methods provide broad, generalizable set of findings presented succinctly and parsimoniously whereas; qualitative methods increase understanding of the cases and situations studied but reduces generalizability.

As mentioned early in this chapter, the data for this study were collected using a case study approach consisting of quantitative and qualitative methods as indicated below:

(a) a cell biology pre-and post-test instrument consisting basically of multiple-choice questions with explanations;

(b) a questionnaire on students' perceptions about the role of practical work in the learning of cell biology;

(c) a questionnaire on lecturers' practical work teaching experiences and views about cell biology course;

(d) interviews; and

(e) classroom observations taking form of field notes.

Research instruments (a), (b) and (c) above were used to collect quantitative data whereas (d) and (e) were used to collect qualitative data. These instruments are described in full in the next sections.

For the purpose of this study, the researcher regarded the use of a case study approach as being adequate. The use of a case study approach is known as providing the researcher an intensive and holistic picture of the case in study. The researcher has the opportunity to examine and describe, for instance, a specific event or situation in- epth and detail, in context and holistically over duration of time (Patton, 1990; Wiersma, 2000; Neuman, 2003).

According to Cohen *et al*. (2000) one of the strengths attributed to case studies is related to their capacity to observe effects in real contexts, recognizing that context is a powerful determinant of both causes and effects by providing in-depth investigations. For this reason, in conducting case studies, contexts are considered as unique and dynamic. They investigate and report the complex dynamic describing interactions of events, human relationships and other factors in a unique instance.

The framework underpinning this study (Chapter 1) is in consonance with the above view. It emphasised the context in which the process of teaching and learning cell biology through practical work took place as well as the interactions between various interveners in the process, from human to material resources (Easton, 1996).

Below some of the characteristics of a case study is given (Cohen *et al*., 2000: 182). According to the authors, a case study:

- Is concerned with a rich and vivid description of events relevant to the case;
- Provides a chronological narrative of events relevant to the case;
- Combines a description of events with the analysis of them;
- Focuses on individual actors or groups of actors, and seeks to understand their perceptions of events;
- Highlights specific events that are relevant to the case;
- The researcher is integrally involved in the case;
- An attempt is made to portray the richness of the case in writing up reports.

Although the case study is considered as unique form of empirical inquiry, many researcher investigators contempt this strategy (e.g.: Cohen *et al*., 2000; Yin, 2003) for the following reasons:

- Case studies are prone to problems of observer bias, despite attempts made to address reflexivity;

- They provide little basis for scientific generalization;
- They are not easily open to cross-checking, hence they may be selective, biased, personal and subjective;
- They take too long and result in massive, unreadable documents and;
- They lack a rigor that is, too many times, the case study investigator has been sloppy, has not followed systematic procedures, or has allowed equivocal evidence or biased views to influence the direction of the findings and conclusions.

3.3 Research design

The study used a pre-experimental design of the type 'one group pre-test – post-test design' (Cohen, Manion & Morrison, 2000; Good, 1972) to respond to research question 1. A single group of students was observed at two time points, before and after undertaking practical work in cell biology. Dekkers (1997) and Mutimucuio (1998) have successfully used a similar method to determine the extent to which practical work could contribute to the development and improvement of students' conceptual understanding. This methodology was preferred to a methodology of measuring the students' performance with respect to a control group by exposing some students to different kinds of instructions. This was because I was concerned with measuring the effects of practical work in the development and improvement of the cell division concepts, not in terms of measuring the students' success in learning such concepts. Below the 'one group pre-test - post-test design' is represented:

Experimental	O_1 X O_2

Where: O_1 = test before instructions

X = instructions

O_2 = test after instructions

However, in conducting this kind of experimental design one has to consider a number of confounding extraneous variables, which can threaten the validity of the research effort and, consequently the research findings of any educational research (Cohen *et al.,* 2000; McMillan and Schumacher, 1993). Below are some of the factors that could jeopardize the internal validity of the research design:

- History: time that separates the pre-test from the post-test;
- Maturation: changes of the subjects between two observations;
- Statistical regression: effects produced by the administration of pre-test and post-test;
- Testing: effect of the pre-test applied at the beginning of the experiment on the scores obtained through post-test;
- Instrumentation: administration of unreliable tests or instruments leading consequently to errors into experiments.

To minimize the interference of such factors certain precautions were taken in designing the research. For instance, before conducting the main study the research instruments were piloted and subjected to content and construct validity by a panel of experts with experience in science education and in teaching practical work. The content of the pre-and post-tests was elaborated so that it could provide the subjects with practice on the type of questions familiarizing them with the content tested.

In order to satisfy research questions 2, 3 and 4 no experimental design of any kind was used. This was because, I was interested in knowing the effectiveness of the activities carried out during practical work and to see how these in turn enhance the students' understanding of cell division concepts. In addition, it was of my interest to determine whether or not the actual motivational conditions contribute effectively to the attainment of the aims of the cell biology practical work in biology course of the EMU. That is, what students and lecturers thought about the importance of the aims of practical work in the teaching and learning of cell biology.

In attempting to investigate the values of the practical work in the teaching and learning process of cell biology, a systemic evaluation model (see chapter 1) was seen as appropriate since it helped me to get a deeper insight into the degree to which the cell biology course accomplished or failed to attain the intended goal of the course taking into consideration the context in which the course had been implemented (Stake, 1967; Ogunniyi, 1984; Easton, 1996). This was done using a case study approach as referred early in this chapter.

3.4 The subjects of the study

This section describes the procedure used to select the subjects involved in the study. In addition, it explains the procedures used to administer the research instruments.

3.4.1 Students

This study involved 41 first-year university students enrolled in the biology course in the Biological Science Department at Eduardo Mondlane University. These students came from several secondary schools of the entire country and had varying levels of cell biology content knowledge and basic process skills acquired through practical work. About two thirds of the students were males (63%) and about a third (37%) were females. The age of the students ranged between 17 to 31 years old (mean 21). The topic of cell biology was taught by a senior Lecturer over one semester and involved two one-hour tutorials per week, and one two-hour practical work per week.

3.4.2 Lecturers

The study involved 11 of the 20 biology lecturers directly involved in the teaching of the first-year biology students. The remaining nine lecturers could not participate due to many constraints such as time, marking assignments and exams and the fact that some of them were undertaking postgraduate studies outside of the country. Five of the lecturers were males and six females. Their age ranged from 35 to 46 years. Their teaching experience varied between 11 to 25 years, except for one of the participants who had three years of experience. Regarding their qualifications, eight of the participants had honours and Masters Degrees and only three had a PhD degree. All the participants taught at least two modules of the biology course. This information allowed me to get a general picture of the background of the teaching staff at the Biological Science Department and to ensure that they were capable of providing reliable information about the impact of practical work in the teaching and learning process of the biology course. In the next section, the procedures employed in this study are described.

3.4.3 Procedures

Table 3.1 below summarizes the research sequence of the instruments administered during the study: pre-and post-tests, post-laboratory and course interviews, classroom observations, students' perceptions questionnaire and lecturers' experience questionnaire. It also gives an overview of the time and nature of the students' practical and cognitive lessons carried out during the study.

Table 3.1: Overview of time and nature of the students' practical and cognitive lessons.

<table>
<tr><th colspan="2">Time</th><th>Type of instrument</th><th>Cognitive lessons</th><th>Practical lessons</th></tr>
<tr><td>February 2005</td><td>Before instruction</td><td>Pre- course test</td><td>-</td><td>-</td></tr>
<tr><td>April – May 2005</td><td>During instruction</td><td>Observations of student activities in laboratory</td><td rowspan="3">Cell division key concepts
Mechanisms, types and localization of cell division
Basic charact. and structure of chromosomes
Basic charact. of mitosis and meiosis
Mitosis and cell cycle events
Meiosis events
Meiosis and life cycles
Gamete formation during meiosis
Types of chromosomes and cells during mitotic and meiotic processes
Differences and similarities between mitosis and meiosis cell division</td><td rowspan="3">Microscope techniques
Procedures to observe slides
Observation of microscope slides on mitosis: onion cells
Observation of microscope slides on meiosis: pollen cells
Procedures to draw the specimens
Procedures to correctly interpret, represent and describe the specimens
Discussion and comparison of the observed specimens
Exercises on mitosis and meiosis stages</td></tr>
<tr><td>May 2005</td><td>During instruction</td><td>Post-Laboratory Interviews</td></tr>
<tr><td>June 2005</td><td>After instruction</td><td>Post-Course Test →
Post-Course Interviews</td></tr>
<tr><td rowspan="2">June 2005</td><td rowspan="2">After instruction</td><td>Students' Perceptions Questionnaire</td><td colspan="2">Understanding of the role of practical work to:
▪ Acquire knowledge and intellectual skills
▪ Acquire and develop procedural and investigation skills
▪ Promote positive attitudes towards science</td></tr>
<tr><td>Lecturers' Experience Questionnaire</td><td colspan="2">Understanding lecturers experiences and views on the aims of practical in biology course</td></tr>
</table>

As indicated in the Table 3.1, the study took place during the first semester (February to June) of the 2005 academic year and involved first-year cell biology students and biology lecturers of the Biological Science Department. As stated in Section 3.4.1 a total of 41 first-year biology students were asked to complete a Cell Biology Test (CBT) at the pre-and post-test stages of the study (found in Appendix A). Specifically, the tests were used to assess the students' conceptions of mitosis and meiosis. The pre-test was administered at the beginning of the topic and the post-test was administered one week after teaching the topic and coincided with the end of the EMU first semester. The tests lasting for 90 minutes were administered to the whole class.

In order to reflect the variability within the group an extreme group sampling approach was used to yield a smaller sample for more intensive interviews. The use of extreme group sampling was adopted as a substitute for random sampling normally used when a group is homogenous (Gall, Borg and Gall, 1996; Holtman, 2000; Patton, 1990). Based on the pre-test results, four students from the upper end and four from the lower end were selected to form the sample for the post-laboratory interview and post-course interview. However, two students opted out of the interviews for unspecified reasons, and therefore only six (2 + 2 + 2) students participated in the interviews. The interviews lasted for about 30 minutes for each pair of students or an individual student. The selection of the students was based on the average (20.439) of the total scores yielded in the pre-test. The upper limit consisted of students who scored above 20 (N = 22) and the lower limit students scored below 20 (N = 19) on the pre-test.

All the 41 students were asked to respond to a questionnaire about their perceptions on the role of practical work in the learning of cell biology. The questionnaire was administered right at the end of the cell biology course and laboratory classes on mitosis and meiosis and students were given two days to complete it. It would have been impracticable to ask students to hand in the questionnaires in the same day because this coincided with the end of the semester and the students were busy writing the final exams.

Classroom observations recorded in the form of the “field notes” were conducted during the laboratory sessions to capture some of the activities and procedures used in the laboratory sessions. As a participant observer, I took notes and spent some time to interact with the students. Because the laboratory space was not sufficient to accommodate all the 41 students at the once, the students were divided into two groups of 20 and 21 each and they undertook the practical work on the same weekday but at different times. The observations lasted for three different days which corresponded to the three laboratory sessions scheduled for cell division topic totalising 12 hours for both groups. The context and the content for the observed laboratory sessions was the same and the same lecturer conducted the sessions.

The lecturers’ questionnaire was designed to test their practical work teaching experiences and ideas about the biology course. As stated in section 3.4.2 only 11 lecturers completed the questionnaire. The questionnaire was handed out to the lecturers during the first week of May 2005 and they were required to return it in 15 days. However, they did so after a month.

The section evaluated was the practical component of the cell biology topic of the biology course. The cell biology topic forms a building block topic for other Biology subjects taught at the Biological Science Department (viz. Botany, Zoology, Microbiology, Ecology, Biochemistry, Plant and Human Physiology, Genetic) and it enabled me to follow the nature of the kind of practical work carried out in this section. Furthermore, there is an emphasis on basic concepts of the cell structure and its functions, cell division, preparation of wet mount slides of tissues, use of microscopes to observe cell structures and events of mitosis and meiosis linking theory and practice. In order to limit the scope of the research, I decided to investigate the sub-topic about cell division, which was considered wide enough in scope to give an indication of the current status of the practical work of the biology course. The selection of the 'cell biology' topic was based on its centrality to the study of biology in general and particularly, for all biology-oriented courses (e.g.: Agronomy, Veterinary Science, and Medicine).

3.5 Pilot study

The aim of the pilot study was to determine whether the four instruments developed for the main study were unambiguous and appropriate for the context aimed at in terms of its content and structure. It also sought to test the effectiveness or otherwise of the research methods in order to ascertain the possible weakness in the instruments as well to ensure the validity and reliability of the instruments developed for the main study. All the four instruments were subjected to the pilot study and revised as a result of the experience gained in this study. In addition, the pilot study helped me to explore the suitability or otherwise of the statistical procedures to be used to analyse and interpret the data gathered in the main study.

The pilot study of the Cell Biology Test was conducted three weeks before the main study. The participants were six students who enrolled in the second year of the biology course. These students had already completed the cell biology course. I sought the permission of the biology course coordinator who in turn asked for volunteers to take part in the pilot study. The pilot test version consisted of 18 main questions about cell division (mitosis and meiosis) and students were allocated 90 minutes to complete the test. The pilot version was then revised for the main study and consisted of 17 main questions. The deficiencies encountered in the pilot study were corrected based on the comments provided by the experts as indicated in the sections below.

In attempting to improve the validity of the instrument, two senior lecturers and experts who taught both the biology course and the science education courses were asked to provide their opinions about the quality of the instruments. They were asked to rank the items from "1 very poor" to "5 excellent". A spearman's ranking order correlation coefficient to determine the relationship between their opinions was calculated. The resulting coefficient ($r_s = 0.97$) showed a positive correlation between the rankings of the two judges.

Despite the high correlation in terms of face validity above, the experts recommended a revision of some questions. Some of the questions appeared ambiguous, as it was apparent from the students' responses. In this regard, adjustments were made to the instrument and changes were introduced before the main study was undertaken. The following adjustments and changes were made: Q 5 was regarded as being the most ambiguous and therefore was reworded. Redundant words were removed to improve the clarity of the item. In Q 3 "mitosis consequences" and Q4 "cytokinesis" were removed, as their content was apparently included in other items of the test. Questions 10 and 11 were regarded as being incomplete to deal with the concept of meiosis and therefore were substituted with two questions, which contained more complete information in terms of names and sequence of meiotic phases. The students' responses in the test also raised important issues about the clarity in the formulation of the questions, as some questions would elicit more than one response.

The final version of the test (outlined in Appendix A) comprised 17 questions, which were considered to be enough to provide substantial information about the effect of practical work in the learning and teaching of the basic concepts of mitosis and meiosis.

Students' and lecturers' questionnaires were also subjected to the pilot study. This was conducted to identify any confusing instructions and problems with regard to the formulation of the items and layout of the instruments. In addition, the items on both instruments were checked to verify whether or not they were selected according to the objectives established for practical cell biology course. The pilot study underlined the importance of the following points:

- For both questionnaires, the wording of the items needed to be clarified, as there were some misunderstandings in translating the instruments from English into Portuguese.
- For the students' questionnaire, it was necessary to adjust the items according to the objectives to be attained through the practical work in cell biology.
- For the lecturers' questionnaire, the items on practical work aims needed to be adequate matched to the aims of practical work carried out at the Biological Science Department.

3.6 Permission for the study

In order to make the study more feasible, ethical issues were considered. I sought permission from the Head of the Biological Science Department and course coordinator. I wrote a letter explaining the importance of conducting the study involving human subjects (students and lecturers) and the permission was granted in 2004 before the pilot study was carried out. The selected subjects were informed about the importance of the study. Additional details were given to the students by the senior lecturer responsible for teaching cell biology course. Coincidently, he was the deputy Dean of the Faculty of Science and also responsible for the scientific investigation area. He explained the nature of the study to be conducted as well my role during the study and classroom observations. As a result of his input, it was easy to establish rapport with the students. The students were also informed about the criteria used to select some students to participate in the interviews and that pseudonyms would be used to maintain confidentiality of the recorded information.

3.7 Validity and reliability of the instruments

In this study it was of particular interest in terms of the validity to look at the content and construct validity. In the light of these two types of validity, a senior lecturer responsible for teaching the cell biology topic checked the content validity, that is, he determined the extent to which the instrument covered the domain area of the content (Cohen *et al.,* 2000). The two experienced biologists/science educators who checked the item's quality in the pilot study also subjected the instrument to construct validity. The combination of the two kinds of validity (content and construct) allows reinforcing the overall acceptance of an instrument in terms of the content coverage, structure and level of the construction and appropriateness of the test items (Neuman, 2003; Mulder, 1986). In addition, the students' responses on the pilot test helped to improve the formulation of questions avoiding in this way the redundant wordings as well as questions with more than one response, as was found from the responses in the pilot test. Thus, the level of understanding in the test was in general greatly improved.

The two questionnaires eliciting lecturers' experiences and students' perceptions were also subjected to content and construct validity by the senior lecturer who taught cell biology and a panel consisting respectively of three experts in Biology, Chemistry and Physics education during the pilot study phase. All the three have experience in the teaching of practical work. In this case, the validity was concerned with the construction of the items in terms of the appropriateness of the content. In addition, it was checked whether the instruments covered the objectives to be attained through practical work in cell biology course (Neuman, 2003; Cohen *et al*., 2000).

In order to determine the coefficient of the internal-consistency for the final CBT at the post-test stage (Appendix B) a Kuder-Richardson 21 formula as modified by Ebel (1979) was used (See Appendix C). Only the post-test scores of the whole class (N = 41) were subjected to the internal-consistency test. This was because I was interested in measuring the extent in which the students constructed their basic concepts of cell division in terms of being uniform in their responses. The test consisted of thirty-nine points. I assumed that this was the most appropriate for this kind of study, as this formula provides us with a modest estimate coefficient of internal-consistency by correcting of some of the underestimation attributable to the original KR 21. The modified formula is applicable when the test items or questions vary in difficulty (Ebel, 1979). The results of the post-test were scored by assigning a value of one for a correct answer, and a value of zero for an incorrect or distorted answer. This was possible because all items independently of being open or closed questions were coded on the same base (correct, incorrect or distorted answer). The estimate of reliability for the entire instrument was 0.78. The internal-consistency for the whole test was considered as acceptable for the kind of the study taking into account that the students had been exposed to the treatment only for four weeks. Yet, according to Gay (1992) it is considered an acceptable value if the internal-consistency of a test equals or is higher than 0.60.

Besides the tests and questionnaires, this study yielded qualitative data by means of the case study interviews and classroom observations. Thus, to address the issues of validity and reliability, triangulation of data sources was used. Triangulation usually involves using alternative data sources or collection processes to corroborate data. For instance, in a study in which the interactions of a group of students were observed, personal records or interviews could corroborate the observational data. In this case, the notion of 'trustworthiness' that integrates issues of credibility, confirmability, transferability and dependability was introduced to replace more conventional measurements issues in quantitative design (Cohen, *et al.,* 2000; Lincoln & Guba, 1985). To ensure the validity of the interviews, the semi-structured questions used in the interviews were selected from the pre-and post-test instrument. This was done to determine whether or not the data yielded by means of interviews compared reasonably well with those of the pre-and post-test measured the same in terms of the students' conceptions of mitosis and meiosis after doing practical cell biology (Cohen *et al*., 2000). In order to avoid the threats to the validity of the study as a result of the possible roles that can be assumed by the informant and the respondent, I was able to establish relationships of trust with the interviewed students during tutorials and laboratory classes. In addition, also of interest was the credibility issue as using different data sources, methods and referential adequacy triangulated the data yielded in this study. Adequate storage of audiotapes of interviews was also therefore ensured (Lincoln & Guba, 1985). I spent considerable time as a participant observer with the students. This probably contributed to the reduction of possible reaction effects that could arise from my interactions with the students (Cohen, *et al*., 2000).

3.8 Development of the research instruments

This section describes the four research instruments used to collect data in the study. These instruments are separately described below.

3.8.1 The Cell Biology Test (CBT)

The CBT composed of the Cell Biology pre-test and of the Cell Biology post-test. The pre- and post-test instruments were designed with the objective of determining students' conceptions about cell division. The CBT consisted of 17 questions, 12 multiple-choice with explanations and 7 with open questions (Appendix A). The questions of the tests were derived from the literature (e.g. Carey, 1991; Lopes, 1993; Purves, Orians, & Heller, 1992) and were designed according to the objectives stated in the cell biology course. In developing the question items I took into account the development of the different types of the basic science process skills (analysis, interpreting, application, explaining, comparing, identifying and, representing).

The final version of the instrument comprised four sub-sets of categories: the first on cell cycle processes with three questions (1, 2 and 3); the second on mitosis events and characteristics with four questions (4, 5, 6 and 7) the third on meiosis events and characteristics with five questions (8, 9, 10, 11 and 12) and, the fourth on comparison of the events and processes of mitosis and mitosis with four questions (13, 14, 15, 16 and 17). All the four sub-sets included the following key concepts: cell cycle; mitosis; meiosis; homologous chromosomes, sister chromatids, haploid cells, diploid cells, centromere, cytokinesis, spindle apparatus, crossing over, genetic recombination, tetrads, chiasmata, synapsis, spermatogenesis. Table 3.2 below is a summary of the questions and concepts included in the Cell Biology pre-and post-test instrument.

Table 3.2: Categories of the pre-test and post-test questions on CBT.

Categories	Question	Concept
Cell cycle processes	1	DNA replication
	2	Chromosomes modification
	3	Interpreting cell cycle graphic (DNA replication)
Mitotic events and characteristics	4, 6	Sequencing mitotic' phases
	5	Identifying mitotic' phases)
	7	Matching events with mitotic' phases
Meiotic events and characteristics	8	Characterizing meiotic' processes (diploid cells, haploid cells)
	9	Sequencing meiotic' phases
	10	Identifying meiotic' phases
	11	Chromosomes appearance in prophase I (chiasmata, synapsis)
	12	Identifying specific events in Prophase I (crossing over)
Differences between mitosis and meiosis	13	Process occurring in germ cells (spermatogenesis)
	14	Identifying types of division and phases (chiasmata, tetrads, diploid cells)
	15	Representing cells (haploid cells)
	16	Interpreting cells (diploid cells, haploids cells, centromere, chromatids)
	17	Differences between mitosis and meiosis (chromosomal number)

The Table 3.2 above shows clearly that most of the concepts appeared in more than one question. Students are required to have mastered all of those concepts to understand the processes and events of cell cycle and cell division in the cell biology course. Below is the description of the four categories of the questions.

Questions 1, 2 and 3 asked students about their scientific knowledge on cell cycle processes. In these questions students were required to show their understanding about the processes occurring during the cell cycle in terms of the knowledge about DNA synthesis. They were also required to use this knowledge to compare chromosomes (Q2) and interpret the graph (Q3) about events during cell cycle.

Questions 4, 5, 6 and 7 were designed to elicit students' understanding about the basic concepts of the mitotic events and characteristics during cell division. Q4 and Q5 refer to the key concepts of mitoses in a plant meristem tissue (interphase, prophase, metaphase, anaphase, telophase, chromatin, chromosomes, chromatids, centromere, cell plate, and cytokinesis. Q6 elicited the students to apply their knowledge of the key concepts of mitosis to indicate the correct sequence of its phases whereas; Q7 attempted to elicit students' alternative conceptions in matching mitotic' stages and associated key events. This question dealt with the following concepts: sister chromatids, threadlike chromosomes, spindle equator and decondensed chromosomes.

Questions 8, 9, 10, 11 and 12 were designed to test students' conceptions about meiosis characteristics and associated events. Q8 tested whether students had mastered the knowledge about the importance of meiosis in living cells. The four basic concepts needed to respond to this question were: haploid cells and diploid cells, reductional and equational divisions. This question would help to identify students' misunderstanding in identifying the names of the meiosis' phases in Q9 and Q10. Q11 and Q12 aimed to elicit students' conceptions about the events occurring during prophase I of meiosis. It was of interest testing the students' understanding about the phenomena of "crossing over", "chiasmatas" and synapsis", as these are considered to be the key events during meiosis in that they allow the recombination of the genes and consequently genetic variability of the specimens.

Questions 13, 14, 15, 16 and 17 were designed to elicit students' understanding about the basic differences between mitosis and meiosis. Q13 aimed at eliciting students' understanding about germ cell formation (gametes) in the cells of living organisms as a consequence of meiosis. Q14, Q15 and Q16 were aimed to test students' understanding of the meaning of the haploid and diploid chromosomal number so that they can interpret and represent events in mitosis and meiosis. These questions were supposed to help in identifying students' conceptions on "formation of chiasmata" and "tetrads" during meiosis as well as "homologous chromosomes", "sister chromatids", "centromere" and "spindle microtubule" during anaphase of mitosis and meiosis. Q17 tested whether or not students understood the main differences between the events and characteristics of mitosis and meiosis.

3.8.2 The interviews

My assumption was that while the Cell Biology Test could reveal certain levels of understanding of mitosis and meiosis it might not provide a comprehensive nature of that understanding and hence it was necessary to probe their understanding of selected concepts regarded as important in the teaching and learning of cell division. The purpose of the interview was to: obtain the details of the students' conceptions about cell division after undertaking practical work in cell biology; determine how confident the students were with the answers they had given in the tests; and get insights into how they arrived at those answers. In addition, the interviews were used to establish rapport with the students; corroborate students' tests answers and to clarify their responses in the CBT. According to Lincoln & Guba (1985) the purpose of an interview includes, among others, obtaining "here-and-now" constructions of persons, events, activities, feelings, motivations, and so on. Interviews can also be used to reconstruct the past, interpret the present or predict the future of such entities as well as to triangulate the information obtained from several data sources (ibid).

In this study, semi-structured interviews in the form of open-ended questions were used. Open-ended questions are considered to have advantages because they allow persons being interviewed to take whatever direction and use whatever words they want to represent what they want to say (Patton, 1990). In other words, open-ended questions allow flexibility, clarification, and probing of the interviewed responses. The questions used in the interviews were selected from the CBT (post-test) and from the practical worksheets (post-laboratory interviews). Prompt questions emerged during the process of interviewing. The interviews were used also to seek information about the current practices taking place during laboratory classes of the biology course.

Post Laboratory Interviews (PLI)

In the PLI students were presented with figures containing a series of pictures about mitosis and meiosis and they were asked questions related to these pictures (Appendix C and D). This technique of interview is called "interview about instances" (White & Gunstone, 1992). It is based on the collection of drawings which students are required to interpret as examples or non-examples. An interview about an instance is an effective way for probing students' understanding of a single concept checking whether the student can recognize a concept or use it in a meaningful way. This technique can help to detect students' alternative conceptions about a specific concept. In addition, it checks whether or not the student can explain his/her decision in the process revealing the quality of his/her understanding of a concept.

Post Course Interview (PCI)

Questions for the PCI were drawn from the CBT (Appendix A). In this case, interview about instance and interview about concept techniques were employed as most of the selected questions contained figures or diagrams on mitosis and meiosis. Interview about concept was used to explore the knowledge that students had about a specific concept (White & Gunstone, 1992) as opposed to interview about instance.

The interview about concept brings forth as much as possible what the student knows about the concept by measuring his/her level of comprehension.

3.8.3 Classroom observations

In this study, classroom participant observations were conducted to investigate the nature of the actual observation of activities carried out during laboratory classes and how these activities in turn enhanced meaningful learning through practical work. The use of observation methods is acknowledged due to its value in providing the researcher the opportunity to gather 'live' data from 'live' situations. It provides the researcher with the opportunity to look at what is taking place *in situ* rather than second hand information (Cohen *et al.*, 2000: 305-16). In other words, observations are an effective or useful way of describing the classroom setting, the activities that take place in that setting, the people who participate in those activities, and capturing the meaning of what is observed from the perspective of those being observed (Patton, 1990). Yet, and according to Lincoln & Guba (1985) the observations are considered as yielding a major advantage in terms of providing "here-and-now" experiences in depth comparing to interviews. Patton (1990) categorizes the role assumed by the researcher in the natural setting of the person or people being studied in participant observer, complete observer, observer participant, or complete participant. As stated early, I assumed the role of a participant observer within this study. I was engaged in an intensive period of social interactions with the students to achieve a greater understanding of the activities taking place during the laboratory sessions (Guba *et al.*, 1981). Furthermore, I attended all tutorials and laboratory sessions on mitosis and meiosis throughout the semester and made notes of what happened during the tutorial and laboratory sessions. Tables 3.3 and 3.4 present some of the categories of the activities recorded during laboratory sessions and lecture course.

Table 3.3: Descriptions of the activities during laboratory sessions.

Descriptions of the activities	Performer
1. Introduction of the laboratory aim and topic: • Basic knowledge and techniques to operate a light microscope • Observation of microscope slides on mitosis: onion apex cells of Allium cepa • Observation microscope of slides on meiosis: pollen mother cells of Lilium candidum	Lecturer Students
2. Explanation and demonstration of the procedures to observe the slides on mitosis and meiosis: • Use of the coarse and fine adjustment knobs to locate and focus on the specimen • Use of different magnifying lenses to observe the specimens • Steps to operate the microscope correctly • How the cells look like in different stages of mitosis and meiosis using different lenses	Lecturer Students
3. Discussion of the laboratory guide: • Clarification of the instructions in the lab guide	Lecturer Students in pairs or group of 2-4
4. Execution of the laboratory activity • Observe the permanent slides containing several phases of mitosis and meiosis • Draw the observed phases	Students, individually or in pairs or group of 2-4
5. Discussion and comparison of the observations • Observed phases of mitosis and meiosis • Differences and similarities between the phases	Students in pairs or group of 2-4
6. Responding to lecturers questions to describe and interpret their observations and drawings • How to know that what is observed is correct • How cells look like at different stages of mitosis and meiosis • What are the basic differences between cells in different stages of mitosis and meiosis • How to observe accurately and interpret what is observed • How to represent correctly what they see at different levels of microscope magnification • Difficulties encountered in observing and drawing microscope specimens.	All students (class as a whole), group of 2-4

Table 3.4 describes the activities carried out during the lecture course on cell division. From the content in the Table it is possible to infer that the lessons were predominately introductory and expository with few interventions by the students. The students were acting as passive recipients of the knowledge. Basically, the students' intervention was when lecturer asked them for some doubts on the topic dealt with at the moment, hence most of the time they were concerned in taking notes.

Table 3.4: Description of the activities during lecture course

Descriptions of the activities	Performer
1. Introduction of the cell division topic: • Historical data of cell division • Overview of cell division process • Importance of cell division in living organisms • Mechanisms and types of division • Localization of the cell division process	Lecturer Students as a whole classe
2. Introduction to the basic characteristics of chromosomes • Explanation of the key concepts underlying chromosomes • Demonstration of a video film on chromosome structure • Discussion about chromosomal number in mitosis and meiosis	Lecturer Students as a whole classe
3. Discussion and explanation of the basic differences between mitosis and meiosis • Basic characteristics of mitosis • Basic characteristic of meiosis	Lecturer Students as a whole classe
4. Discussion and explanation of mitosis and cell cycle • Importance and descriptions of the cell cycle events • Description of the stages of mitosis: slides	Lecturer Students as a whole class
5. Discussion and explanation of meiosis • Asexual and sexual reproduction • Overview of meiosis • Description of the stages of meiosis: slides	Lecturer Students as a whole class
6. Discussion and comparison of the two divisions • Notions of the concept homologous chromosomes • Descriptions of the gamete formation during meiosis and life cycles • Differences and similarities between phases meiotic and mitotic phases	Lecturer Students as a whole classe

3.8.4 Questionnaires

In this study two kinds of questionnaires were used namely, the students' perceptions questionnaire (found in Appendix E) and lecturers' experiences questionnaire (found in Appendix F). Both questionnaires were used to investigate whether or not the motivational conditions needed to achieve the effectiveness of any teaching/learning process were satisfactory. According to Dekkers (1997), cognitive, methodological and motivational conditions altogether need to be satisfied in order for conceptual development to occur. Classroom observations, tests and interviews normally are focused on determining whether or not all necessary cognitive and methodological conditions as well cognitive outcomes of the teaching and learning activities were adequate. For this reason, this study employed also the questionnaires to investigate the students' perceptions about the role of practical in the learning of cell biology and to investigate lecturers' practical work teaching experiences in biology course. This information would help to relate the cognitive outcomes (conceptual development) of the teaching and learning activities with the students and lecturers' views about the importance placed on the aims of practical work in biology course. The two questionnaires are briefly described below.

Students' perceptions questionnaire (SPQ)

This questionnaire was designed to find out the students' perceptions in relation to the role of practical work in the teaching of cell biology (Appendix E). The SPQ consisted basically of two Sections: Section A was about students' personal details. Section B contained statements on the aims of practical work in cell biology. The SPQ used the Likert format asked the students to rate their opinions about each of the statements from 1 to 25 on the scale of 1 ("strongly disagree") to 5 ("strongly agree"). An open-ended question was added to the SPQ, in which students were invited to give their opinions about what they think should be done so that the practical work can contribute effectively to the teaching and learning of biology in general. For ease of analysis the students' responses were grouped into three categories according to the aims of practical work in science teaching. The first category was on acquisition of knowledge and intellectual skills (items 1, 2, 3, 5, 6, 7, 8, 22 and 24). The second category was on procedural knowledge and investigations skills (items 4, 9, 10, 11, 12, 13, 14, 14, 15, 16, 17, 21 and 25). The third category was on acquisition of positive attitudes towards practical work (items 18, 19, 20 and 23). In general, all the statements were designed to elicit students' understanding about the importance placed on the aims of practical work in the process of developing knowledge, skills and attitudes.

The researcher recognizes that manipulative skills are considered as being one of the reasons for doing practical work in science. However, in this study, manipulative skills were not treated as a specific category compared to the three categories contained in the SPQ. The understanding here, was that in somehow manipulative skills would be encompassed into the category of procedural and investigations skills. In fact, this view contrasts with what the literature says. Manipulative skills are defined as consisting of the following skill components: experimental techniques, procedures, manual dexterity and orderliness (van den Berg & Giddings, (1992).

Despite this omission on manipulative skills, the data obtained in this were analysed in the perspective of the three domains (affective, cognitive and practical) as indicated in the literature and framework underpinning this study. Furthermore, the results of this study laid down some evidences that the cell biology practical not only helped the students to improve their knowledge and intellectual skills, procedural and investigation skills. It has also helped the students to improve their manipulate skills to operate laboratory equipment (e.g.: light microscope). More details in this issue are found in Chapter 4.

Lecturers' experience questionnaire (LEQ)

This questionnaire was designed to explore the lecturers' practical work teaching experiences in terms of their laboratory current practices, the nature of practical work content and activities and their perceptions on the importance placed on the aims of practical work in the biology course. The LEQ comprised 7 questions with open comments (Appendix F). The questions were divided into four Sections: Section A was about lecturers' personal details. Section B consisted of the open-ended questions (1, 2 and 3) with comments and asked lecturers to report on some of the current practices taking place during laboratory classes in biology course. Section C comprised three questions (4, 5 and 6) and was related to various types of practical work (nature of practical work content and activities) in Biology. Question 4 asked the lecturers to indicate the ‘frequency of use’ of the eight kinds of practical work using a Likert-scale from 1 (“never used”) to 5 (“frequently used”). Questions 5 and 6 were closed with comments and asked lecturers to choose the frequency in which they students did practical work of any kind. Section D consisted of one question (Question 7) with comments and was concerned with the lecturers’ perceptions of the importance being placed on the aims of practical work. This section comprised 10 items (10 aims) which were selected and adapted from the set of 20 aims of practical work in science produced by Beatty and Woolnough (1982). The lecturers were invited to rank the 10 aims in order of importance from 1 to 10. The most important aim was ranked ‘1’ followed by the second most important ‘2’ … and ‘10’ for the least important.

3.9 Data analysis

This section describes the methods used in the analysis of the tests, interviews, classroom observations and questionnaires data gathered in the study. As stated early, this study used a case study approach. Therefore, the data collected at various stages were analysed in a holistic perspective that is, quantitative and qualitative data were combined in the perspective of understanding the case in study as a whole (Patton, 2000). Basically, to analyse the data emerged from the Cell Biology Test at the stages of the pre-and post-test and interviews, descriptive statistics and qualitative analytical procedures were applied. Alongside descriptive statistics, a phenomenological analytic approach was also employed. This was to determine any emerging trend regarding the students’ understanding of selected concepts in cell biology in terms of characterizing the qualitatively different ways that specific phenomena might have been experienced (i.e. conceptualised, viewed, perceived, understood, etc) (Marshall and Linder, 2005). I preferred to use this kind of approach because it enabled me to observe the levels of the students' understanding of the cell division conceptions before, during and after the intervention through practical work. In fact, in this study, I analysed the impact of practical work in learning cell biology, not the effectiveness as I did not use a control group. Hence, I had to recognize that the results emerged from this study might have been influenced by other factors like tutorials, readings, documents, books and informal environment not only from practical work. To determine the overall impact of the practical work in the learning of the cell division concepts, a 'Wilcoxon Signed-Rank Test' for repeated measures was applied as a non-parametric alternative method to the repeated measures t-test (Newton & Rudestam; Pallant, 2005). Figure 3.2 below presents a summary of an analytical model used in this study.

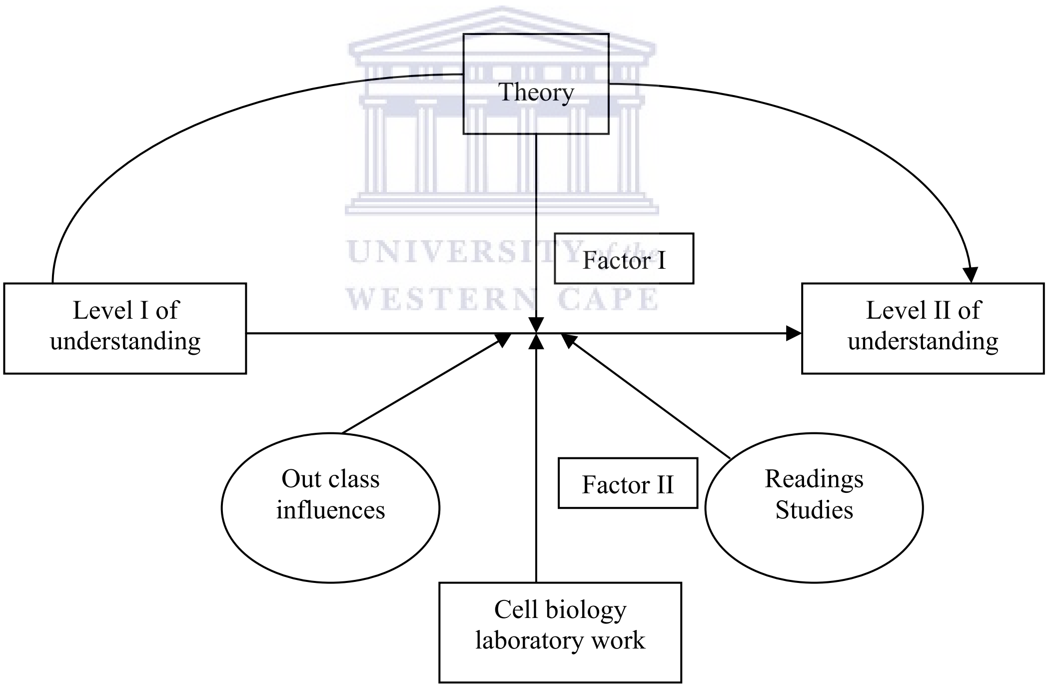

Figure 3.2: Analytical model to assess the impact of practical work into the transactions

This analytical model was designed in the light of the theoretical framework underpinning the study (refer to chapter I). Level I of understanding represents any conditions existing prior to the intervention that is, before the instruction through practical work and/or tutorials. Level II represents the students' understanding after the intervention. Factors I and II are the main factors which were considered as being the most important in terms of its impact in the teaching and learning process of cell division concepts. In this case, the impact of practical work into the transactions was observed from Level I to Level II of understanding without ignoring other factors which might have influenced the students' understanding of the cell division concepts.

For the interviews a constant comparative method (Merriam, 1998; Dye, Schatz, Brian & Coleman, 2000) in parallel to a phenomenological approach was used. In a constant comparative method, the answers recorded by the interviews were compared constantly and grouped into categories according to their trends in terms of the similarities and differences of the students' responses. This enabled to generate categories of the students' response on the specific concepts provided in the CBT and during the practical work on cell division. As referred early, the phenomenological approach enabled to qualitatively determine the students' level of understanding of the cell division concepts in the categories emerged during the interviews.

Raw data from participant classroom observations were analysed on the basis of the completed observations notes. A summary reporting what took place or did not take place in the laboratory environment in relation to the teaching/learning activities, as well as conceptual and procedural knowledge was written. It was also recorded how certain skills were passed on and/or acquired during the laboratory time for each observed session and how practical work activities enhanced the students' understanding of cell division concepts. A description of the activities which took place during the observed laboratory sessions has been already given in the Table 3.3 of this chapter.

The data collected from the questionnaires were analysed using descriptive statistics. SPSS version 12 (Pallant, 2005) and EXCEL (Frye, 2002) packages were employed. These data reflected the (i) lecturers' practical work teaching experiences in terms of their laboratory current practices; the nature of practical work content and activities and their perceptions about the importance placed on the aims of practical work in the cell biology course; (ii) students' perceptions about the role of practical work in the learning of cell biology course; and (iii) lecturers' comments and students' explanations in the questionnaires resulted from open questions (qualitative data). These were analysed and categorized according to their trends (differences and similarities) and then transformed into quantitative data.

3.10 Summary

This study was designed with the aim of investigating the role of practical work in the teaching and learning of cell biology at Eduardo Mondlane University in Mozambique. The summary of the research design used in this study is outlined in Figure 3.1 in this chapter. Both quantitative and qualitative methods were employed to achieve the aims of this study. These methods included five types of research instruments, namely: (i) Cell Biology Test at the stage of pre-and post-test; (ii) Students' Perception Questionnaire; (iii) Lecturers' Experience Questionnaire; (iv) Interviews and: (v) Classroom Observations. The sample of this study consisted of 41 first-year biology students and eleven biology lecturers. The study took place during the first semester of the academic year from February to June 2005. This chapter described also the development of the research instruments including piloting of the instruments, issues of validity and reliability, data collection procedures, methods of data analysis and interpretation and ethical issues. In the Table 3.5 below a summary of the activities and procedures carried out in order to answer the research questions of this study is described.

Table 3.5: Summary of the activities and procedures used in this study.

Research questions	Activities	Research Instruments	Data analysis
1. What are the students' conceptions of cell division before and after undertaking practical work in cell biology?	Forty-one first-year biology students were be asked to complete test on cell division concepts.	Cell Biology Pre-test/Pos-test	Quantitative (descriptive statistics) and qualitative analytical procedures.
	Eight students were interviewed to probe their answers and understanding of the cell division concepts.	Post-laboratory and post-course interviews	Qualitative analysis based on constant comparison method to generate categories of students' conceptions on cell division.
2. How do the laboratories activities enhance the students' understanding of cell division?	Forty-one students were observed during laboratory sessions.	Observation notes from participant observation	Analysis based on the completed notes reporting the environment in terms of teaching/learning activities during laboratory sessions.
3. What are the students' perceptions of the role of practical work in the learning of cell biology?	Forty-one first-year biology students were asked to complete a questionnaire on their perceptions.	Students' Perception Questionnaire	Quantitative analysis, based on Likert-scale for closed questions and qualitative analysis for the open question.
4. What are the lecturers' practical work teaching experiences and views about the cell biology practical work?	Twenty biology lecturers were asked to complete a questionnaire on their experiences and views in teaching biology through practical work.	Lecturers' Experience Questionnaire	Quantitative analysis, for closed questions. Qualitative analysis for the open questions and/or comments.

The next chapter presents and discussions the findings obtained in this study. These are discussed in the light of the extant literature review and the conceptual framework underpinning this study.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

As indicated in Chapter 3, the data of this study were collected using a case study approach, and analysed using quantitative and qualitative methods. Furthermore, the study involved the use of five types of research instruments: the Cell Biology Test (CBT), Interview schedule, Classroom Observations taking the form of field notes, Lecturers' Experience Questionnaires (LEQ) and Students' Perceptions Questionnaire (SPQ) to collect relevant data. The data yielded by these instruments were at two levels, namely, cognitive and motivational. The cognitive level comprises the students' conceptual understanding and intellectual skills and the motivational level includes the conditions needed for the effective attainment of the aims of cell biology practical work. The CBT, Classroom observations and Interviews were employed at the cognitive level and the SPQ and LEQ instruments at the motivational level. In this chapter a detailed analysis of the data is made in the context of the theoretical framework underpinning the study as well as the extant literature.

Since a case study approach was used, the data collected at various stages were not compared in terms of independent - dependent or cause – effect relationship. Rather, the data collected before, during and after the intervention were interpreted using descriptive statistics and qualitative analytical procedures. Thus, alongside descriptive statistics, a phenomenological analytic approach (i.e. qualitative description of the different ways of experiencing phenomena) was employed. This was done to evaluate the effects of practical work in ameliorating the students' conceptions of cell division. This analytical approach was necessary because the treatment, that is, the lecturers' intervention were not controlled but observed unobtrusively. It would have been inappropriate to use inferential statistics such as the t-test, which would have implied a direct causal relationship between the pre-and the post-test data. Therefore, a non-parametric alternative method, that is, 'Wilcoxon Signed Rank Test' for repeated measures to determine the statistical differences between the pre-test and post-test scores was applied.

The results from the interviews (post-laboratory and post-course) were used to probe the students' understanding of the specific concepts provided in the CBT and during the practical work on cell division (mitosis and meiosis). Classroom observations provided information about the actual activities carried out during laboratory sessions and how these enhance the students' understanding of cell division. The LEQ and SPQ were employed to provide information about the current laboratory practices as well show the importance of practical work in the teaching and learning of cell biology.

4.2 Results of the Cell Biology Test (CBT)

The Cell Biology Test (CBT) was designed to answer research question 1: "*What are the students' conceptions of cell division before and after undertaking practical work in cell biology*?" The results of the CBT (pre-and post-test) are presented under four main themes: (i) processes in the cell cycle; (ii) sequence of events in mitosis; (iii) sequence of events in meiosis; and (iv) differences between mitosis and meiosis.

As stated early, the results of the pre-and post-test were analysed using both descriptive statistics and qualitative analytical procedures in form of a phenomenological analytical approach. Thus, to qualitatively determine whether or not practical work enhanced the students' conceptions of cell division on the four themes, criteria ranging from poor = 1, fair = 2 and good = 3 were used to designate the students' conceptions of cell division (Table 4.1). These criteria emerged after examining, several times, the students' responses in terms of their trends in conceptual understanding. However, as indicated in Chapter 3, others factors such as tutorials, readings, documents, books and informal environment might have contributed to the effects of practical work (See Figure 3.2).

Table 4.1: Criteria to analyse students' conceptions of cell division.

Aspects of Cell Division	**Poor**	**Fair**	**Good**
Topic	No answer or lack of basic understanding	Distorted answer or partial understanding	Correct answer or hold basic understanding
	Lack of scientific knowledge to:	Partial application of scientific knowledge to:	Appropriate application of scientific knowledge to:
Cell cycle:	• describe mechanism for DNA synthesis • identify events in cell cycle • compare structural changes chromosomes • read graphs, diagrams or pictures on cell cycle events •		
Mitosis	• describe sequence of events in mitosis • identify the phases in mitosis • differentiate structure of chromosomes • relate phases of mitosis and sequence of events		
Meiosis	• describe sequence of events in meiosis • identify the phases in meiosis • describe the events in meiosis • describe the specific events in meiosis		
Differences between mitosis and meiosis	• relate number of chromosomes with process the of cell division • distinguish and interpret cells in nature of division • represent cells in mitotic and meiotic division • differentiate characteristics of mitosis and meiosis		

For ease of analysis as well as to follow students' reasoning, it seems apposite to first provide an overall picture of the students' responses on pre-and post-tests on the four themes before delving into a detailed analysis of the data on each theme.

4.2.1 Overall results of the students' responses on pre-and post-test

In order to evaluate the overall impact of practical work on students' scores on the conceptions of cell division in terms of the difference between the pre-and post-test scores, a 'Wilcoxon Signed-Rank Test' for repeated measures was applied. It is a non-parametric alternative to the repeated measures t-test, but instead of comparing means, it converts scores to ranks and compares them at Time 1 and at Time 2. This test is used when the same subjects being studied are tested on two separate occasions, or under two different conditions. That is, Time 1 (before intervention) and Time 2 (after intervention) (Newton & Rudestam, 1999; Pallant, 2005). In the light of this test, the results displayed in Table 4.2 indicate that there is a noticeable shift in students' conceptual understanding of cell division as depicted by mean scores, standard deviations and t-value of the pre-and post-test scores. As can be seen from Table 4.2, there was a substantial difference between pre-and post-test results with a gain of a mean of 7.73 in the post-test. That is, the students' conceptions of cell division increased from Time 1 (Mean 19.00, SD = 5.93) to Time 2 (Mean = 26.73, SD = 5.44), t-value = 30.12; p<.05. This difference is statistically significant on a 5% alpha level. To determine the practical difference, Cohen's D-value was calculated as 1.303 which indicates a large practical effect.

Table 4.2: Overall students' results on the pre-and post-test Scores.

N = 41	Mean	Minimal	Maximum	Std. Deviation
Pre-test (Time 1)	19.00	5.00	26.00	5.93
Post-test (Time 2)	26.73	10.00	36.00	5.44
Pre-test versus Post-test	t-value = 30.12* df =40 p<.05			

***the differences are significant at p<.05**

In the Table 4.3 the differences between the students' results in the pre-and post-test are displayed by theme. Similarly, to the overall results, there is a noticeable change in the students' conceptual understanding of cell division as indicated by mean scores, standard deviations and t-value for related samples. The results displayed in the Table show that all the calculated t-values for the four topics (Cell cycle = 4.11; Mitosis = 4.51; Meiosis = 8.64; and Differences between mitosis and meiosis = 7.10) are larger than the critical t-value (2,021 at 5% alpha level) for a two-tailed test with 40 degrees of freedom. This indicates that there is a substantial difference between the pre-and post-test scores of students at 95% confidence level suggesting that practical work enhanced the students' conceptions of cell division.

Table 4.3: Students' results on the pre-and post-test by theme.

Theme (N = 41)		Mean	SD	t-value	p-value
A: Processes in the cell cycle	Pre-test	1.39	0.70	4.11*	0.0008
	Post-test	2.09	0.88		
B: Mitosis: Characteristics and events	Pre-test	8.24	2.69	4.51*	0.0001
	Post-test	9.75	2.27		
C: Meiosis: Characteristics and events	Pre-test	5.58	2.67	8.64*	0.0000
	Post-test	9.17	2.88		
D: Differences between mitosis and meiosis	Pre-test	3.78	1.66	7.10*	0.0000
	Post-test	5.70	1.66		

***marked tests are significant at p<.05; df = 40**

The next section presents and discusses the results of the students' responses to the first theme of the Cell Biology Test. It comprises questions 1, 2 and 3 which focus on the processes in the cell cycle needed for cell division to happen.

4.2.2 Students' responses to questions about processes in the cell cycle

This section deals with students' understanding about processes in the cell cycle. Table 4.4 presents the students' percentage scores for three questions (Q1, Q2 and Q3). In these questions students were required to demonstrate their knowledge about the processes in the cell cycle and use this knowledge to compare chromosomes and interpret the graphs of the cell cycle representing DNA replication. In general, the results presented in Table 4.4 indicate that there is a noticeable difference between the percentage scores of the students at the pre-test and post-test. It also seems that in the pre-test most of students experienced difficulties in selecting the correct answer for the processes occurring during the cell cycle in comparison with the post-test. The details of the results obtained in each question of this section are described in the following sub-sections. The bold figures in Table 4.4 are the correct responses and the others are the distracters - except the “no answer” item which represents the students who did not choose any alternative answer.

Table 4.4 Student’s percentage scores on processes in the cell cycle.

Cell cycle	**Optional response-alternative**	**Pre-% scores**	**Post-% scores**
Q1 Event not forming part of the processes in the life cell cycle	Consists of mitosis and meiosis	25	2
	Cell’s DNA replicates during G1	**54**	**85**
	Cell remains in G1for weeks or much more	7	0
	Proteins are formed throughout subphases of interphase	2	2
	Histones are synthesized primarily during the S phase	12	2
	No answer	0	7
Q2 Phases of the cell cycle representing chromosome modification in figures 1 and 2	Interphase, metaphase	2	2
	Interphase, anaphase	**56**	**68**
	Interphase, telophase	7	0
	Prophase, anaphase	25	26
	Prophase, telophase	5	2
	No answer	5	2
Q3 Interpretation of the graph to indicate the events that occur during the life cell cycle	I indicates the interphase	34	24
	II indicates the mitosis	17	5
	I and II represent the meiosis	2	2
	I and II represent cell cycle in a somatic cell	**29**	**56**
	II indicates the meiosis	7	0
	No answer	10	12

N = 41

Question 1: Students’ responses on the event not taking part in the processes of the cell cycle

In question 1, the students had to indicate the event which did not form part of the processes in the cell cycle needed in order for cell division to happen. The students’ percentage scores on this question are illustrated in Table 4.4. At the pre-test 54% of the students indicated the correct option regarding the fact that "cell's DNA replicates during G1" compared to (85%) at the post-test. Also, 46% and 6% at the pre-and post-test respectively chose any distracter while 0% and 7% at the pre-and post-test gave no answer. These results show that although there is a noticeable improvement in the students' conceptions of the events occurring during the cell cycle, 6% of the students still held some erroneous ideas even after the instruction through practical work. A possible reason for this could be that they had very little understanding of the events occurring during the cell cycle in terms of its importance to cell division and for the continuity of genetic information in living organisms. Table 4.5 shows the frequencies of students' explanations of the events occurring during cell cycle.

Table 4.5: Pre-and post-test percentages of students' explanations about events in the cell cycle.

Types of explanations	**Pre-**	**Post-**
	% of stds.	**% of stds.**
1. DNA replicates during S phase of interphase	34	37
2. In G1 restarts the synthesis of RNA	0	5
3. In G1 intensive metabolic activity occurs	12	2
4. In G1 proteins synthesis and RNA ribosome occur	0	34
5. Cell cycle consists of mitosis and interphase	12	5
6. No explanations	41	17

N = 41

Table 4.5 provides students' explanation to question 1. The students had to demonstrate their understanding of the processes occurring during the cell cycle in order for cell division to happen. The frequencies of the different kinds of the explanations they gave at the pre-test differ considerably from those provided in the post-test. In both tests, 34% and 37% at the pre-and post-test respectively gave an adequate explanation corresponding to the subphase where DNA replication and other events occur during the cell cycle. The rest of the explanations provided by the students were considered as alternative answers to question 1. Zero scores indicate items on which the students provided no explanation or gave incorrect explanations.

From these results it is possible to infer that students' conceptions of the pre-conditions needed in order for cell cycle to occur was probably enhanced by the practical work in which they participated. This is further shown by the decline in the number of "no response" scores from 41% to 17% at the pre-and post-test respectively. The students' responses on the interviews also revealed that there was a noticeable improvement after practical work on mitosis regarding the events occurring in the cell cycle in order for DNA replicates and the correspondent subphase that is 'subphase **S** of interphase'. Despite this improvement, the difficulties experienced by the students in the interviews were comparable to those showed in their responses on both tests. For instance, they showed inconsistencies to establish analogies between chromosomes and chromatin to correctly describe the events taking place during the interphase as indicated in Section 4.3.1 of the interviews. In fact, students revealed during the laboratory sessions on mitosis that they had a good theoretical understanding of the concepts. However, their ability to apply this theoretical knowledge in practice was rather limited. This fact suggests that the students continued to have incoherent views of chromosome structure and associated functions after instruction through practical work (Chattopadhyay, 2005, Chinnici, *et al*., 2004).

Question 2: Students' responses on the phases representing the chromosome modifications in figures 1 and 2

This question asked the students to indicate the correct sequence of the phases of the cell cycle representing chromosome modifications in figures 1 "interphase" and 2 "anaphase" respectively. According to the results illustrated in the Table 4.4 above, there is very little difference between the pre-test and post-test scores. Thus, in the pre-test 56% of the students gave the correct response, that is, "interphase, anaphase" compared to 68% in the post-test; whereas 39% and 30% of the students at the pre- and post-test respectively indicated the distracters as the correct response. These results suggest that a considerable percentage (37% in the pre-test and 28% in the post-test) of the students continued to experience some problems in distinguishing and/or relating the form of chromosomes to its events even after being taught cell division through practical work. Despite this, the majority of the students were able to provide correct explanations for their answers. For example, the number of students who gave no explanation or provided incorrect explanations reduced considerably: Figure 1 on “interphase” from 51% to 15% and Figure 2 on “anaphase” from 29% to 10% at the pre-and post-test respectively (Table 4.6).

Based on the finding illustrated in Table 4.6, it is possible to suggest that although most of the students seem to know what happens in each phase of the cell cycle in terms of the content knowledge, a noticeable percentage of the students in both tests still lacked sufficient understanding to apply this knowledge to correctly describe chromosome modifications during the cell cycle. Another possible explanation might be linked to the lack of the basic process skills such as observing, analysing and interpreting the events in order to correctly differentiate and identify the chromosomes according to their structure during a cell division process. However, from the results for question 2, it can be assumed that practical work enhanced students’ conceptions about chromosome modifications during the cell cycle.

Table 4.6: Pre-and post-test percentages of students’ explanations about chromosome modification.

Type of explanations Fig. 1: Interphase	Pre- % of stds.	Post- % of stds.	Type of explanations Fig. 3: Anaphase	Pre- % of stds.	Post- % of stds
1. Chromosomes are twisted and not differentiated	12	37	1. Divided homologous chromosomes move to opposite poles of the cell	29	51
2. Chromosomes are long and decondensed	7	12	2. Spindle equator move chromosomes to opposite sides of the cell	7	12
3. Chromosomes seems to replicate its’ DNA in interphase	17	10	3. Centromere divides and sister chromatids move to opposite side of the cell	37	27
4. Chromosomes are disorganized and not paired	12	27	4. No explanations	29	10
5. No explanations	51	15			

N = 41

Question 3: Students' responses regarding the interpretation of the life cell cycle graph in a somatic cell

Question 3 asked the students to interpret the graph about DNA replication during the life cell cycle in a somatic cell. The findings with respect to this question show that there was a reasonable change between pre-and post-test scores (see Table 4.4). At the pre-test 29% of the students in the pre-test compared to 56% in the post-test chose the correct answer by indicating that "I and II represent cell cycle in a somatic cell". However, 60% of the students in the pre-test and 31% in the post-test gave an incorrect interpretation of the graph indicating the distracters as the correct answer; whereas 10% and 12% of the students provided no answer to this question at the pre- and post-test respectively. These results suggest that although most of the students possessed sufficient scientific knowledge about the events occurring during the cell cycle, they still had problems in using that knowledge to correctly interpret graphs, coupled with the lack of the specific skills to examine and interpret graphs. For instance, in some of their tentative explanations that are described below (Table 4.7) they did not provide complete scientific explanations of the graph direction in terms of matching DNA quantity and phases represented in Part I "Interphase" and II "Mitosis" of the graph.

Table 4.7: Pre-and post-test percentages of students' explanations on cell cycle graph.

	Types of explanations	**Pre-** % of stds.	**Post-** % of stds.
1.	Part I of the graph shows the replication of DNA, synthesis of proteins and RNA in S phase; part II of the graph shows the phases of mitosis in a somatic cell where replicated DNA remains constant	10	32
2.	Part I of the graph shows that interphase comprises G1, S and G2 subphases; part II of the graph shows that mitosis consists of four phases (P, M, A and T).	24	17
3.	The graph shows clearly that during the interphase cells prepare for mitotic division.	10	5
4.	Part I and II of the graph represent both mother and daughter cells with X chromosomal number.	2	2
5.	The graph shows that somatic cells suffer constant mitotic division to facilitate the regeneration of cells.	0	2
6.	The graphic shows the replication of DNA quantity from X → 2X.	2	2
7.	The graphic presents a complete cell cycle consisting of interphase and mitosis.	20	22
8.	No explanations	32	17

N = 41

The results displayed in Table 4.7 indicate that only 10% and 32% of the students interpreted correctly the events illustrated in Part I and II of the cell cycle graph. The rest of the students provided incomplete interpretations (58% and 50% at the pre-and post-test respectively) of the graph. Also, 32% and 17% at the pre-and post-test did not provide any interpretation to the cell cycle graph. These results reveal, to some extent that although most of the students gained awareness of the scientific concepts (content knowledge) about processes and events occurring during the cell cycle when influenced by instruction (practical work), their explanations are inconsistent. This shows that they still lack sufficient ability to correctly interpret graphs. This is coupled with their weakness to link the cell cycle events with the DNA quantity in living organism. These results are consistent with evidence from other research that most of the students mismatched the DNA quantity with the events of the cell cycle and with the structure of the chromosomes during the process of cell division (Lewis & Robinson, 2000). This mismatch can be related to the lack of awareness by the students of the relationship between cell division and the continuity of genetic information in the living organisms as well as ability to integrate their knowledge of cell structures with corresponding functions in cell division (Driver *et al*., 1994; Kindfield, 1994). This lack of ability to integrate the ideas about different topics in cell biology into overall picture has negatively impacted in the teaching and learning process of subjects such as genetics, evolution and inheritance (Lewis & Robinson, 2000; Flores *et al*., 2003).

In the next paragraph, a summary of the findings on the first category of the CBT is presented. This is based on a phenomenological analytic approach to qualitatively determine whether or not practical work enhanced the students' conceptions of cell division. The criteria of analysis of the students' level of understanding presented early in Table 4.1 are applied. Table 4.8 shows the students' percentage scores regarding different aspects of cell division at the pre-and post-test stages.

Table 4.8: Students' percentage scores relative to different aspects of cell division.

Levels of understanding			Poor %	Fair %	Good %
Processes in the cell cycle	Q1: Event not forming part of the processes in the cell cycle	Pre-test	0	46	54
		Post-test	7	6	85
	Q2: Phases of the cell cycle representing chromosome modification in figures 1 and 2	Pre-test	5	39	56
		Post-test	2	30	68
	Q3: Graph interpretation of the events occurring during the cell cycle	Pre-test	10	60	29
		Post-test	12	31	56

N = 41

The findings displayed in Table 4.8 indicate that before the instruction through practical work began, only a very small percentage (5%) of the students had a poor understanding with respect to aspects of cell division depicted in questions 1 – 3. Also, nearly a half (48%) of the students showed a fair level of understanding on aspects of cell division depicted in the three questions. 46% of the students showed a good understanding of the processes occurring during the cell cycle before the instruction through practical work. The scores on the post-test indicate that a large percentage of the students (70%) had developed a valid understanding of the processes in the cell cycle after instruction through practical work. According to the data displayed in Table 4.8 most of the students who improved their understanding moved from fair to good, that is, the percentage of students scoring in the good category increased by 24%. This is evidence that the cell biology practical work improved the level of the students' conceptions of cell division. Even so, the percentage of the students showing poor understanding was increased by 7% in Q1 and 2% in Q3 at the post-test. This might be linked to the fact that the administration of the post-test coincided with the end of the semester when students were probably under pressure from writing tests in other courses and hence, their concentration was reduced. However, this would require further inspection of the data. In the next section the students' responses on the events and characteristics of mitosis are presented and discussed.

4.2.3 Students' responses to questions about events of mitosis

In this section students were expected to apply their theoretical knowledge about the basic characteristics and events in mitotic cell division in order to correctly identify the sequence (Q4 and Q6) and names (Q5) of the mitotic phases as well as to match the phases with associated key events (Q7). The results of this section are displayed in the Tables 4.9, 4.10, 4.11, 4.12 and 4.13 respectively. The bold font indicates the correct responses and the others are the distracters except the "no answer" item which represents the responses of students who did not choose any alternative answer. Overall, the results in the five tables suggest that there is a noticeable improvement in the students' theoretical framework regarding the use of their scientific ideas to correctly identify the sequence and names of the mitotic phases as well to match the phases with associated key events after instruction through practical work.

Questions 4 and 6: Students' responses to items on the sequence of events in mitotic phases

Question 4 required the students to apply their knowledge to identify the correct sequence of mitotic phases illustrated in the picture of a plant meristem tissue. Question 6 asked students to apply their knowledge to indicate the correct sequence of mitotic phases using four different diagrams. As can be observed in the Table 4.9, most of the students did not experience difficulties in indicating the correct sequence of mitotic phases in both questions. Thus, for question 4, 83% of the students in the pre-test and 95% at the post-test gave the correct response regarding the sequence of the mitotic phases, that is "c→f→e→a→b→d: interphase, prophase, metaphase, early anaphase, later anaphase, and telophase". For question 6, 93% and 95% at the pre-and post-test stages respectively indicated the correct option regarding the sequence of mitotic phases, that is "II, IV, I, III: prophase, metaphase, anaphase, and telophase". Based on these findings one can assume that students have developed the essential concepts for identifying the correct sequence of the phases. In other words they had become confident in their answers about the way the figures and/or diagrams were presented.

Table 4.9: Students' percentage scores on the sequence of mitotic phases.

Mitosis	Optional response-alternative	Pre- % scores	Post- % scores
Q4	a→b→c→d→e→f	0	0
Sequence of phases	**c→f →e→a→b→d**	**83**	**95**
	f→b →a→e→d→c	5	2
	e→f →c→a→b→d	5	0
	f→e →c→b→d→a	5	0
	No answer	2	2
Q6	I, IV, III, II	0	0
Sequence of phases	IV, II, I, III	2	2
	I, IV, II, III	2	0
	II, IV, I, III	**93**	**95**
	II, III, I, IV	2	0
	No answer	0	2

N = 41; Q4- a: early anaphase: b: late anaphase: c: interphase; d: telophase; e: metaphase; f: prophase. Q6- I: anaphase; II: prophase; III: telophase; III: metaphase.

In order to verify whether or not the students gave the correct responses by chance, they were required to provide the names of the phases using the picture of a plant meristem tissue illustrated in question 4 instead of explaining their answers as indicated in question 5.

Question 5: Students' responses regarding the names of the mitotic phases

This question demanded the students to use their scientific knowledge of the basic characteristics of the mitotic division to name each of its phases using the picture of a plant meristem tissue illustrated in question 4. This was done to verify whether or not the students' responses to questions 4 and 6 were indicative of genuine understanding rather than guess work. Table 4.10 displays the results in this regard.

Table 4.10: Students' percentage scores regarding the names of the mitotic phases.

Q5	Identifying phases of mitosis	Pre- % scores	Post- % scores	Q5	Identifying phases of mitosis	Pre- % scores	Post- % scores
	Interphase	2	7		Interphase	2	2
	Prophase	10	0		Prophase	0	0
	Metaphase	34	27		Metaphase	5	5
a	**Early anaphase**	**37**	**61**	d	Early anaphase	2	2
	Late anaphase	0	0		Late anaphase	5	0
	Telophase	7	0		**Telophase**	**81**	**83**
	No answer	10	5		No answer	5	7
	Interphase	2	0		Interphase	12	0
	Prophase	0	10		Prophase	44	15
	Metaphase	10	0		**Metaphase**	**37**	**71**
b	Early anaphase	0	0	e	Early anaphase	0	2
	Late anaphase	**66**	**75**		Late anaphase	0	5
	Telophase	22	10		Telophase	2	2
	No answer	0	5		No answer	5	5
	Interphase	**54**	**54**		Interphase	39	12
	Prophase	17	31		**Prophase**	**37**	**63**
	Metaphase	5	5		Metaphase	7	7
c	Early anaphase	2	0	f	Early anaphase	0	0
	Late anaphase	0	0		Late anaphase	0	0
	Telophase	7	0		Telophase	5	7
	No answer	15	10		No answer	12	10

N = 41

An examination of Table 4.10 suggests that only a few students were able to correctly identify the following phases in the pre-test: early anaphase (37%); metaphase (37%) and prophase (37%). However, after the instruction through practical work, the students' responses show a noticeable improvement. Thus, a reasonable percentage of the students could name the three phases correctly: early anaphase (61%); metaphase (71%) and prophase (63%) in contrast to the pre-test results.

Despite this improvement, it appears that in both tests, some students still had difficulties in distinguishing between metaphase and early anaphase; late anaphase and telophase; prophase and metaphase and; interphase and prophase. For instance, in item 5a, 34% of the students in the pre-test and 27% at the post-test indicated metaphase instead of early anaphase; in item 5b, 22%of the students in the pre-test and 10% at the post-test named it telophase instead of late anaphase; in item 5c, 17%

of the students in the pre-test and 13 at the post-test selected prophase as alternative to interphase; in item 5e, 44% of the students in the pre-test and 15% at the post-test indicated prophase instead of metaphase; and in item 5f, 39% and 12% of the students at the pre- and post-test respectively chose interphase in the place of prophase. This suggests that although their knowledge of basic characteristics of mitotic division shows some improvement after instruction, some students continued to experience difficulties in understanding the structure of the chromosomes in order to correctly identify the mitotic phases (Kindfield, 1991). The Kindfield (1991) study revealed that the most prevalent misconceptions showed by the participants, novice or expert, were related to the chromosomes. For instance, the participants viewed the chromosome structure as a function of chromosome number. In order to deal with this issue the development of instruction which distinguishes both concepts clearly is suggested. In addition, activities designed to encourage students to verbalize as well draw chromosomes correctly at the school level might serve as a tool to help students visualize their conceptions of chromosomes and hence, identify correctly the mitotic phases (Kindfield, 1991).

In order to analyse the students' consistency of responses, an inter-item cross-tabulation between questions 4 and 6 about sequencing mitotic phases was determined. Cross-tabulation is a measure used in descriptive statistics. In this study, it was used to verify the number of the students responding in the same way on the same concept. The inter-item cross-tabulation may also provide further understanding of the students' difficulties on a specific concept. Table 4.11 presents inter-item cross-tabulation of the pre-test results, whereas Table 4.12 shows the cross-tabulation of the post-test results.

Table 4.11: Question 4 and Question 6 cross-tabulation on pre-test results.

			Question 6				Total
			IV, II, I, III	I; IV, II, III	**II, IV, I, III**	II, III, I, IV	
Question 4	f, e, c, b, d, a	% of Total	.0%	.0%	**4.9%**	.0%	4.9%
	e, f, c, a, b, d	% of Total	.0%	.0%	**4.9%**	.0%	4.9%
	f, b, a, e, d, c	% of Total	2.4%	.0%	**2.4%**	.0%	4.9%
	c, f, e, a, b, d	**% of Total**	**.0%**	**2.4%**	**78.0%**	**2.4%**	**82.9%**
	No answer	% of Total	.0%	.0%	**2.4%**	.0%	2.4%
Total		% of Total	2.4%	2.4%	**92.7%**	2.4%	100.0%

N = 41 *The figures in bold are the correct responses; **Q4- a: early anaphase: b: late anaphase: c: interphase; d: telophase; e: metaphase; f: prophase. Q6-I: anaphase; II: prophase; III: telophase; III: metaphase.

The pre-test results illustrated in Table 4.11 show that 83% of the students gave the correct response about the sequence of the mitotic phases, that is "c→f→e→a→b→d: interphase, prophase, metaphase, early anaphase, later anaphase, and telophase" in question 4. Out of these, 78% have also responded correctly to question 6 indicating "II, IV, I, III: prophase, metaphase, anaphase, and telophase" as the correct sequence of the mitotic phases. Based on this, it seems that most of the students were consistent in their reasoning regarding the sequence of mitotic events. In this case, it is possible to suggest that 5% out of 83% of the students who responded correctly to question 4 continued to hold some erroneous ideas about the basic characteristics of the mitotic division in order to correctly identify and differentiate its phases, as can be seen in Table 4.11.

Table 4.12 below illustrates cross-tabulation between the students' responses to questions 4 and 6 at the post-test. Looking into the results displayed in Table 4.12, it is obvious that the students' responses to both questions were highly consistent compared to the pre-test as indicated in Table 4.11. Ninety five percent of the 41 students chose the correct option, that is "c→f→e→a→b→d: interphase, prophase, metaphase, early anaphase, late anaphase, and telophase" of mitotic phases. Out of the 95% of the students, 90% also chose the correct option "**d**" in question 6, that is

"II, IV, I, III: prophase, metaphase, anaphase, and telophase". The students (5%) who did not choose the correct response for the two questions might have difficulties similar to those experienced by the other 5% of the students in the pre-test. Interestingly five students who gave incorrect response in both questions moved to the correct optional response in both questions after the laboratory - based instruction.

Table 4.12: Question 4 and Question 6 cross-tabulation on post-test results.

			Question 6			Total
			No answer	I; IV, II, III	**II, IV, I, III**	
Question 4	f, b, a, e, d, c	% of Total	.0%	.0%	**2.4%**	2.4%
	c, f, e, a, b, d	**% of Total**	**2.4%**	**2.4%**	**90.2%**	**95.1%**
	No answer	% of Total	.0%	.0%	**2.4%**	2.4%
Total		% of Total	2.4%	2.4%	**95.1%**	100.0%

N = 41 *The figures in bold are the correct responses; **Q4- a: early anaphase: b: late anaphase: c: interphase; d: telophase; e: metaphase; f: prophase. Q6-I: anaphase; II: prophase; III: telophase; III: metaphase.

Question 7: Students' responses regarding their conceptions in matching mitotic events with its phases

This question was designed to elicit students' alternative conceptions in matching mitotic stages with key events. The results in Table 4.12 suggest that most of the students were able to correctly match the key events of mitosis with its phases in both pre-and post-tests. In the pre-test 83% out of 41 students gave the correct response to anaphase, 78% to prophase, 88% to telophase and 78% to metaphase compared to the post-test results where 95% of the students gave the correct response to anaphase, 95% to prophase, 95% to telophase and 93% to metaphase. However, a small percentage of the students (13% and 5% at the pre-and post-test stages respectively) were unable to correctly match the key events of mitosis with its phases in both tests. Five (5%) and zero (0%) percent of the students provided no answer in both tests respectively (Table 4.13).

Table 4.13: Students' percentage scores on matching the events with the phases of mitosis.

Q7: Events	Mitosis' phases	Pre- % scores	Post- % scores
a. Sister chromatids of each chromosome separate and move to opposite sides	Metaphase	7	2
	Prophase	5	2
	Telophase	2	0
	Anaphase	**83**	**95**
	No answer	2	0
b. Threadlike chromosomes condense and microtubule spindle are formed	Metaphase	2	2
	Prophase	**78**	**95**
	Telophase	5	2
	Anaphase	7	0
	No answer	7	0
c. Chromosomes decondensed, daughter nuclei reform	Metaphase	2	0
	Prophase	0	2
	Telophase	**88**	**95**
	Anaphase	2	2
	No answer	7	0
d. All chromosomes become aligned at spindle equator.	**Metaphase**	**78**	**93**
	Prophase	10	0
	Telophase	2	0
	Anaphase	7	7
	No answer	2	0

N = 41

Table 4.14 presents a summary of the findings on the second theme of the CBT according to the criteria of analysis of the students' level of understanding of cell division concepts (refer to Table 4.1).

Table 4.14: Students' percentage scores relative to aspects of mitotic events.

Levels of understanding			Poor %	Fair %	Good %
Mitotic events and characteristics	Q4: Sequence of mitotic phases through a plant meristem picture	Pre-test	2	15	83
		Post-test	2	2	95
	Q5: Names of mitotic phases	Pre-test	8	40	52
		Post-test	7	25	68
	Q6: Sequence of mitotic phases through four diagrams	Pre-test	0	6	93
		Post-test	2	2	95
	Q7: Matching phases of mitosis with key events	Pre-test	5	13	82
		Post-test	0	5	95

N = 41

Table 4.14 shows that only a very small percentage (4%) of students showed a poor understanding about the events and characteristics of mitosis in the four questions before laboratory instruction. Eighteen percent (18 %) of students showed a fair level of understanding while 78% showed a good understanding. At the post-test, however, 88% showed a good level of understanding of the characteristics of mitosis and events. As can be seen in Table 4.13 most of the students who improved their understanding moved from fair to good. In other words, the percentage of students scoring in the good category increased by 10%. This suggests that, overall the cell biology practical work most probably had enhanced students' understanding of cell division by mitosis.

4.2.4 Students' responses to questions about events of meiosis

This section describes the students' responses to questions 8, 9, 10, 11 and 12. These questions were designed to elicit students' conceptions about the basic characteristics of meiosis and associated events. In this regard, students were required to use their knowledge to identify, differentiate and describe the events occurring during the meiotic cell division. The data obtained on these questions are displayed in Tables from 4.15 to 4.21. The bold font in each table are indicative of correct responses while those in lighter print are the distracters except the "no answer" which represents the students who did not choose any alternative answer.

Question 8: Students' response regarding the basic characteristic of meiosis

This question was designed to test students' conceptions about the basic characteristics of meiosis in terms of its importance in the living organisms before students were exposed to practical work. Students were asked to indicate the correct statement, which illustrates a typical characteristic of meiosis (Table 4.15).

Table 4.15: Students' percentage scores on characteristics of meiosis.

Meiosis	Optional response-alternative	Pre- % scores	Post- % scores
Q8 Characteristics of meiosis	A 2n cell originates two cells with 2n	2	2
	A 2n cell originates, through one division, four cells with n chromosomes and genetically distinct between them and from original cell	7	0
	A 2n cell, through two consecutive divisions, originates four haploid cells, genetically distinct between them and from original cell	**36**	**71**
	A 2n cell, through two consecutive cell divisions (reductional and equational), originates four haploid cells identical between them and from the original cell	52	24
	A n cell originates four haploid cells and identical between the and from the original	2	0

N = 41

An examination of Table 4.15 shows that 36% of 41 students in the pre-test gave the correct response that is that "A 2n cell, through two consecutive divisions, originates four haploid cells, genetically distinct between them and from original cell" compared to 71% at the post-test. Fifty two percent (52%) and 24% of the students at the pre-and post-test respectively indicated that "A 2n cell, through two consecutive cell divisions (reductional and equational), originates four haploid cells identical between them and from the original cell". The reason why these students regard the originated cell as identical between them and from the original cell can be connected to the everyday knowledge (common knowledge) acquired through the surrounding environment. For example, in Mozambique, there is a belief that the newborn hold the same genetic characteristics like their parents ignoring the importance of meiosis to generate genetic variation. This is coupled with the lack of connections between the role of cell division and inheritance (Kindfield, 1991; Lewis & Wood-Robninson, 2000). Therefore, it can be assumed that the students' responses on question 8 were based on their everyday life experiences acquired in their environments rather than the scientific explanations of the importance of meiosis in the living organisms. Despite this, there is a substantial difference between the percentage scores of the students at the pre-test and post-test suggesting that the students' conceptions about the basic characteristics of meiosis was probably enhanced by the practical work on cell division.

Question 9: Students' responses about the sequence of phases in meiosis

Question 9 asked the students to identify the sequence of meiotic phases in a plant cell illustrated in four diagrams. Table 4.16 shows the findings on this question.

Table 4.16: Students' percentage scores on the sequence of meiotic phases.

Meiosis	Optional response-alternative	Pre- % scores	Post- % scores
Q9	$A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow F_1 \rightarrow F_2 \rightarrow F_3 \rightarrow F_4 \rightarrow F_5 \rightarrow G$	0	0
Sequencing the meiosis	$C \rightarrow G \rightarrow E \rightarrow A \rightarrow F_2 \rightarrow F_1 \rightarrow F_5 \rightarrow F_3 \rightarrow F_4 \rightarrow B \rightarrow D$	2	2
phases	$F_2 \rightarrow F_3 \rightarrow F_4 \rightarrow F_1 \rightarrow F_5 \rightarrow E \rightarrow C \rightarrow A \rightarrow D \rightarrow G \rightarrow B$	0	0
	$F_2 \rightarrow F_3 \rightarrow F_4 \rightarrow F_1 \rightarrow F_5 \rightarrow E \rightarrow C \rightarrow D \rightarrow G \rightarrow A \rightarrow B$	**90**	**95**
	$F_2 \rightarrow F_4 \rightarrow F_3 \rightarrow F_5 \rightarrow F_1 \rightarrow A \rightarrow E \rightarrow B \rightarrow D \rightarrow C \rightarrow G$	5	2
	No answer	2	0

N = 41; A: anaphase II; B: telophase II; C: anaphase I; D: telophase I; E: metaphase I; F1: pachytene; F2: interphase; F3: leptotene; F4: Zygotene; F5: diakinese; G: metaphase II.

The findings on this question can be compared with those obtained through question 4 on the sequence of mitotic events because the students' average percentage score was high for the correct response for both pre-and post-test. At the pre-test, 90% of 41 students demonstrated a valid understanding of meiosis compared to 95% of the students at the post-test. Apparently, in both tests, students showed a good understanding of the sequence of the meiotic phases when represented in diagrams. However, one cannot assume, in this case, that practical work enhanced students' understanding of the different stages of meiosis as the students experienced many difficulties in naming the phases of the chosen sequence. This can be seen in the results of question 10 below.

Question 10: Students' responses regarding the names of the meiotic phases

This question was designed to verify the students' level of understanding about the basic characteristics of meiosis and associated events by naming each of the phases illustrated in the diagrams of the question 9. The students' responses to question 10 are presented in Tables 4.17 and 4.18. Table 4.17 illustrates the students' percentage scores on items A, B, C, D, E and G while Table 4.18 shows the students' percentage scores on items F1, F2, F3, F4 and F5, respectively.

Table 4.17: Student's percentage scores on meiotic phases for question 10, items A - G.

Q10	Phases of meiosis	Pre- %	Post- %	Q10	Phases of meiosis	Pre- %	Post- %	Q10	Phases of meiosis	Pre- %	Post- %
A	Interphase	2	0	B	Interphase	0	0	C	Interphase	0	0
	Leptotene	2	0		Leptotene	2	0		Leptotene	0	2
	Zygotene	0	0		Zygotene	0	0		Zygotene	0	0
	Pachytene	0	0		Pachytene	0	0		Pachytene	0	0
	Diplotene	0	0		Diplotene	0	0		Diplotene	0	0
	Diakinese	0	0		Diakinese	0	0		Diakinese	0	0
	Metaph. I	0	0		Metaph. I	0	0		Metap. I	10	7
	Anaph. I	12	5		Anaph. I	2	0		**Anaph. I**	**56**	**73**
	Teloph. I	2	0		Teloph. I	7	2		Teloph. I	2	5
	Proph. II	0	0		Proph. II	0	2		Proph. II	2	0
	Metaph. II	2	0		Metaph. II	0	0		Metaph. II	7	5
	Anaph. II	**68**	**88**		Anaph. II	5	0		Anaph. II	7	0
	Teloph. II	0	0		**Teloph. II**	**73**	**88**		Teloph. II	0	0
	No answer	10	7		No answer	10	7		No answer	15	7
D	Interphase	2	0	E	Interphase	0	0	G	Interphase	0	0
	Leptotene	2	0		Leptotene	7	0		Leptotene	5	0
	Zygotene	0	2		Zygotene	0	0		Zygotene	0	0
	Pachytene	0	0		Pachytene	0	2		Pachytene	0	0
	Diplotene	0	0		Diplotene	0	0		Diplotene	0	0
	Diakinese	0	0		Diakinese	0	0		Diakinese	0	0
	Metaph. I	2	0		**Metaph. I**	**54**	**76**		Metaph. I	10	0
	Anaph. I	2	0		Anaph. I	7	5		Anaph. I	2	0
	Teloph. I	**63**	**71**		Teloph. I	0	0		Teloph. I	0	0
	Proph. II	2	15		Proph. II	1	0		Proph. II	0	2
	Metaph. II	0	2		Metaph. II	7	7		**Metaph. II**	**56**	**80**
	Anaph. II	5	0		Anaph. II	0	0		Anaph. II	2	2
	Teloph. II	10	0		Teloph. II	0	0		Teloph. II	2	5
	No answer	10	10		No answer	22	10		No answer	22	10

N = 41; A: anaphase II; B: telophase II; C: anaphase I; D: telophase I; E: metaphase I; G: metaphase II.

Table 4.18: Students' percentage scores on meiotic phases for question 10, items F1 - F5.

Q10	Phases of meiosis	Pre-%	Post-%	Q10	Phases of meiosis	Pre-%	Post-%	Q10	Phases of meiosis	Pre-%	Post-%	Q10	Phases of meiosis	Pre-%	Post-%	Q10	Phases of meiosis	Pre-%	Post-%
F1	Interph.	12	0	F2	**Interp.**	**29**	**71**	F3	Interp.	15	12	F4	Interp.	10	17	**F5**	Interp.	7	0
	Leptot.	20	7		Leptot.	27	2		**Leptot.**	**22**	**56**		Leptot.	5	0		Leptot.	5	0
	Zygot.	0	2		Zygot.	5	10		Zygot.	2	0		**Zygot.**	**17**	**37**		Zygot.	0	2
	Pach.	**0**	**44**		Pach.	0	0		Pach.	7	10		Pach.	0	20		Pach.	0	0
	Dipl.	0	24		Dipl.	0	0		Dipl.	0	0		Dipl.	5	5		Dipl.	2	0
	Diak.	2	2		Diak.	0	2		Diak.	0	0		Diak.	0	2		**Diak.**	**22**	**68**
	Met.I	2	0		Met. I	5	0		Met. I	7	5		Met. I	5	5		Met. I	5	7
	Anap.I	2	2		Anap. I	0	0		Anap. I	2	5		Anap. I	5	2		Anap. I	2	0
	Telop.I	0	0		Telop. I	0	0		Telop. I	0	0		Telop. I	0	0		Telop. I	2	0
	Prop.	10	2		Prop.	2	2		Prop.	5	2		Prop.	17	2		Prop.	15	10
	II	0	0		II	2	0		II	0	0		II	5	0		II	5	2
	Met. II	2	0		Met. II	0	0		Met. II	0	0		Met. II	0	0		Met. II	0	0
	Anap.	0	0		Anap.	0	0		Anap.	0	0		Anap.	0	0		Anap.	0	0
	II	49	15		II	29	12		II	39	10		II	31			II	34	10
	Telop.II				Telop.II				Telop.II				Telop.II				Telop.II		
	No				No				No				No				No		
	answer				answer				answer				answer				answer		

N = 41; F1: pachytene; F2: interphase; F3: leptotene; F4: Zygotene; F5: diakinese.

In examining carefully the results displayed in Tables 4.17, and 4.18, it is evident that there was widespread uncertainty in identifying the names of the meiotic phases illustrated in the diagrams A, B. C, D, E, F1, F2, F3, F4, F5 and G of the question 9 particularly, in the items concerned with the interphase (item F2) and sub-phases of the prophase I of meiosis (items F1, F3, F4 and F5) as indicated in the Tables 4.17 and 4.18. This shows that the students' responses to question 9 might have been given by chance and not because they had a well developed understanding of the chromosome structure and specific events that occur during meiosis (like crossing-over, the order and timing of events). Regardless of this, the results displayed in the two tables show clearly that there was a reasonable change in the total percentage scores of the students performing well at the pre-test (42%) and post-test (68%). It is also obvious that, in general, most of the students continued to have many difficulties in distinguishing the appearance of the chromosomes in terms of the structure in several stages of meiosis, even after the instruction through practical work. Thirty two percent (32%) and 22% of the students at the pre-and post-test stages could not identify any meiotic phases. Also, 25% and 10% of the students at the pre-and post-test stages respectively did not provide any answer in this regard. This can be associated with the fact that the time of the students' exposure to practical work on meiosis and also the nature of the exercises performed during the laboratory sessions might not have been enough for them in order to develop a solid knowledge base regarding the basic characteristics of meiosis and associated key events. Furthermore, the light microscopes available in the laboratory did not allow the students to observe more details of cells in several stages of meiosis particularly, the differences between the subphases of prophase I. Classroom observations confirmed that most of the students did not have a good understanding of how to use the light microscope in order to make accurate observations and descriptions of the observed specimens. On the other hand, students' responses on the interviews demonstrated that students experienced many difficulties in identifying the meiotic phases particularly, the prophase I subphases as illustrated in section 4.3.1 of the post-laboratory interviews.

This misunderstanding might be linked to the lack of conceptual understanding of the basic concepts such as: structure of chromosomes during prophase I as well as the status of the chromosomes in terms of the movements. Early studies on meiosis corroborate these findings. It has been shown that the first part of meiotic division, especially chromosome movement during prophase was the hardest part of meiotic division to explain to students (Kindfield; 1994; Yip; 1998). For instance, the most salient difficulties were coupled to the poorly developed understanding of chromosome structure, specific events that occur during meiosis such as: crossing-over, (called "event-specific process misunderstanding"), the importance of the order and timing of events (called "whole-process misunderstanding"). Other authors believe that this problem might be associated with the way this subject matter is taught during the teachers' higher education training (Öztas *et al*., 2003). Therefore, an assumption was built up that, when subjects such as cell division and the DNA-chromosome relationship are not well taught to students this can result in misunderstanding of the topics and this can be reflected in their subsequent teaching. In the face of this, in this study, it is assumed that a review of the teaching methodology of subjects such as cell division at higher education would provide teachers with an adequate level of knowledge for their teaching at the school level as well at higher education.

Question 11 and 12: Students' responses regarding the events occurring during prophase I

These questions aimed at eliciting students' conceptions regarding the events occurring during prophase I of meiosis. From an analysis of the results in the Table 4.19, it became obvious that there were disparities in the students' responses to both questions. Question 11 asked the students to indicate the correct alternative, which shows the events occurring during prophase I of meiosis according to the appearance of the chromosomes. Question 12 also asked students to indicate the correct alternative that represents the events occurring during prophase I of meiosis.

Table 4.19: Students' percentage scores on events in the prophase I.

Events in Prophase I	Optional response-alternative	Pre- % scores	Post- % scores
Q11 Events according to the appearance of chromosomes in prophase I	I and II	7	2
	I and III	5	7
	I and IV	10	5
	II and III	**66**	**78**
	II and IV	7	5
	No answer	5	2
Q12 Specific events during prophase I	All the statements are correct	5	2
	Statements I, II and III are correct	0	10
	Statements I, III and IV are correct	24	7
	Statements I and II are correct	32	32
	Statements I, II and IV are correct	**37**	**46**
	No answer	2	2

N = 41; Q11- I: Separation of the chromatids; II: Paring of homologous chromosomes; III: Exchange of the segments between chromatids; IV: Division of the centromere. Q12- I: Trough crossing-over, homologous chromatids exchange segments, originating new gene combinations; II: Crossing-over occurs during the prophase of meiosis I; III: At the end of interphase, in the metaphase and anaphase of mitosis, the chromosomes are, respectively, singles, duplicated, singles; IV: Gametes with 14 chromosomes are formed from somatic cells with 28 chromosomes.

In question 11, there is a noticeable difference in the percentage of students choosing the correct response in both tests (66% in the pre-test and 78% at the post-test). In question 12, only 37% students in the pre-test could indicate the correct response compared to 46% at the post-test. Table 4.19 also shows that in question 12, almost 63% and 53% of the students at the pre-and post-test respectively were unable to indicate the correct response. These results suggest that a considerable number of the students still had difficulties in understanding the mechanisms of the events and processes occurring during meiotic cell division and in genetic variability resulting from crossing-over. In this question, students were not asked to explain their answers. However, the results from the interviews demonstrated that there is some misunderstanding in interpreting the importance of crossing-over during prophase I of meiosis and that this misunderstanding still persisted after instruction. More details about the results of the interviews are given in section 4.3 of this chapter.

The results yielded in these questions corroborate with what the literature says regarding the students' difficulties in understanding the specific events occurring during meiosis, particularly the first part of meiotic division, that is, chromosome movements during prophase I (Kindfield, 1994; Yip, 1998; Chnnici *et al*., 2004). In connection to this, Öztas *et al*. (2003) in examining the difficulties biology teachers face when teaching cell division found that most of them perceived cell division as one of the most difficult subject, particularly the meiosis compared to other areas of cell division. It is considered the hardest part of meiotic division to explain to students.

Tables 4.20 and 4.21 below illustrate a cross-tabulation of the students' responses in terms of consistency in questions in Q11 and Q 12. This was done because both questions were testing the same concepts in terms of the events happening during the prophase I. Table 4.20 presents the cross-tabulation between question 11 and 12 in the pre-test; whereas Table 4.21 shows the cross-tabulation of the post- test results for questions 11 and 12.

Table 4.20: Question 11 and Question 12 cross-tabulation on the pre-test results.

			Question 12					Total
			No answer	All statements correct	Statements I, III and IV	Statements I and II	**Statements I, II and IV**	
Question 11	II and IV	% of Total	.0%	.0%	2.4%	4.9%	**.0%**	7.3%
	II and III	**% of Total**	**2.4%**	**4.9%**	**9.8%**	**19.5%**	**29.3%**	**65.9%**
	I and IV	% of Total	.0%	.0%	2.4%	2.4%	**4.9%**	9.8%
	I and III	% of Total	.0%	.0%	2.4%	2.4%	**.0%**	4.9%
	I and II	% of Total		.0%	4.9%	.0%	**2.4%**	7.3%
	No answer	% of Total	.0%	.0%	2.4%	2.4%	**.0%**	4.9%
Total		% of Total	2.4%	4.9%	24.4%	31.7%	**36.6%**	100.0%

N = 41 *The figures in bold are the correct responses. Q11- I: Separation of the chromatids; II: Paring of homologous chromosomes; III: Exchange of the segments between chromatids; IV: Division of the centromere. Q12- I: Trough crossing-over, homologous chromatids exchange segments, originating new gene combinations; II: Crossing-over occurs during the prophase of meiosis I; III: At the end of interphase, in the metaphase and anaphase of mitosis, the chromosomes are, respectively, singles, duplicated, singles; IV: Gametes with 14 chromosomes are formed from somatic cells with 28 chromosomes.

The results displayed in Table 4.20 indicate that in question 11, before instruction, through practical work began, 66% of 41 students chose the correct optional-response, that is “II and III: paring of homologous chromosomes, and exchange of the segments between chromatids”. Out of these 66% only 29% students also chose the correct optional-response in question 12, that is “statements I, II and IV: trough crossing-over, homologous chromatids exchange segments, originating new gene combinations; crossing-over occurs during the prophase of meiosis I; and gametes with 14 chromosomes are formed from somatic cells with 28 chromosomes”. These results show clearly a low consistency between the students’ responses to Q11 and Q12. It can be assumed that the 37% of the students who provided no answer to Q12 possess gaps in their conceptual understanding regarding the events occurring during the prophase I of meiotic division. Table 4.21 shows a cross-tabulation between questions 11 and 12 during the post-test.

Table 4.21: Question 11 and Question 12 cross-tabulation on the post-test results.

			Question 12						Total
			No answer	All statements correct	Statements I, II e III	Statements I, III e IV	Statements I e II	**Statements I, II e IV**	
Question 11	II and IV	% of Total	.0%	.0%	2.4%	.0%	.0%	**2.4%**	4.9%
	II and III	**% of Total**	**.0%**	**2.4%**	**4.9%**	**7.3%**	**29.3%**	**34.1%**	**78.0%**
	I and IV	% of Total	.0%	.0%	2.4%	.0%	.0%	**2.4%**	4.9%
	I and III	% of Total	.0%	.0%	.0%	.0%	2.4%	**4.9%**	7.3%
	I and II	% of Total	.0%	.0%	.0%	.0%	.0%	**2.4%**	2.4%
	No answer	% of Total	2.4%	.0%	.0%	.0%	.0%	**.0%**	2.4%
Total		% of Total	2.4%	2.4%	9.8%	7.3%	31.7%	**46.3%**	100.0%

N = 41; *The figures in bold are the correct responses. Q11- I: Separation of the chromatids; II: Paring of homologous chromosomes; III: Exchange of the segments between chromatids; IV: Division of the centromere. Q12- I: Trough crossing-over, homologous chromatids exchange segments, originating new gene combinations; II: Crossing-over occurs during the prophase of meiosis I; III: At the end of interphase, in the metaphase and anaphase of mitosis, the chromosomes are, respectively, singles, duplicated, singles; IV: Gametes with 14 chromosomes are formed from somatic cells with 28 chromosomes.

From the results displayed in Table 4.21 there seems to be no obvious change in the students' conceptions of the events occurring during prophase I even after the instruction through practical work. Only 34% of the 32 students who responded correctly answered to questions 11 and 12. As indicated early, students continued to hold erroneous ideas about the meaning of the events occurring during the prophase I of meiotic cell division. This might be one of the reasons why they did not perform well either in the pre-test or in the post-test. Some evidence from the literature explaining why the students have difficulties in understanding the events occurring during prophase I of meiosis are highlighted by Kindfield (1994), Yip (1998) and Chinnici *et al*. (2004). For instance, the results of the Kindfield study revealed the existence of meiosis misunderstandings linked to chromosome structure, replication of chromosomes and crossing-over. As was emphasized by Chinnici *et al*., 2004) the nature of these misconceptions is associated with the lack of understanding of the basic terms such as: doubling (replication), paring (synapsis), and separating (disjunction). In addition, it is common that students confuse chromatids with chromosomes, or replicated chromosomes with unreplicated chromosomes.

In Table 4.22, a summary of the students' level of understanding on the third theme of meiosis - "meiotic events and characteristics" - is presented. Criteria established early in Table 4.1 of this chapter are applied.

Table 4.22: Students' percentage scores relative to aspects of meiotic events.

Levels of understanding			**Poor %**	**Fair %**	**Good %**
Characteristics of meiosis and associated events	Q8: Basic characteristics of meiosis	Pre-test	2	61	36
		Post-test	0	26	74
	Q9: Sequence of meiotic phases	Pre-test	2	7	90
		Post-test	0	4	95
	Q10: Names of meiotic phases	Pre-test	25	32	42
		Post-test	10	22	68
	Q11and 12: Events in prophase in meiosis	Pre-test	3	45	52
		Post-test	2	35	62

N = 41

In general, the results displayed in the Table 4.22 show that a considerable percentage of the students shifted their level of understanding from fair to good after the instruction through practical work. Thus, the percentage of the students scoring in the good category increased by 14%. This suggests that the practical work enhanced students' understanding of characteristics of meiosis and associated events. The scores on the pre-test indicate that only 8% of the students exhibited poor understanding in each of the four questions about characteristics of meiosis and associated events before the instruction through practical work began. The results indicate also that a large percentage (36 %) of the students had a fair level of understanding in each of the four questions before the instruction. The scores on the post-test indicate that a considerable number (75%) of the students enhanced their understanding of the characteristics of meiosis and associated events after the instruction through practical work. Despite this improvement, there is evidence that students did not consistently apply their knowledge about the basic characteristics of meiosis in order to correctly name its phases and describe the events in prophase I. For instance, 10% and 22% of the students' understanding belong to the poor and fair category respectively on the question about meiotic phases, and 35% to the fair category on the question about events in prophase I. The reasons for the prevalence of these misunderstanding were highlighted previously.

4.2.5 Students' responses to questions dealing with differences between mitosis and meiosis

This section deals with the students' understanding about the basic differences between mitosis and meiosis. The questions exploring this are: 13, 14, 15, 16 and 17. The results will include the students' understanding about formation of germ cells (gametes) and the students' understanding of the meaning of the haploid and diploid chromosomal number. Tables 4.23 - 4.27 illustrate the students' percentage scores in these questions.

Question 13: Students' responses regarding the type of cell division in germ cells

This question was designed to elicit the students' alternative conceptions of the type of cell division occurring in the living organisms in order to form germ cells. The answers to this question are illustrated in Table 4.23.

Table 4.23: Students' percentage scores on the type of cell division in germ cells.

Q13 **Type of cell division in germ cells**	**Optional response-alternative**	**Pre-** **% scores**	**Post-** **% scores**
	Diagram A	12	0
	Diagram B	**85**	**100**
	No answer	2	0

N = 41; Diagram A: Mitosis; Diagram B: Meiosis.

Table 4.23 shows that in question 13 most of the students could indicate the correct optional-response (Diagram B: meiosis) in both tests (85% and 100% at the pre-and post-test respectively). They could relate correctly the diagram representing the process occurring in germ cells of the living organisms (Diagram B) with the type of cell division (meiosis). However, 14% of the students were unable to achieve the correct response at the pre-test as indicated by 12% of the students who chose Diagram A (mitosis) as the correct response and 2% who provided no answer. It appears that most of the students rightly related the meiosis processes with the processes of gamete formation. However, they showed some uncertainty when asked to explain their answers as illustrated in the Table 4.24.

Table 4.24: Pre- and post-test percentages of students' valid explanations about processes in germ cells.

Type of explanations	Pre- % of sdts.	Post- % of sdts.
1. Fusion of gametes with 23 chromosomes originating a zygote with 46 chromosomes to maintain the species occurs in meiosis	34	12
2. Meiosis occurs in germ cells to form gametes with haploid chromosomal number	12	20
3. Meiosis forms gametes with the half chromosomal number of the original cell	24	37
4. Mother cell divides originating 4 haploid daughter cells with different chromosomal number from the mother cell	7	10
5. During meiosis cells undergo two consecutive divisions (reductional and equational) originating 4 haploid cells genetically distinctive from the mother cell: 2n → n	5	12
6. No explanations	17	7

N = 41

The students' valid explanations for this question showed also that, overall, students have a different understanding of the processes occurring in the cells of living organisms in order to form germ cells. This can be seen by the diversity of their explanations provided in Table 4.24. For instance, only 5% and 12% of the students at the pre-and post-test respectively attempted to explain their optional response based on the type of division and chromosome number (Lewis *et al*, 2000; Lewis & Wood-Robinson, 2000). Lewis *et al* (2000) found in their study on the processes of cell division and fertilization that only 11% of 481 students could distinguish between gonads and somatic cells, but not between mitosis and meiosis. It seemed that the students could recognize the differences between gonads and somatic cells in terms of cell division but they were unclear about the nature of those differences as they were unable to indicate the location of each type of cell division. It can be assumed that this misunderstanding might be linked to the failure of making any distinction between meiosis and mitosis on the basis of chromosome number, genetic information, or location of each type of cell division.

Question 14: Students' responses regarding types of cell division and associated phases

Question 14 asked students to identify the type of cell division and the phases illustrated in two drawings of the same animal whose diploid number of chromosome is 4 (2n = 4). Table 4.25 shows the results of the students' percentage scores according to the type of the cells (Cell A and Cell B).

Table 4.25: Students' percentage scores on cell division type of a cell with 2n = 4.

Cell A						**Cell B**					
Type of division	**Pre- % scores**	**Post- % scores**	**Phases**	**Pre- % scores**	**Post- % scores**	**Type of division**	**Pre- % scores**	**Post- % scores**	**Phases**	**Pre- % scores**	**Post- % scores**
			Interph.	15	5				Interph.	5	5
Mitosis	39	29	Proph.	27	10	**Mitosis**	**51**	**58**	**Proph.**	**39**	**49**
			Metaph.	7	15				Metaph.	12	10
			Anaph.	0	0				Anaph.	5	5
			Teloph.	2	0				Teloph.	5	7
Meiosis	**54**	**66**	**Proph. I**	**29**	**61**	Meiosis	37	32	Proph. I	12	10
			Metaph. I	7	2				Metaph. I	0	2
			Anaph. I	0	0				Anaph. I	0	2
			Teloph. I	0	0				Teloph. I	0	0
			Proph. II	5	2				Proph. II	2	2
			Metaph. II	0	0				Metaph. II	2	0
			Anaph. II	0	0				Anaph. II	0	0
			Teloph. II	0	0				Teloph. II	0	0
No answer	7	5	No answer	7	5	No answer	12	10	No answer	17	7

N = 41

An analysis of the results in Table 4.25 shows that the there is a reasonable change between pre-and post-test scores on the identification of the type of cell division according to the chromosome number. In Cell A, 54% out of 41 students in the pre-test were able to correctly identify the type of division that is, "meiotic" compared to 66% at the post-test; whereas 39% of the students in the pre-test and 29% at the post-test were unable to correctly identify this type of division. Concerning the phase illustrated in Cell A, only 29% of the students correctly indicated the name of the phase in the pre-test that is, "prophase I" - as opposed to 61% at the post-test. In Cell B, 51% and 58% of 41 students at the pre-and post-test respectively were able to identify the type of the cell division that is, "mitotic". Like in Cell A, the students experienced the same difficulties in identifying the name of the phase. Thus, only 39% of the students in the pre-test compared to 49% at the post-test correctly named the phase, that is "prophase", according to the type of cell division. In Cell B, only 37% of the students in the pre-test and 32% at the post-test named correctly the type of cell division.

From these results it is possible to suggest that a considerable number of students still continue to experience difficulties, even after the instruction through practical work, to apply their conceptual knowledge into practice in order to analyse, interpret diagrams or pictures representing cell division events and processes. It seems that they lack sufficient basic process skills to perform tasks of this nature. The explanations they gave for this question also showed that a considerable percentage of students continue to hold erroneous ideas on chromosome structure such that they could not correctly distinguish and identify the mitotic and meiotic phases (Kindfield, 1991; Kindfield, 1994). Table 4.26 shows the prevalence of the explanations provided by the students before and after instruction through practical work.

Table 4.26: Pre- and post-test percentages of students' explanations about types of cell division of a cell with 2n = 4.

Type of explanations Cell A	Pre-	Post-	Type of explanations Cell B	Pre-	Post-
	% of stds.	% of stds.		% of stds.	% of stds.
1. Homologous chromosomes are paired and form chiasms	27	17	1. Homologous chromosomes not paired but duplicated	7	39
2. Cell still have nuclear envelope	7	5	2. Disappearance of nuclear envelope	10	2
3. Pairing of homologous chromosomes	2	37	4. Chromosomes are linked by centromere	0	2
5. Chromosomes grouped in tetrads	2	7	4. Chromosomes are short and thick	0	2
5. Chromosomes are linked by centromere	0	2	5. Chromosomes are duplicated and condensed	0	12
6. No explanations	61	32	6. No explanations	83	41

N = 41

Similarly to question 14, the results in Table 4.26 show that, in general, less than one-third of the students demonstrated valid understanding of the chromosome structure in order to describe the events of the phases represented in Cell A and Cell B respectively. This can be seen by the prevalence of the percentages of "no explanation" at the pre-and post-test for both cells. In Cell A, only 27% and 17% of the students at the pre-and post-test respectively attempted to explain their answer based on the structure of the chromosomes and specific events in prophase I of meiosis. In Cell B, only 7% of the students in the pre-test and 39% at the post-test gave valid explanation regarding the type of cell division and the phase represented. Some possible reasons of the students' understanding in relating the chromosome structure as well chromosome number with the types of cell division have been reported in the literature by several authors (e.g. Kindfield, 1991; Kindfield, 1994; Lewis *et al*., 2000; Chinnici *et al*., 2004) and highlighted in previous sections of this chapter.

Question 15: Students' responses regarding metaphase and anaphase I drawings

In this question students were required to make two drawings showing a mitotic metaphase and an anaphase I of meiosis of diploid animal cell whose chromosomal number is to n = 3. Table 4.27 shows the students' percentage scores on this question.

Table 4.27: Students' percentage scores on drawings of cells in metaphase and anaphase I.

Making drawings of an animal cell with n = 3		Answer	Pre-% scores	Post-% scores
Q15a Mitotic metaphase	Cell A	**Correct**	**15**	**59**
		Incorrect	75	29
		No answer	10	12
Q15b Meiotic anaphase I	Cell B	**Correct**	**15**	**51**
		Incorrect	75	37
		No answer	10	12

N = 41

The results illustrated in Table 4.27 indicate that there is a considerable change between the correct percentage scores from the pre-test to post-test. As shown in the table, in Cell A, only 15% of 41 students in the pre-test compared to 59% in the post-test could correctly draw a cell indicating a mitotic metaphase; whereas 76% and 29% of the students at the pre-and post-test respectively made incorrect drawings. For the Cell B, also only 15% out of 41 students in the pre-test and 51% at the post-test could draw correctly a cell in an anaphase I of meiosis. Like in Cell A, 76% of the students in the pre-test and 37% at the post-test were unable to correctly draw a cell representing an anaphase I of meiosis. In both cells, 20% of the students in the pre-test and 12% at the post-test could not provide any drawing. It is assumed that the reason why the students did not perform well in this question might be linked to the lack of understanding of the meaning of the chromosomal number (haploid and diploid), that is, a misinterpretation of the difference between these two concepts during mitotic and meiotic events (Kindfield, 1991).

The implications of this might be associated with several reasons. Some of them have been mentioned in this study. For instance, the students attending the cell biology were drawn from several secondary schools (rural and urban) throughout the country. Most of the schools lack either books, maps or models illustrating cell division events as well they do not offer at least any kind of practical work. Cell division concepts are considered difficult for both teachers and students as well for experienced and inexperienced novices at all educational levels (Flores *et al*., 2003; Wood-Robinson, 2000; Kindfield, 1991; Kindfield, 1994). In this regard, this study assumes that the university needs to adapt new mechanisms for dealing with the first-year biology students taking into account their prior knowledge and their level of understanding of the cell division concepts as well as the context in which they were taught cell division topics at their schools. These students, during the laboratory sessions on meiosis, varied in their understanding of meiotic concepts as well skills needed to correctly observe and represent the events occurring during meiotic events in the drawings. Thus, in order to make the process of teaching and learning cell division concepts through practical work more meaningful, it would best to first equip the students with an adequate theoretical understanding of concepts and development of physical manipulative skills. Only in that way they will be able to correctly operate the light microscope and consequently, make appropriate observations, represent and interpret their drawings of the cell division events. In doing so, one can expect practical work to promote meaningful learning rather than memorization of the concepts (Hodson & Reid, 1988). An inquiry-based approach in which students are given the opportunity to engage in scientific investigations and problem solving can promote more cognitive involvement and thus, improve thinking ability as opposed to traditional laboratory activities (Tamir *et al*., 1992; German *et al*, 1996; Crawford, 1998; Trowbrigde, *et al*., 2000).

Question 16: Students' responses regarding drawings representing three cells in anaphase of mitosis and meiosis

This question asked students to indicate the correct option representing drawings with three cells in the anaphase of cell division (mitosis and meiosis) of an organism whose diploid number is equal to 6 (2n = 6). In this question students were expected to use their scientific knowledge about mitotic and meiotic events to identify the correct option. From the results displayed in Table 4.28 it is obvious that most of the students did not progress significantly on cell division concepts (e.g. chromosome structure, chromosome number) in order to distinguish between mitotic and meiotic events, even after the instruction through practical work as there is very little difference between pre- and post-test scores.

Table 4.28: Students' percentage scores on drawings of cells in anaphase.

Interpreting drawings with 3 cells in anaphase: 2n = 6	Optional response-alternative	Pre- % scores	Post- % scores
Q16	Mitosis, meiosis I and meiosis II	12	22
	Meiosis I, meiosis II and mitosis	**29**	**34**
	Meiosis II, mitosis and meiosis II	12	7
	Meiosis I, mitosis and meiosis II	24	29
	Meiosis II, meiosis I and mitosis	15	2
	No answer	7	5

N = 41

The findings in Table 4.28 show that only 29% and 34% of the students at the pre-and post-test respectively could indicate the correct option representing the three cells in anaphase of meiosis and mitosis that is, "meiosis I, meiosis II and mitosis". These results suggest that most of students have a weak understanding of the basic differences between the events and processes occurring during the mitotic and meiotic cell division coupled with the lack of the basic knowledge of the structure of the chromosomes in terms of the haploid and diploid chromosomal number. This is supported by the literature on this topic (Kindfield, 1994; Chinnici et al., 2004). In addition, it appears that students continued to show a lack of good mastery of the specific skills so that they could correctly analyse, interpret, differentiate and identify the phases of mitotic and meiotic cell division even after the instruction through practical work.

Question 17: Students' responses regarding the basic characteristics of mitosis and meiosis

In this question students were expected to use their knowledge to compare the basic characteristics of mitotic and meiotic cell division by indicating the option they thought was incorrect. The findings of this question show that the students have a fairly good grasp of the main characteristics of mitosis and meiosis. However, there is no change in their conceptions at the pre-and post-test stages (Table 4.29). For both tests, 76% of students gave the correct response, that is, "in mitosis there is a reduction of chromosomal number while in meiosis there is no reduction of chromosomal number".

On the contrary the percentage of the students who provided "no answer" increased from 10% at the pre-test to 17% at the post-test. Because students were not asked to explain their answers, one is not in position to explain what was behind this situation. On the other hand, 14% of students in the pre-test compared to 7% in the post-test chose the distracter as the correct response. As was state previously in other sections, students lack ability to differentiate between the basic concepts (e.g. DNA replication, reduction of chromosome number, chromosome structure, crossing-over, pairing and separation of chromosomes) in order to understand the whole process of cell division.

Table 4.29: Students' percentage scores on the characteristics of mitosis and meiosis.

Comparing basic characteristics of mitosis and meiosis	Optional response-alternative	Pre- % scores	Post- % scores
Q17	Mitosis forms two cells and meiosis four new haploid cells	0	5
	In mitosis there is a reduction of chr. nr., in meiosis no reduction	**76**	**76**
	In mitosis there is no exchange of gen. inf., in meiosis there is exchange	7	0
	Mitosis occur in somatic cells and meiosis in germ cells	5	0
	In mitosis there is chromosome duplication for one cell and in meiosis for the two cell divisions.	2	2
	No answer	10	17

N = 41

In order to check for consistency in students' responses, an inter-item cross-tabulation between questions 16 (differences between events of mitosis and meiosis) and 17 (differences between basic characteristics of mitosis and meiosis) was carried out. This was done because, in order for them to correctly respond to question 16, they were required to have good mastery of the basic differences of the two kinds of cell division, mitosis and meiosis, in terms of the their characteristics and associated events. Tables 4.30 and 4.31 present the cross-tabulation between question 16 and 17 in the pre- and post-test respectively. Table 4.30 shows cross-tabulation between Q16 and Q17 in the pre-test.

Table 4.30: Question 16 and Question 17 cross-tabulation on the pre-test results.

			Question 17					Total
			No answer	**Mitosis reduction and meiosis no reduction of chr. nr.**	Mitosis no exchange and meiosis exchange of gen. inf.	Mitosis in somatic cells and meiosis in germ cells	Chr. duplication for one cell in mitosis and for the two cell in meiosis div.	
Question 16	Meiosis II, meiosis I and mitosis	% of Total	.0%	**9.8%**	2.4%	2.4%	.0%	14.6%
	Meiosis I, mitosis and meiosis II	% of Total	2.4%	**17.1%**	4.9%	.0%	.0%	24.4%
	Meiosis II, mitosis and meiosis II	% of Total	2.4%	**9.8%**	.0%	.0%	.0%	12.2%
	meiosis I, meiosis II and mitosis	**% of Total**	**2.4%**	**22.0%**	**.0%**	**2.4%**	**2.4%**	**29.3%**
	Meiosis, meiosis I and meiosis II	% of Total	2.4%	9.8%	.0%	.0%	.0%	12.2%
	No answer	% of Total	.0%	7.3%	.0%	.0%	.0%	7.3%
Total		% of Total	9.8%	75.6%	7.3%	4.9%	2.4%	100.0%

N = 41; Q16: differences between events of mitosis and meiosis; Q17: differences between basic characteristics of mitosis and meiosis

An analysis of the results in Table 30 reveals that of the 29% students who responded correctly to question 16, only 22% gave a correct answer to question 17. It means that students not only showed inconsistency in their responses they also revealed many difficulties in their knowledge about the basic characteristics of the two kinds of cell division in order to respond correctly to question 16. This is also associated with their misunderstanding of the meaning of haploid and diploid chromosomal number as well as the lack of ability to differentiate the chromosomes according to their structure, whether simples or duplicated. For instance, they were not able to identify the differences between the three cells representing anaphase of meiosis I, meiosis II and mitosis, respectively.

The students' responses in the post-test did not differ significantly from the pre-test in terms of consistency (Table 4.31). Thirty four percent (34%) of the students chose the correct option in question 16 indicating the correct alternative that is, "meiosis I, meiosis II and mitosis". Out of these 34% students, 27% have also chosen the correct alternative response in question 17 that is, "in mitosis there is reduction of chromosomal numbers and in meiosis there is no reduction of chromosomal number". These results suggest that even those students who responded to both questions still held erroneous ideas about the basic characteristics of mitosis and meiosis, structure of the chromosomes, as well as about the meaning of haploid and diploid chromosomal number (Table 4.31). It means that practical work, to some extent, did not seem to help the students to improve their understanding in this regard.

Table 4.31: Question 16 and Question 17 cross-tabulation on the post-test results.

			Question 17				Total
			No answer	Mitosis forms two and meiosis four new haploid cells	**Mitosis reduction and in meiosis no reduction of chr. nr.**	Chr. duplication for one cell in mitosis and for the two cell in meiosis div.	
Question 16	Meiosis II, meiosis I and mitosis	% of Total	.0%	.0%	**2.4%**	.0%	.4%
	Meiosis I, mitosis and meiosis II	% of Total	4.9%	.0%	**24.4%**	.0%	29.3%
	Meiosis II, mitosis and meiosis II	% of Total	2.4%	.0%	**4.9%**	.0%	7.3%
	meiosis I, meiosis II and mitosis	**% of Total**	**4.9%**	**.0%**	**26.8%**	**2.4%**	**34.1%**
	Meiosis, meiosis I and meiosis II	% of Total	4.9%	4.9%	**12.2%**	.0%	22.0%
	No answer	% of Total	.0%	.0%	**4.9%**	.0%	4.9%
Total		% of Total	17.1%	4.9%	**75.6%**	2.4%	100.0%

N = 41; Q16: differences between events of mitosis and meiosis; Q17: differences between basic characteristics of mitosis and meiosis.

Table 4.32 presents a summary of the findings on the fourth category about differences between mitosis and meiosis of the CBT. This summary is made in the light of the established criteria used for analysing the students' level of understanding as outlined in Table 4.1 of this chapter.

Overall, the results displayed in Table 4.32 show that most of the students scored at the fair level of understanding in Q14 (46%), Q15 (75%) and Q16 (63%) before instruction through practical work began. According to the results, 81% of the students had a good understanding of the basic differences between mitosis and meiosis before instruction began. The scores in the post-test indicate that only a few students shifted their level of understanding from poor to fair and fair to good in Q14, Q15 and Q16. Therefore, for the three questions, the students' level of understanding increased by only 20% on average. It means that a considerable percentage of the students still continued to have difficulties in identifying the types of cell division and its phases as well as interpreting and representing drawings of cell division. For Q13 all students who scored at the poor and fair levels of understanding moved to the good level of understanding. This suggests, in this case, that the cell biology practical work enhanced all (100%) the students' understanding of the types of division in germ cells. It is interesting to note that the students' understanding of the basic characteristics of mitosis and meiosis did not change after the instruction through practical work. As can be seen in the Table 4.32, the percentage of the students scoring at the poor level increased to 7%, that is, students moved from fair to poor level of understanding in the post-test. This suggests that these students did not understand the main characteristics that differentiate mitosis and meiosis even after the instruction through practical work.

Table 4.32: Students' scores relative to aspects of the basic differences between mitosis and meiosis.

Levels of understanding			Poor %	Fair %	Good %
Differences between mitosis and meiosis	Q13: Type of cell division in germ cells	Pre-test	2	12	85
		Post-test	0	0	100
	Q14: Types of cell division and associated phases of animal cell with 2n = 4	Pre-test	11	46	43
		Post-test	7	34	59
	Q15: Metaphase and anaphase I drawings of animal cell with n = 3	Pre-test	10	75	15
		Post-test	12	33	55
	Q16: Drawings of 3 cells in anaphase I of animal cell with 2n = 6 in mitosis and meiosis	Pre-test	7	63	29
		Post-test	5	60	34
	Q17: Basic characteristic of mitosis and meiosis	Pre-test	10	14	76
		Post-test	17	7	76

N = 41

As was stated early, in this study, interviews were conducted to get a comprehensive nature of the students' understanding of the selected cell division concepts. Thus, the next section presents and discusses the data obtained through interviews.

4.3 Results of the interviews

In order to complement the students' responses yielded in the Cell Biology Test through pre-and post-tests, two kinds of interviews were conducted: post-laboratory and post-course interviews. The information gathered by the two types of interviews contributed to answering research question one: "*What are the students' conceptions of cell division before and after undertaking practical work in cell biology*?" The interviews were administered in order to obtain the details of the students' conceptions about cell division. The interviews were used also to determine how confident the students were with the answers they gave in the pre- and post-test and to get insight into how they arrived at the given answers. More details about the nature of the interviews are given in Chapter 3, section 3.6.2. For ease of analysis, the information yielded through the two types of interviews is presented separately. The first to be presented and discussed are the results of the post-laboratory interviews followed by the post-course interviews.

4.3.1. Results of the post-laboratory interviews (PLI)

The post-laboratory interviews (PLI) were conducted over two days following the day of the practical work on mitosis and meiosis. The main concern in these interviews was to determine the extent to which practical work contributed to the students' understanding of the basic concepts of mitosis and meiosis in terms of their functions, characteristics and events after practical work instruction on cell biology. Thus, the interviews were focused on the activities performed during the laboratory sessions on mitosis and meiosis. The two worksheets (found in Appendix C and Appendix D) used during the interviews comprised of a series of pictures, that is, "interviews about instances" (Gunstone and White, 1992) were used as outlined in chapter 3. The interviewees were six students selected according to the criteria already explained in chapter 3. During the analysis of the interviews it was possible to group the students' responses according to their similarities and differences using a constant comparative method as described in Chapter 3. Although they were some inconsistencies in the students' answers during the interviews, all six interviewees appeared to have a common understanding of the basic concepts of mitosis and meiosis after they had been taught these concepts through practical work instruction. The categories indicated in Table 4.33 below are representative of the students' answers in this regard. The figures in bold are the pre-determined categories under which are indicated the categories which emerged from the students' responses during the interviews. These categories represent the alternative ways in terms of the concepts used by the students to respond to the questions.

Table 4.33: Categories of the students' responses on post-laboratory interviews.

Topics	Categories	
Mitosis	***Function of mitosis:*** • Type of the transmitted information in mitosis • Chromosomal number in the formed daughter cells • Number of the originated cells • Types of cells in mitosis	***Identification and description of the mitotic phases*** • Chromosomes appearance • Chromosomes structure/status • Chromosomes actions • Cell structure/appearance • Cells formed • Differences between cells • Chromosomal number • Differences chromosomes and chromatids
Meiosis	***Function of meiosis*** • Formation of gametes • Cells produce sexually • Types of meiosis • Number of originated cells • Characteristics of the originated cells • Chromosomal number • Preservation of species	***Identification and description of the meiosis' phases*** • Chromosomes appearance • Chromosomes structure/status • Chromosomes actions • Cell structure/appearance • Chromosomal number • Chromatids and chromosomes number • Cells formed • Differences between cells • Types of formed cells

Interviews with students after the laboratory session on mitosis

In general, all the six interviewed students were able to characterize the function of mitosis and identify and describe the events during the mitotic division after practical work on mitosis. These results presupposed that the practical work helped the students to further their understanding about the basic concepts and events occurring during the mitosis. The excerpt below illustrates a part of the interview with students S5 and S6 about the function of mitosis.

I: What do you think is the function of mitosis?

S5: Mitosis is a process of cell division in which a mother cell divides to originate two daughter cells with the same number of chromosomes.

S6: Well … it is a process where … from one cell it is possible to obtain two daughter cells genetically identical between them and from the mother cell.

I: Do you know which is the mother and daughter cells chromosomal number?

S6: …It is equal to 2n.

I: What is the meaning of 2n?

S5: 2n means paired number of chromosomes.

S6: Means a cell is diploid.

I: Why paired number of chromosomes?

S6: It is so in mitosis … the final result in genetical terms is … it is known that mitosis occurs in somatic cells and … in somatic cells the chromosomes are always paired.

From the excerpt above, it is clear that both students stated the function of mitosis taking into account the number and characteristics of the originated cells as well as its chromosomal number, although both students were not clear in explaining the meaning of 2n chromosomal number. Yet, in this regard students S1 and S3 referred to mitosis as being important in multiplying living organisms through transmission of the same characteristics from mother cell to the daughter cells. The following parts of the interviews illustrate this:

I: What do you think is the function of mitosis?

S1: Well … the function is to transmit identical characteristics to the daughter cells as the mother cell.

S2: think that mitosis has the function of multiplying living organisms transmitting to the daughter cells the same type of characteristics as the mother cell.

In comparing the students' responses in these excerpts of the interviews with their responses from the pre-test concerning the basic characteristics of mitosis, it seems that there was a substantial improvement in terms of the conceptual understanding after the students had been taught cell division through practical work.

With respect to the identification and description of the phases of mitosis, all six interviewees used the same criteria to respond to the questions during the interviews as indicated in the Table 4.33. However, it was noted that in some instances students were confronted with difficulties in correctly identifying and describing the mitotic events during the cell division coupled with their misinterpretation of the structure of the chromosome as indicated by the following excerpt of the interview with students S1 and S2:

I: Looking at the picture in the worksheet, which cells do you think are not in division?
S1: Cells 1, 2, 4 and 5 are in division.
S2: Stated the same answers.
I.: Could you explain why this is so?
S2: Nucleus still covered by the nuclear envelope; the filaments still not separated.
S1: It is condensed not separated.
I: What is condensed?
S1: Nucleus.
I: Do you think so?
S1: No … the chromatin is condensed.
I: Is this so? Can you observe again cells 1, 2, 4 and 5?
S2: I think it is interphase.
I: Why?
S2: … Nuclear envelope is breaking up….

S1: Interphase because centromere is dividing.

I: Do you know the meaning of interphase?

S2: Starting of cell division … cells prepare to divide.

Although students could exactly indicate the cells that were not in division, they showed some difficulties in explaining their answers. The main problem might be linked to the fact that they lacked enough ability to distinguish between chromosomes and chromatin so that they could describe correctly the events taking place during the interphase. For instance, S1 stated that in interphase the centromere is dividing instead of saying that at interphase DNA is replicated and proteins are synthesized. However, two other students responded correctly as shown by the following excerpt:

I: Why do you think cells 1, 2, 4 and 5 are not in division?

S3: … Because they still in interphase …cell is preparing to divide.

I: Why do you say so?

S3: I think the cell need to replicate its DNA first.

S4: Yes … in phase S.

S4: No … it is interphase.

I: Why do you say interphase?

S4: Because it is formed by G1, S and G2 phase.

I: And … could you explain what happens in each phase?

S4: In G1 there is a synthesis of proteins; in S phase occurs DNA duplication; in G2 cells repairs errors preparing to start division in mitosis.

S3: DNA duplicates and there is an increment of the nucleus volume.

In the pre-test S4 had responded prophase instead of interphase when asked to identify the name of the phases representing chromosomes modifications during cell cycle. S4 asserted that the chromosomes were condensed and the microtubule fibres were formed. In this case, Student S4 improved his understanding in identifying and describing correctly during the interviews what happens during the interphase after the instruction through practical work.

During the interviews, students were also asked to identify in the same worksheet cells that were in the process of starting to divide and to describe associated events. Students S3, S4, S5 and S6 correctly indicated the three cells in the process of division. They also showed a good understanding of the events occurring during the mitosis corresponding to its phases, as indicated by the excerpts of the interviews below:

I: Which cells do you think are starting to divide?

S5: Cells 9, 10 and 11.

S6: Stated the same cells.

I: Why do you think so?

S6: At the start of division the nuclear envelope is breaking up.

I: How you know it?

S6: From the dotted line.

S5: There is a visualization of chromosomes.

I: What do you mean by visualization?

S5: … chromosomes become visible … start to condense.

Analysing this excerpt of the interviews, it seems that the students could expand their knowledge and skills in terms of identifying and describing correctly the phase represented by the numbers 9, 10 and 11 in the pictures. This contrasts with the answers they gave in the pre-test when asked to name the mitotic phases illustrated in a picture of a plant meristem tissue. For example, students S3, S4 and S6 named the phase as synthesis and interphase, respectively, instead of prophase. It seems that after the instruction through practical work, the students had improved their understanding of the basic differences between interphase and prophase.

Furthermore, the students were asked to identify the cells that were advanced in their division and describe the events occurring in each phase. The excerpts of the interviews illustrated below show that most of the students seemed to have no difficulties in identifying the correct names of the phases as well as to describe the associated events. It also seems that students were aware of the similarities and differences between the phases.

I: Looking at cells 6 and 7, which one is more advanced in its division?

S6: Cell 6.

I: Why do you think so?

S6: In cell 6 the nucleus is evident while in cell 7 homologous chromosomes are separated and are migrating to opposite poles.

I: Which phases are represented in these two cells?

S6: Cell 7 is anaphase, cell it shows the end of metaphase or start of anaphase.

I: And between cells 7 and 12, which is more advanced?

S5: Cell 12.

I: Why?

S5: Cell 12 has a dotted line in the middle indicating that it is the end of anaphase; the chromatids are already in the poles … means that the dotted line shows the cytoplasm division.

I: Are you sure?

S5: …Yes. It is cytoplasm.

S6: I think also that the dotted line shows the place where the cytoplasm will be divided.

Students S3 and S4 were able to point to some significant differences and similarities between cells 3 and 6, stating that cell 3 has three paired chromosomes while cell has 6 have six loosed chromosomes. In order to explore the extent of their reasoning the following questions were asked:

I: Why do think the chromosomes are loosed?

S3: Because they are already divided.

I: And what is concretely divided?

S3: The chromosomes are divided by the centromere.

I: How do you call these chromosomes?

S4: Chromatids.

I: What is the name of the phases represented?

S3: Cell 3 is a metaphase.

I: Why?

S3: Chromosomes are lined up at the spindle equator and attached to spindle.

I: And in cell 6, which is the phase?

S4: Later metaphase. It is the start of anaphase.

In general, all the interviewees succeeded in providing valid explanations about the differences and similarities between the two cells (cells 3 and 6). This means that after the instruction the students could expand their conceptions about the events occurring during the mitosis. In the pre-test the same students showed many difficulties in identifying the names of the mitotic phases represented in a picture of a plant meristem tissue. They held some erroneous ideas about the basic characteristics and events occurring during the mitosis resulting in confusion and consequently misidentification of the mitotic phases.

Interviews with students after laboratory session on meiosis

Similarly to mitosis, the interviews on meiosis were concerned with the characteristics and functions meiosis associated events occurring during meiosis cell division. Apparently, the practical work brought some significant improvements in the students' conceptual development about the basic meiotic concepts and associated events. This can be observed by their responses in the interviews. S2 stated that "meiosis is a process by which cells reproduce sexually; a cell originates four daughter cells with the number of chromosomes reduced to a half". Because S2 did not specify the meaning of these concepts, the interviewer posed more questions to explore the extent to which S2 was aware of the meaning:

I: Do you know where meiosis occurs?

S2: In germ cells.

I: Imagine that a somatic cell has 36 chromosomes, how many chromosomes will have its germ cells?

S2: Half…18 chromosomes.

I: What happens concretely?

S2: Reduction in the number of the chromosomes.

I: How could this happen?

S2: Well … it can be that a mother cell went through a reductional meiosis.

From the excerpt above one can conclude that S2 had a good understanding of the basic concepts related to meiosis division and associated events after laboratory instruction on meiosis.

Other students showed considerable growth in their conceptual knowledge about the functions of meiosis compared to their previous ideas before being taught through practical work. They characterized the functions of meiosis in terms of the gamete formation, types of meiosis, chromosomal number and preservation of the species as indicated by the following excerpt:

S5: Meiosis is related with the gamete formation; haploid cells are the basis of sexual reproduction.

S6: I agree with my colleague, meiosis produces haploid cells or gametes that serve for fertilization.

I: And how many types of meiosis exist?

S5: Two types, reductional meiosis and equational meiosis.

I: Which is the difference?

S5: Meiosis I or reductional forms two haploid cells while in equational the two cells form 4 haploid cells.

I: How do you characterize these two cells?

S5: The two formed without entering to a new interphase divides forming four haploid cells.

I: And how do you characterize these four cells?

S5: They are genetically different.

I: What do you mean by this?

S6: They have to be genetically different because one of the functions of meiosis is the variability of the species.

With regard to the identification of meiotic phases using a diagram illustrating different phases, most of the interviewed had improved in their understanding compared their responses in the pre-test. At the pre-test the same students showed many difficulties in identifying the subphases of the prophase I of meiosis. This problem might be linked to the lack of the ability to differentiate the structure of the chromosomes during prophase I resulting in confusion and misidentification of the phases. For instance, S2 could list the names of the phases but was not able to identify the phases in the figure as indicated in the following excerpts:

I: How many subphases constitute prophase I?

S2: Five.

I: Could you list them?

S2: Zygotene, leptotene, pachytene, diplotene and diakinese.

I: Can you identify here in the figure the diagrams in which these phases are represented?

S2: Oh! No… it is difficult.

Students S5 and S6 also revealed some weakness in identifying and describing the events occurring during the prophase I of meiosis. There was no significant improvement between their answers from the interviews and from the pre-test. Both students failed to name correctly the subphases of prophase I in the pre-test. During the interview, S5 could only identify and describe one subphase "F5 – diakinesis" remarking that in F5 subphase crossing-over occurred because chromosomes are crossed, forming chiasmatas. For instance, S6 did not try to answer any question in this regard. It seems that the students did not improve their knowledge with respect to basic characteristics and events associated with prophase I. events so that they could identify and correctly describe its subphases.

The difficulties encountered by the students in the interviews are similar with those obtained in the pre-and post-tests results and reported in the literature with regard to specific events in prophase I (Kindfield; 1994; Yip; 1998). Other factors which could have contributed to this weakness might be the kind of microscopes used during practical work. They seemed not to have a high enough magnification power to allow accurate observations of the chromosomes status during cell division. On the other hand, most of the students had difficulties in operating the microscope correctly, that is, they did not have the mastery of the basic knowledge and skills needed to operate a light microscope in an organized way. In line with this, similar difficulties were revealed by the first-year biology students (Foundation Program) in a study conducted by Cossa (1998) in Mozambique. Other examples of the students' inability to operate the light microscope during laboratory sessions on mitosis and meiosis are described in the section pertaining to classroom observations (Section 4.4).

4.3.1. Results of the Post-Course Interviews (PCI)

The Post-Course Interviews (PCI) were conducted at the end of the cell biology course, which coincided with the end of the first semester of the Eduardo Mondlane University. The questions for the PCI were based on the Cell Biology Test (found in Appendix A) used at both the pre-and post-test. The PCI was used to explore the students' understanding of the basic concepts of mitosis and meiosis after the instruction laboratory and tutorials. Thus, interviews about instances and concepts were used as explained in Chapter 3. The PCI involved the same six students who participated in the Post-Laboratory Interviews. This provided the opportunity to compare the students' conceptual knowledge development between the pre-test to the post-test. During the analysis of the interviews it was possible to group the students' responses according to their similarities or differences. The categories displayed in the Table 4.34 below are representative of the students' responses in this regard. Overall, the results of the PCI revealed that, although, the students showed some inconsistencies in their answers, their understanding about the basic concepts of mitosis and meiosis seemed to have improved considerably. This suggests that the practical work did enhance the students' conceptions of basic concepts of mitosis and meiosis and hence improved their conceptual understanding of the two concepts.

Table 4.34: Categories of the students' responses on post-course interviews.

Topics	Categories	
Mitosis	***Characteristics of mitosis division*** • Appearance of the cells • Types of chromosomes • Types of cells formed • Cell cycle constitution • Cell cycle events • DNA quantity • Chromosomes number • Number of cells formed	***Identification and description of the mitosis' phases*** • Chromosomes appearance • Chromosomes structure/status • Chromosomes actions • Cell structure/appearance • Cells formed • Differences between cells • Chromosomal number • Differences chromosomes and chromatids • Events characteristics
Meiosis	***Characteristics of meiosis division*** • Types of division • Number of formed cells • Types of formed cells • Characteristics of formed cells • Chromosomal number • Variability of species • Genetic recombination • Chiasmata formation • Types of chromosomes	***Identification and description of the meiosis' phases*** • Chromosomes appearance • Chromosomes structure/status • Chromosomes actions • Cell structure/appearance • Chromosomal number • Chromatids and chromosomes number • Number of cells formed • Number of chromosomes in the cells • Differences between cells • Types of formed cells • Types of events occurring in cells

Interviews with students after the course on mitosis

Overall, the students' understanding of basic characteristics of mitosis and associated events improved considerably after the instruction through practical work and tutorials. However, it appears that to some extent students experienced similar problems in the interview encountered in the tests regarding the use of basic process skills such as correctly interpreting graphs and drawings about the cell cycle and differentiating, classifying, describing and identifying mitotic' events. This can be illustrated by the following excerpts from the interview with students S1and S2:

I: Can you interpret this graphic about the cell cycle in a somatic cell?

S2: Yes, first we have in part I interphase divided into 3 subphases; in part II mitosis but I have some doubts because we have PM.

I: Do you know what is meant by PM? S2: PM….it is not prophase...?

S1: PM means prometaphase.

S2: I think in this case prophase is not here…

I: And what does prometaphase mean?

S2: I think it is a phase before the metaphase, is not that…?

I: Which do you think is the correct alternative in Question 3?

S2: Well…I think is d).

I: Why?

S2: Because we have interphase and mitosis; phases of cell cycle.

S1: I agree that is d) because we have interphase with 3 subphases and mitosis.

I: Can you explain why do you think d) looking into the graphic?

S1: Observing the graphic we see that in S the graphic is ascending, means that there was a DNA replication and in mitosis we can see that the graphic maintains because DNA remains constant by the end of mitosis…telophase.

S2: …I understand that but…I think that G1 is a phase before mitosis because if we interpret the graphic we have G1 as the first phase and after mitosis we have again G1.

I: Why do you think G1 appears before and after mitosis?

S2: Because after the cell have completed the cell cycle and forms 2 cell daughters, each cell daughter can reinitiate the process of mitosis that is what we see in the graphic.

It appears that the students' interpretation of the graph was primarily based on the constitution of the cell cycle and not in terms of the direction of the graph. Further, S1 tried to explain this using the variation of the DNA quantity in the course of the graph representing cell cycle as illustrated in the excerpts of the interview above. Therefore, contrasting their responses before and after the instruction, one can assume that the practical work and tutorials helped them to improve their conceptual knowledge about the events happening during the cell cycle. For instance, S1, regardless of indicating the correct optional response in the pre-test, was not able to expand his understanding in terms of interpreting the graph correctly. The explanation of S1 was that "in part I and II of the graph there is a duplication of the cells". S2 did not indicate the correct option in the pre-test which was not the case in the post-test and during the post-course interviews.

With regard to the identification of the mitotic phases using a picture of a plant meristem tissue most of the interviewees succeeded to some extent when compared to their responses in the pre-test. At the interviews all the six students were able to identify the correct option by indicating the correct sequence of events in mitosis. However, some inconsistencies persisted in their descriptions of the events occurring in each phase of mitosis as demonstrated in the following excerpt:

I: Observe this picture of a plant meristem tissue and indicate the correct sequence of mitotic phase from the given alternatives.

S3: Is sequence **b)**.

S4: I chose **b)** also.

I: Why do you think it is **b)**?

S3: Is **b)** because we can see that figure **c** is interphase; **f** is prophase… the chromosomes are more visible; in **e** the chromosomes are aligned in equator plate it is metaphase…

I: Why metaphase?

S4: No…I think it is prophase.

S3: Prophase because the chromosomes are condensed and the chromatin is more visible.

I: What more?

S3: Chromosomes are short.

I: Can you identify the phases indicated by **a**, **b** and **d**?

S3: Phase **a**, is an anaphase because the centromere is divided and the chromosomes are moving to opposite poles; **b**, I think is also anaphase…later anaphase and **d** telophase.

I: Can you explain what is happening in figure **d**?

S4: I think we have telophase because two daughter cells are formed and cytoplasm is dividing…we have cytokinesis.

S3: Yes… it is cytokinesis.

Although S3 and S4 still showed confusion in identifying some of the phases (for example, prophase and metaphase), both students had expanded their knowledge about the events occurring in each phase of mitosis in comparison with their responses in the pre-test. For instance, in the pre-test S3 could neither indicate the correct sequence in mitosis nor the names of each phase. But, in the post-test and post-course interviews S3 showed a good understanding on this issue suggesting that the practical work did enhance his conceptual understanding of mitosis.

In attempting to get more insight about the level of the students' understanding regarding the sequence and identification of mitotic phases, they were asked to compare the pictures or diagrams illustrated in questions 4 and 6. S5 asserted that, "in question 6 we have the mitosis' phases starting with prophase while question 4 starts with interphase". S6 said that, "the relationship between questions 4 and 6 was because all the pictures were illustrating mitotic' phases". The excerpts of the interview with S5 and S6 below illustrate this quite vividly:

I: How do you relate questions 4 and 6?

S5: Both are mitosis' phases; well… in question 6 we have mitosis starting with prophase while in question 4 mitosis starts with interphase.

S6: I think in both cases mitosis' phases are represented.

I: And which cell indicates the prophase?

S5: Cell II.

I: Could you indicate the correct sequence of the mitotic phases in question 6?

S5: Sequence **d)**.

I: And what are the names of the phases?

S6: Here we have prophase in figure II and in figure IV metaphase.

I: What tells you it is metaphase?

S6: Well… the chromosomes are at the equatorial spindle.

I: And what about the other phases?

S6: Figure I shows anaphase; the chromosomes are moving to opposite poles and finally we have figure III is telophase.

I: Could you describe what happens in telophase?

S6: Oh! …Yes. The nuclear envelope is appearing again and there is a cytoplasm division.

This shows that both S5 and S6 saw the relationship between questions 4 and 6. They were able to compare and describe correctly the mitotic phases illustrated in the pictures or diagrams of the two questions. Thus, one can infer that both S5 and S6 had a clear understanding of mitotic events even when they are represented in different forms (e.g. pictures or diagrams). This suggests an improvement in their understanding of the basic scientific concepts needed to identify and describe the mitotic phases after the instructions through practical work and tutorials.

Interviews with students after the course on meiosis

The interviews on meiosis were concerned with the students' understanding of meiosis and related events. The categories of the students' responses during the PCI are found in Table 4.34. Overall, all the six students interviewed after the course correctly identified and characterized the phenomenon in the diagrams illustrated in question 9 of the Cell Biology Test (found in Appendix A). For instance, when asked to explain why they thought the phenomenon was meiosis, S5 asserted that:

> In meiosis we have two consecutive divisions; meiosis I, reductional division where a mother cell originates two daughter cells with the half of the mother cell chromosomal number; then, these haploid cells suffer equational division, meiosis II, originating also four haploid cells.

In order to ascertain whether or not S5 was aware of the differences between the two kinds of meiotic division, S5 was asked to indicate in the diagrams the cells showing reductional and equational divisions of meiosis. Student S5 responded correctly and consistently:

I: Can you indicate an example of the diagram showing cell in a reductional division?

S5: I know that during the first division of meiosis, two daughter cells are formed; then it is cell D.

I: And which phase of meiosis is represented?

S5: I have noted that the chromosomes…it is telophase I because of the number of the cells formed.

I: How many cells do we have?

S5: We have two cells.

I: Which is the chromosomal number of these cells?

S5: We have n chromosomes, haploids.

I: Why do you think so?

S5: Because a reductional meiosis occurred with the half of the mother chromosomal number.

I: Can you indicate cells representing a second division of meiosis?

S5: We have cell A, anaphase II and cell B, telophase II

I: Can you explain what happens to cell A?

S5: …chromosomes divided; there was separation of chromosomes to originate four daughter cells.

I: Dou you know which structure divided the chromosomes?

S5: Yes. It is centromere.

I: And ...which is the chromosomal number in these four cells?

S5: Haploid.

By comparing the students' responses at the post-course and post-laboratory interviews, it seems that S5 showed consistent understanding of the basic characteristics of the meiosis. It means that the practical work had a positive impact on his conceptual understanding as he was able to use his knowledge to compare, identify and describe meiotic events illustrated in the diagrams.

In an attempting to follow the students' reasoning about the events in meiosis, two students were asked to indicate the correct sequence of the phases illustrated in the diagrams. Both S1 and S2 were able to give the correct sequence. However, both students experienced conceptual difficulties both the pre-and post-test particularly with respect to: (1) the structure of the chromosomes; (2) the differences between chromosomes and chromatids; and (3) the diploid and haploid chromosomal number. Hence, the students were interviewed to understand their difficulties better. The outcome of the interview is presented below:

I: What are the differences between phases A and G illustrated in the diagrams?

S2: In phase G the chromosomes are lined up at the equatorial plaque and in phase A there was division of centromere and the chromatids move to the opposite poles.

I: Which is the chromosomal number of these cells?

S1: There are haploids; half of the mother chromosomal number.

S2: I agree. I think are haploids.

I: And what is the difference between the chromosomes in cell G and A?

S1: In cell A we have chromatids; there was division of centromere and each chromosome forms two chromatids.

I: And what about cell G?

S1: Well… in cell G the chromosomes are duplicated …I think so.

Students' responses in this interview reveal that both S1 and S2 demonstrated a better understanding of meiosis than at the pre-and post-test stages. For example, not one of the two students could respond correctly to any of the questions concerned with chromosomal number of the cells in order to identify, describe, represent and contrast cells in mitosis and meiosis division in both tests (found in Appendix A). These results suggest that, although the students showed a significant improvement in the interview, they still held many erroneous ideas about the real meaning of haploid and diploid chromosomal number. This confirms what is found in the literature. This might be the reason why they were not able to draw, for example, a cell with chromosomal number "n = 3" representing metaphase of mitosis and anaphase I of meiosis as well to indicate a correct option for a cell with diploid chromosomal number as equal to "6" in the anaphase of mitosis and meiosis.

The students' performance on the events occurring during prophase I of meiosis did not increase substantially from pre-test to the post-test. The most difficulty experienced by the students was the identification of the diagrams representing each subphase of prophase I and associated events. The six interviewed students showed a weak understanding of the importance of the "crossing-over" during a cell division in both tests. For instance, only three students out of the six interviewed gave a correct option to the question concerned with "crossing-over" (found in Appendix A) in the post-test. The students who did not perform well were interviewed to get their views about the events occurring during prophase I of meiosis. For example, on the question describing and identifying a diagram representing "crossing-over", S3 and S4 expressed their arguments as follows:

S4: Crossing-over is a phenomenon in which homologous chromosomes exchange their segments creating in this way new genetic combinations.

S3: In crossing-over, homologous chromatids exchange segments where genetic combinations occur and then there is a fusion and living organisms will present new characteristics.

I: Looking into the diagrams, which cell shows, that crossing-over happened?

S3: Cell F4.

I: Can you observe carefully?

S3: [Silent]

S4: [Silent]

I: Which is the cell according to your explanation?

S4: Cell F5.

I: Why F5?

S4: We can see that chromosomes formed chiasmatas where the homologous are crossed.

S2 indicated "cell A" as representing evidences of crossing-over, arguing that: "I think that in crossing-over there is a break up of the segments and the homologous chromosomes exchange parts, that is, genetic information to form new genetic combinations".

It appears that all three interviewees hold a reasonable idea of the events occurring during prophase I of meiosis, particularly the importance of crossing-over. However, when asked to identify the diagrams showing evidence of crossing-over they seemed to be inconsistent in their responses as illustrated in the excerpts of the interview with S3 and S4. Student S2, although seeming to be aware of the importance of crossing-over, was unable to associate her ideas with a diagram showing that crossing-over happened. S2 indicated "cell A" as the correct diagram instead of "cell F5".

In conclusion, the results of the post-laboratory and post-course interviews reveal that the laboratory instruction brought visible changes in the students' conceptual understanding of the basic concepts of mitosis and meiosis. It is important to point out that the students continued to hold some erroneous ideas about the meaning of haploid and diploid chromosomal number and structure of the chromosomes. These problems limited students' understanding to identify and describe mitosis and meiosis and associated events. Some of the reasons students continue to experience some difficulties in understanding these concepts even after the instruction through practical work and tutorials are outlined in the next section 4.4. The information in that section was obtained through classroom observations. Several studies involving secondary and high schools students and teachers (novice and experienced) have revealed the prevalence and tenacity of misunderstandings, with regard to h chromosome structure which is regarded as a function of chromosome number coupled. Also implicated here is the lack of basic knowledge on the differences between chromatids and chromosomes, replicated chromosomes and unreplicated chromosomes (e.g.: Kindfield, 1991; Chinnici *et al*., 2004).

4.4. Results of the classroom observations

In order to investigate the nature of the activities carried out during laboratory classes in cell biology, classroom participant observations were conducted. Detailed field notes captured the data. The main purpose of the classroom observations was to investigate the way these activities enhanced the students' understanding of mitosis and meiosis. Thus, the classroom observations addressed research question two: "*How do the laboratories activities enhance the students' understanding of cell division*?" The description of the activities recorded during laboratory sessions were grouped into four categories, namely: (1) introduction of the laboratory aim and topics; (2) explanation and demonstration of the procedures to observe the slides on mitosis and meiosis; (3) discussion of the laboratory guide and; (4) discussion and comparison of the observation of the slides. More details about the content contained in each of the categories are outlined in the Table 3.3, section 3.8.3 of Chapter 3.

Before starting analysing the results yielded through classroom observations it is important to note that the activities carried out during the cell division practicals (12 hours in total) were in somehow repetitive. That is why, the researcher in reporting the results on field notes opted of summarizing the observed activities into four categories avoiding in this way repetitions. Furthermore, the observations made during the lectures on cell division revealed the same situation. This was coupled to the fact that the most prevalent teaching strategies used by the lecturer were introductory and expository lessons being the students passive recipients of knowledge. Being a case study, the researcher, recognizes this as having contributed, to some extent, to the limitation of the scope in analysing the data yielded in this regard. As indicated in the literature, case studies are prone to problems of observer bias, despite attempts made to address reflexivity (Cohen *et al*., 2000; Yin, 2003).

The results of the classroom observations revealed that the kind of difficulties encountered by the students during the practical work on mitosis and mitosis were of the same kind. Most of the difficulties were linked to the poor knowledge and skills of the students in operating the light microscope correctly and efficiently in order to make accurate observations and descriptions of the microscopic slides of mitosis and meiosis. The experiences gained during the observations are sketched in the sections that follow.

Laboratory environment

The laboratory presented the minimal conditions needed to conduct laboratory sessions on mitosis and meiosis such as: light microscopes, microscope slides, models and maps of mitosis and meiosis. The ordinary way of grouping students were two per bench. In principle, each student should be allocated with a microscope, but, due to high student numbers in the laboratory some of them used the same microscope. No practical guides were available therefore the lecturer provided the students with practical worksheets on mitosis and meiosis during the laboratory sessions. Because of this, the students attended laboratory sessions without preparation. Before the laboratory sessions started, all students were required to check whether or not their microscopes were in working order.

Introduction of the laboratory aim and topics

The lecturer commenced normally by presenting the topic of the laboratory sessions and its aims on the blackboard. Because the lecturer seemed to know beforehand that the students had difficulties in operating a light microscope correctly, the way he presented the aims and explained the tasks were largely teacher- centred. He usually explained and demonstrated on the blackboard the steps needed to observe the microscope slides and which parts of the onion apex cells and pollen mother cells should be observed. The students were usually asked questions to ascertain whether or not they were clear about the aim and purpose of the laboratory content. Basically, in this introductory part, the students' task was to pay attention to the lecturers' explanations, to ask questions for further clarification and take notes. The most typical questions were revolving around: (i) how to locate the onion apex cells; (ii) how to operate the microscope; (iii) how to place a slide on the microscope stage; and (iv) what to observe in the slides. These kinds of questions are indicative of the lack of opportunity on the part of students to operate the light microscope in order to observe specimens in a laboratory environment. As was stated early in this study, almost a third of the students attending the biology course came from different backgrounds without practical work experience at high school level and having therefore different ranges of knowledge and skills. For some of students this presented a first chance at operating a light microscope to observe slides with specimens, which means that students require more time to master the skills needed to correctly operate the light microscope.

Explanation and demonstration of the procedures

During the explanations and demonstrations, students seemed not to understand how to use the different types of microscope objective lenses in a logical sequence to make accurate observations and descriptions of the mitotic and meiotic phases. The lecturer explained repeatedly and demonstrated what cells look like in different stages of mitosis and meiosis using different objective lenses of the light microscope. He also made sketches on the blackboard illustrating the appearance of the whole tissues to be observed using the light microscope.

In order to ascertain whether or not students were already aware of the requirements needed to operate the light microscope students were allocated some time to train and practise procedures on how to observe the slides. Thus, in this part of the laboratory sessions, the main task of students was to practice the basic skills needed to observe the slides of mitosis and meiosis under the microscope. Students worked cooperatively in mixed gender groups. They shared ideas while manipulating the microscope. They seemed to be very active in performing this task probably because they knew beforehand that this was an important step for them in order to learn mitotic and meiotic events in a meaningful way.

Execution and discussion of the performed activities

During the execution of the laboratory activities, students showed that they were already aware of the tasks to be performed. The laboratory activities were performed individually or in groups of two students and this allowed them to exchange their views about what was supposed to be observed in the microscope slides as well as discuss the differences and similarities between the observed phases. The main aims of the practical work were concentrated on observing events associated with mitotic and meiotic cell division using the microscope. Students were also required to draw and describe what they observed with respect to onion apex cells and pollen mother cells. In the course of the laboratory sessions, it was clear that the number of students outstripped the number of available microscopes. As a result, the lecturer could not attend to all individual students' needs. My help was solicited several times by students to clarify or explain the events that they were observing under the microscope. It means that in some instances I took the role of the lecturer. As an observer, I asked some of the students to explain what they were observing. Overall, the students showed good understanding of the theories and they were able to identify the phases in the slides compared with those provided by the lecturer in the worksheets and with those displayed in the maps [charts] hanging in the laboratory. In other words, students could link their theoretical ideas with practical experiences in that they were able to recognize the phases and associate events of mitosis and meiosis. However, it is important to note that, despite this, they were not able to distinguish between chromosomes and chromatids; this confirms what I found during tests and interviews. In this case, it can also be linked to the status of the microscopes available in the laboratory. As was stated earlier, the magnification power of the microscopes did not allow them to see more details of the specimens.

During my conversation with students, a student said, "Now it makes sense what we have learnt in tutorials because we have chance to see it in practice". Despite this, a big problem which persisted was the students' inability to draw accurately what they observed. Most of the students could not transfer what they were observing in the microscope slides to the drawing paper. Associated with the lack of the skills to make accurate drawings, was the inadequate time allocated for practical work. Students complained about not having sufficient time to draw what they observed. They also complained about the fact that the microscopes were not in a good condition such that the microscopes' magnification power did not allow them to see more details of the specimens. In fact, the students' complains are in consonance with the current practices of the practical work at EMU as was stated early in this study. Irrespective of the conditions of the microscopes, the time allocated for practical work was not enough taking into account the characteristics of the students in terms of their backgrounds. Most of the time was spent in explaining to students what they should observe, what to draw as well how to draw a cell.

Getting more evidence from the lecturer

In an informal conversation with the lecturer in order to know how he thought practical work helped students to understand the basic concepts of mitosis and meiosis, he confirmed that he believed that students improved their knowledge. He however thought that some of them were too immature to be at university. To him, many of the students lacked the culture of being at the university in terms of behaving like university students. This is also coupled with the fact that they did not show enough concentration in performing their laboratory activities. Regarding the time allocated for the laboratory sessions, he said that the time should be sufficient but because of the nature of the students, the time (two hours) was not enough. Students lacked good background on how to use the light microscope correctly to make accurate observation in identifying different stages of mitosis and meiosis. It was his view that most of the time was used in teaching and demonstrating how to operate the microscope correctly rather than the actual performance of assigned laboratory tasks.

Overall, regardless of the students' shortcomings in operating correctly the light microscope to make accurate observations and descriptions, the kind of activities (for example, observing different slides containing different phases of mitosis and meiosis, drawing and interpreting their observations) performed during the laboratory sessions contributed considerably to students' understanding of the basic concepts mitosis and meiosis. During the execution of the laboratory activities, students were given opportunity to discuss and compare their views about what they were observing under the microscope slides and coming to a common understanding of what was represented in the microscope slides. This suggests that the students were given chance to negotiate their knowledge so that they could make their learning about the basic concepts of mitosis and meiosis more meaningful. Therefore, it would be unfair to say that the way the lecturer conducted the practical work was not effective since the nature of the students taking a cell biology course was divergent in terms of their background knowledge and skills for correctly using the microscope to make accurate observations and descriptions of mitotic and meiotic events. In terms of the gender patterns, I did not pay a particular attention as this aspect was outside the scope of the study. However, it was possible to note that; overall, the girls experienced relatively more difficulties, particularly in manipulating the microscope, compared to the boys. I suspect that the girls lacked confidence in themselves to perform this kind of task to some extent. It can be associated to what we observe in informal environments; that is that boys usually perform better than girls when it has do with manipulation of equipment or instruments (Kalu, 2005; Sinnes, 2006).

4.5 Results of the Questionnaires

In order to investigate whether or not the motivational conditions needed to achieve the effectiveness of the practical work in the teaching and learning of cell biology course, two kinds of questionnaires were employed namely, the Students' Perceptions

Questionnaire (SPQ) (found in Appendix E) and the Lecturers’ Experiences Questionnaire (found in Appendix F). The focus of the SPQ was to answer the third research question: “W*hat are the students’ perceptions of the role of practical work in the learning of cell biology*?” The LEQ was designed to answer the fourth research question: “*What are the lecturers’ practical work teaching experiences and views about the cell biology course*?” More details about the nature of the questionnaires are outlined in Chapter 3, section 3.8.4. The results of the two questionnaires are presented and discussed separately.

4.5.1 Results of the Students’ Perceptions Questionnaire

The Students’ Perceptions Questionnaire (SPQ) was administered at the end of the course on cell biology. This questionnaire was concerned with eliciting students’ perceptions in relation to the role of practical work in terms of its aims and contributions in the learning of cell biology (found in Appendix E). Students’ opinions on the role of practical work were grouped into three categories according to the aims of practical work: (1) acquisition of knowledge and intellectual skills; (2) acquisition and development of procedural knowledge and investigation skills; and (3) change of attitudes towards practical. In this study, the first category includes the development of conceptual understanding and intellectual skills such as problem solving and creative thinking. The second category consists of manipulative skills, development of intellectual skills and cognitive strategies in performing scientific investigations, including the students’ scientific attitudes, communicative and cooperative skills. The last category refers to factors which motivate and influence their attitudes towards science. As indicated in Chapter 3, the SPQ is comprised of 25 closed Likert type items with the range from 1 (“strongly disagree”) to 5 (“strongly agree”). The respondents were to rank their opinions in five categories: strongly disagree; disagree; don’t know;

agree; and strongly agree. To clarify the interpretation of the results yielded through the SPQ, the first two rankings "strongly disagree and disagree" were grouped as negative and the last two "agree and strongly agree" as positive. In order to assess the internal consistency between the items a Cronbach's coefficient alpha was calculated. It was calculated at 0.89. This shows that the SPQ was adequate for measuring the underlying attribute. In the next section the results of the first category are presented.

Acquisition of knowledge and intellectual skills

This section asked students to rank their opinions about the role of practical work on their acquisition of knowledge and intellectual skills. It comprises eight items with a mean of 0.29 inter-item correlations which can be considered as an optimal value as it falls within the range of 0.2 to 0.4. The results of this section are displayed in Figure 4.1. Overall, the results displayed in Figure 4.1 show that most of the respondents (80%) were positive in their opinions sharing the perceptions that practical work is useful in: learning basic cell biology concepts (89%); learning cell biology events and facts (79%); understanding and accepting new scientific concepts about the cell (66%); clarifying the principles and theories discussed in cell biology tutorials (97); making cell biology abstract concepts to become more real (74%); verifying facts and principles already taught in cell biology tutorials (89%); enabling the diagnosis and dispelling of misconceptions about the cell biology 25(66%); and developing critical ways of thinking and analysis in problem-solving (76%). However, about 9% of the respondents were negative in their opinions while 11% did not have any opinion related to the contribution of practical work in acquiring knowledge and intellectual skills as indicated in the Figure 4.1.

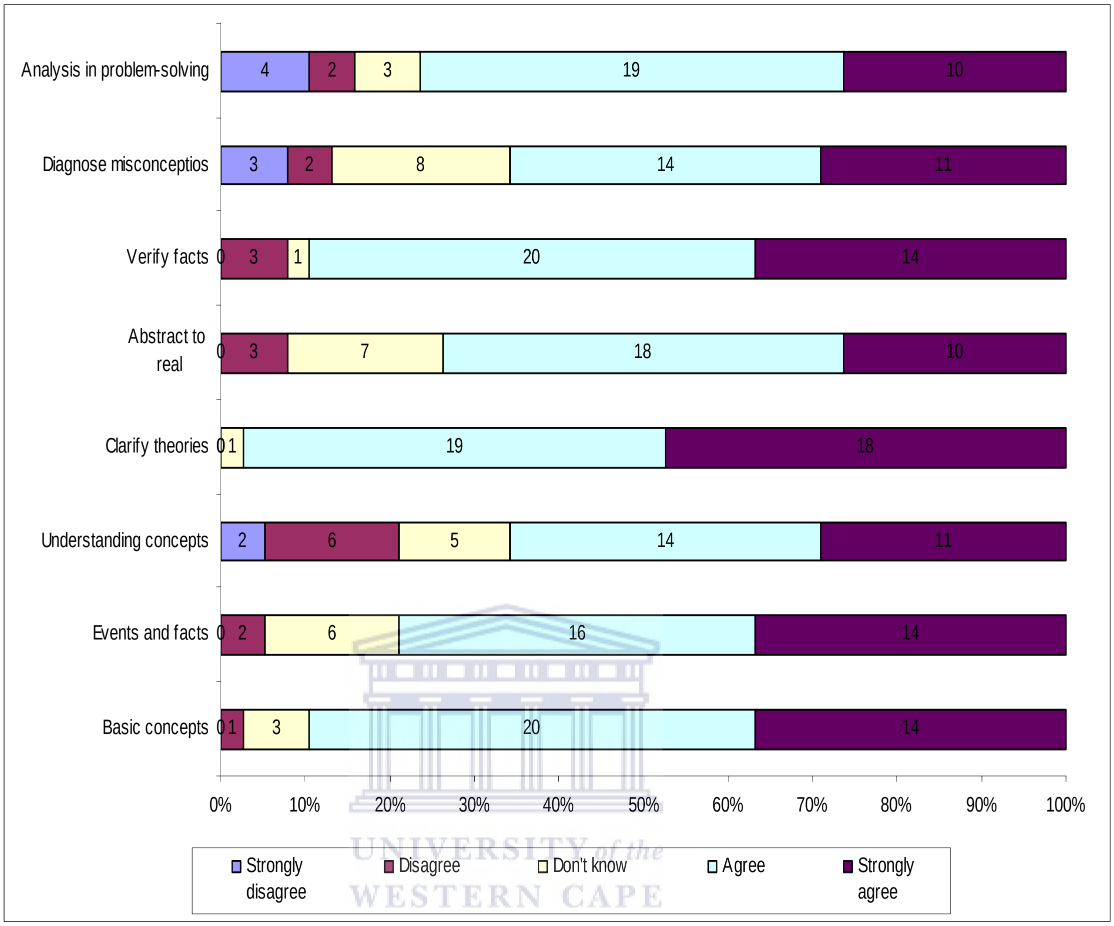

Figure 4.1: Students' opinions on acquisition of knowledge and intellectual skills by means of practical work (N = 38).

Acquisition and development of procedural knowledge and investigation skills

In this section students were required to indicate their opinions about the role of practical work in acquiring and developing procedural knowledge and investigation skills. This section comprised 12 items with a mean of 0.3 inter-item correlations. It can be considered as an optimal value in the range from 0.2 to 0.4. The data set reflected in this section is displayed in Figure 4.2.

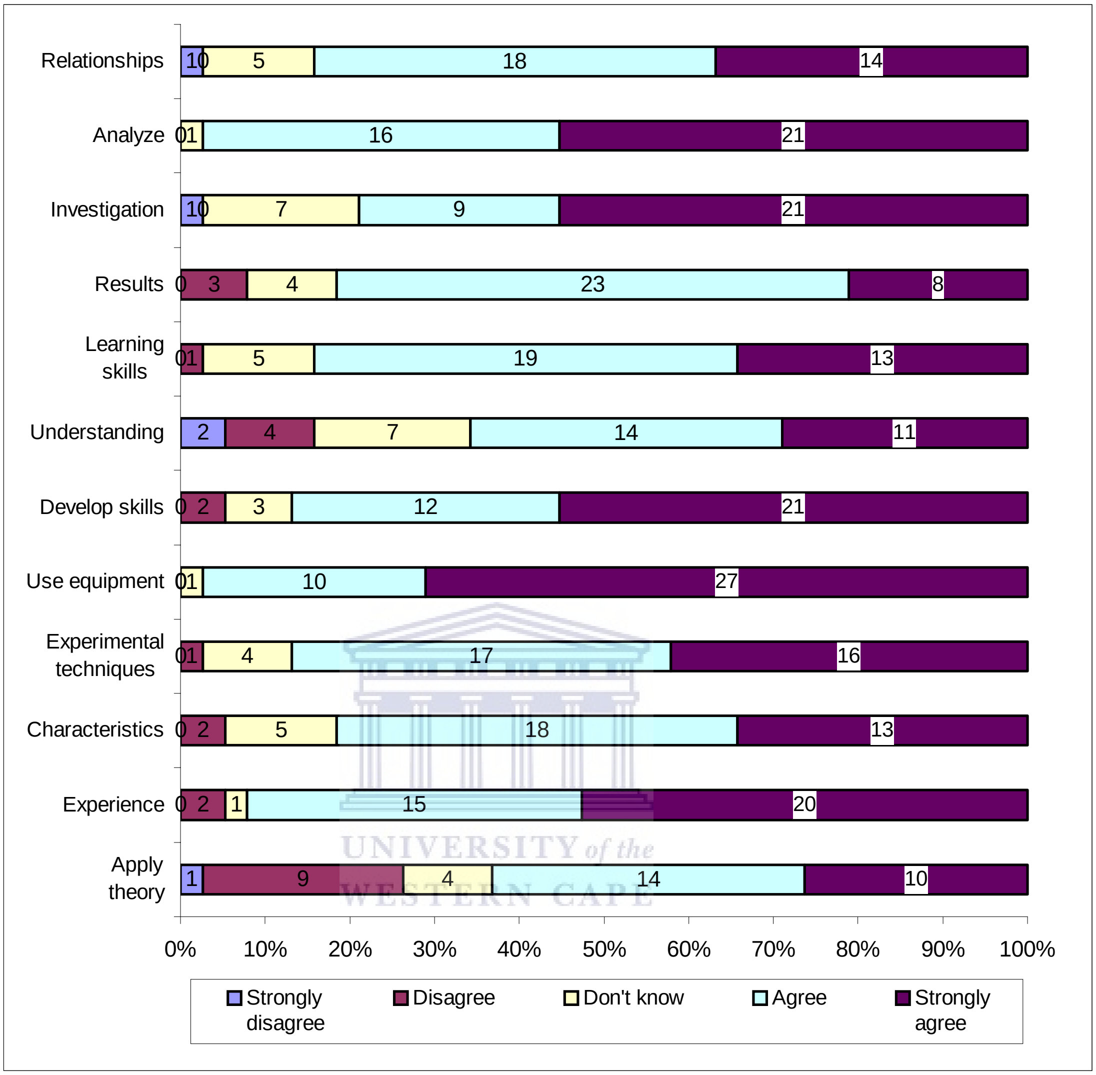

Figure 4.2: Students' opinions on the acquisition of procedural knowledge and investigation skills by means of practical work (N = 38).

In general, most of the respondents (84%) were positive in the sense that practical work in cell biology can help in learning skills to analyse and interpret results of observations and experiments (97%); use laboratory equipment and common measurement instruments (97%); develop skills to plan and perform experiments in laboratory conditions (87%); record and organize data obtained from observations and experiments

(84%) and explain relationship between cell structures (84%). Likewise, 87%, 82% and 79% of the students respectively were also positive in their opinions indicating that practical work helps to develop skills to plan and perform experiments in laboratory conditions and to apply the results of observations and experiments in new situation as well helping to present science as an investigative process. Twenty four students (63%) agreed that practical work enables one to apply theory to practice (Figure 4.2).

Change of attitudes towards practical work

This section asked the students to rate their opinions regarding the change of their attitudes towards practical work. It consists only of five items with a 0.2 inter-item correlation. This value is still optimal as it falls in the range of 0.2 to 0.4 inter-item correlation values. The findings of this section are displayed in Figure 4.3 below. According to the findings displayed in Figure 4.3, the majority of the respondents (78%) agreed that their attitudes towards practical work after cell biology course changed positively. Thus, their opinions indicated that practical work in cell biology helped to arouse and maintain their interest in biology, (84%); encouraged the development of creativity, (84%); enhanced their skills to make accurate observations and descriptions of cell events, (82%); improved their logical reasoning, (74%); and helped to develop positive attitudes towards biology, (66%). Despite these positive opinions, there was a group (17%) of students that did not indicate whether or not practical work helped them to change their attitudes towards biology. For instance, 29%, 21% and 16% of the students respectively said that they “don’t know” whether or not practical work in cell biology encourages positive attitudes towards biology; facilitates the development of logical reasoning and encourages the development of skills to make accurate observations and descriptions of events in cell division.

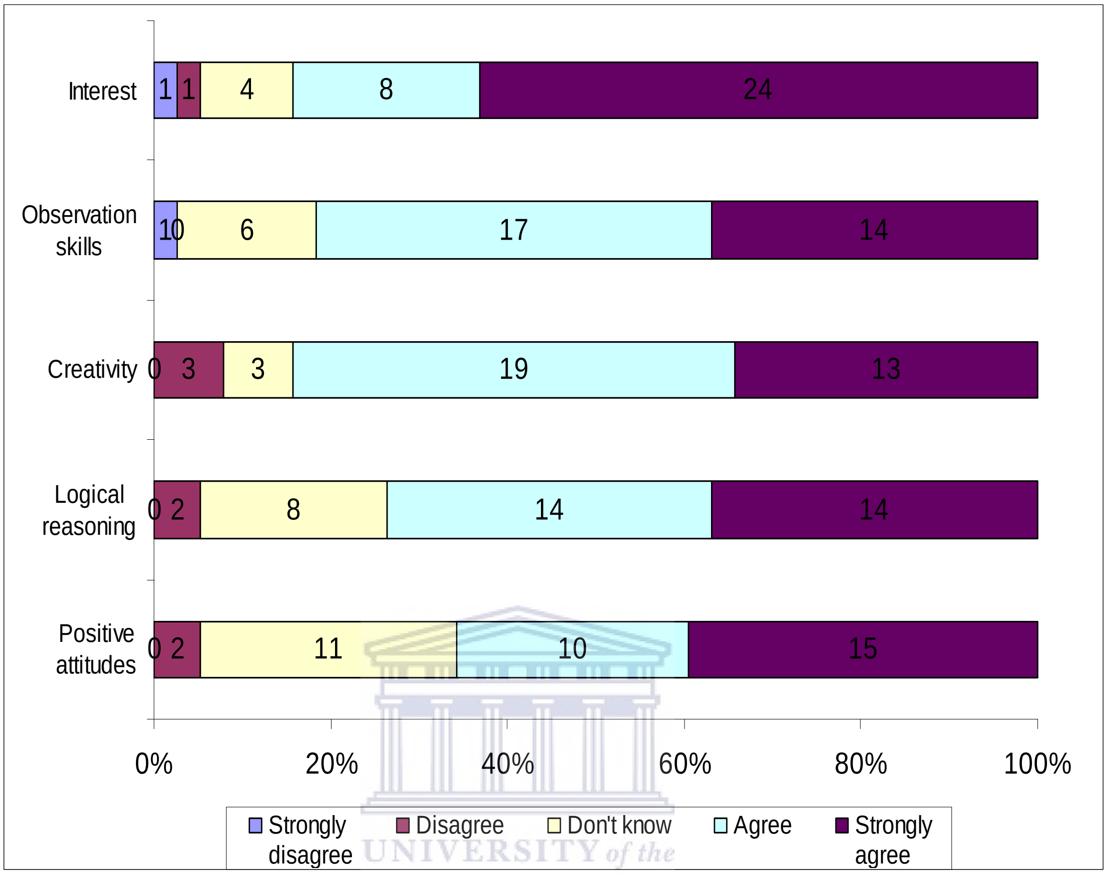

Figure 4.3: Students' opinions on attitudes towards practical work (N = 38).

Reflecting on the results of the Cell Biology Test (section 4.2), interviews (section 4.3) and classroom observations (section 4.4), one can assume that, perhaps, the students who did not provide this kind of feedback are those who did not perform well during the process of teaching and learning cell biology through practical work. If this is the case it then means that they did not see practical work as an important means to increase their interest, curiosity as well as their confidence in learning cell biology. But also perhaps those who did well felt they could cope with the work and that they could have done well even without practical work to stimulate their interest, curiosity as well as their confidence in learning cell biology.

In order to complement the students' perceptions of the role of practical work in the learning of cell biology, students were required to indicate their opinions freely on what they thought could be done so that practical work could contribute effectively to the teaching and learning of cell biology. The information obtained was analysed and classified into six categories (Table 4.35).

Table 4.35: Students' opinions on effectiveness of practical work.

Categories of opinions	Number of the respondents	%
Availability and maintenance of laboratory equipment/materials	29	76%
Laboratory wok in secondary schools	11	29%
Frequency of practical work activities	8	21%
Integrating theory with practical work	7	18%
Clarification of laboratory sessions objectives and procedures	6	16%

N = 38

Table 4.35 shows that the majority of the respondents (76%) suggested that practical work equipment were neither available nor adequately maintained. This finding corroborates with the annotations from the classroom observations regarding the status of microscopes and lack of practical guides and chemicals. Most of them, justified their position stating that their performance during cell biology practical work was poor because the kind of the microscopes did not allow them to see more details of the cells. This led them to misidentify the phases and events occurring during mitosis and meiosis. Secondly, 29% of the respondents indicated that it is important to introduce practical work in biology right at the secondary school level so that they could gradually become familiarized with the laboratory equipment and acquire the skills needed to operate it or other equipment correctly. The frequency of practical work activities was indicated by 21% of the students as deserving consideration as this may provide them with more opportunities to gain necessary skills to work with laboratory equipment and consequently, help to link theory and practice. Seven students (18%) regarded the integration of the theoretical and practical work as being crucial as this might have implications for the clarification of the practical work objectives and procedures as indicated by 16% of the students. Another important element suggested by three students (16%) was the use of scientific journeys and teleschool programs being offered parallel to practical work. They thought that in doing so they would become motivated as well as develop interest and confidence in learning cell biology and improve their attitudes towards practical work.

The six students that were interviewed after the course were also asked to express their opinions about the importance and effectiveness of practical work in the teaching and learning of cell biology. All six students agreed that practical work improved their level of learning in terms of applying theory to practice and in manipulating laboratory equipment. They all agreed that their attitudes towards practical work changed in a positive way. Overall, they claimed that they were able to:

- Use the laboratory equipment (microscope) never used in secondary school.
- Put into practice theoretical concepts mainly learnt at secondary school.
- Observe mitotic and meiotic events on the microscope.
- Understand and explain mitosis and meiosis in a clear manner.

The following excerpts of the interview illustrate further some of the claims made by students S1 and S2:

I: How do you feel after being taught cell biology through practical work?

S1: I think we learnt to use laboratory instruments that I never saw at secondary schools for example, microscope; we observed many things that we use to see only in books… I never thought that some day I would observe such things.

I: What for example in cell biology?

S1: The first time that I observed meiosis I thought that each cell consisted only of one phase; I never thought that in a cell we could observe all the phases.

S2: I think we learnt in practice a lot of what is taught in tutorials; well … we did not know that such things happen in reality because we never had opportunity to observe them.

I: Like what, for example?

S2: For example, here we learnt to observe various phases of mitosis and meiosis … we learnt to use laboratory instruments what we never did in secondary schools; now we can observe and describe cells.

The six interviewees were asked to state what they would like to see in order to make practical work become an effective means for teaching and learning of cell biology. They all suggested that there is need to provide more modern laboratory equipment and materials, maintain the laboratory equipment (e.g. microscopes and slides), reduce the number of students attending each laboratory sessions and increase the frequency of laboratory sessions. For example, S4 asserted that:

> "...first of all I would like to have more intensive practical work; one session per week is not sufficient; for example, if I get a chance to observe a cell on the microscope it means that I will do it in a week time; then it is very difficulty for me as my first time to remember what I have learnt in the previous laboratory sessions."

S3 said: “we should have laboratory sessions twice per week” He added that, “Another problem is related to the lack of microscopes with higher resolution; it is not possible to see more details of the cell with the 40X objective lens.” In the same sense, S5 states that:

> “...the microscope helps to understand and explain facts but, their objective lenses are not in good conditions; also we should have in parallel to practical work documentaries from television illustrating various phases of mitosis and meiosis so that we can link theory and practice.”

In conclusion, the results of the SPQ suggested that the students were, to some extent, aware of the role of practical work in the learning of cell biology. They shared a common view that practical work in cell biology helped to further their level of learning in terms of acquiring and developing conceptual knowledge and intellectual skills, procedural knowledge and investigations skills. It was clear from the interviews that practical work contributed extensively in helping them to use laboratory equipment thereby enhancing their manipulative skills as well as to helping them to observe, understand and explain the mitotic and meiotic events by linking theory and practice. Thus, they could improve their overall learning of the subject matter and develop the needed skills to correctly operate the light microscope and consequently make accurate observations and descriptions of the observed cell events. The students shared the opinion that practical work changed their attitudes positively by increasing their interest, curiosity as well as their confidence in learning cell biology. Irrespective of the difficulties experienced by the students during the whole process of learning cell division concepts through practical work, the findings of the SPQ provided evidence that the cell biology practical promoted students’ practical understanding of the basic concepts of cell division as well as improved their intellectual and conceptual development. During the classroom observations I saw that the students were working actively toward finding ways of solving some practical problems that challenged them, such as: manipulating the microscope, making accurate observations and drawings, making accurate descriptions of their observations. In other words, practical work provided students with opportunities to develop their abilities in problem-solving through actual experience. With respect to this, Tamir *et al*. (1992), Calloids *et al*.(1997), Dekkers, (1997) and Guzman, (2000) emphasized the importance of practical work in providing students with opportunities to acquire direct experiences and also as a means of providing opportunities for students to foster a sense of success, motivation and control in learning science. It is believed that practical work arranged in this way can create the conditions for meaningful learning rather that rote learning and thus, shifting the balance from reception of information to interaction and manipulation of ideas (Novak, 1984; Head, 1985).

4.5.2 Results of the Lecturers' Experiences Questionnaire

The Lecturers' Experience Questionnaire (LEQ) was designed to test the lecturers' practical work teaching experiences and ideas about the biology course. Specifically, the LEQ aimed at exploring the lecturers' practical work teaching experiences in terms of their current practices, the nature of practical work content and activities, and their perceptions on the importance placed on the aims of practical work in the biology course. The LEQ comprised four sections: Section A included lecturers' demographic information; Section B asked the lecturers to report on some of the current practices taking place during laboratory classes in Biology courses; Section C was related to various types of practical work in biology and Section D was concerned with the importance being placed on the aims of practical work (found in Appendix F). More details about the nature of the questions are given in Chapter 3, section 3.8.4. The results of Section A were employed to describe the lecturers' characteristics as indicated in

Chapter 3, section 3.4.2. The results obtained through Sections B, C and D are analysed and discussed separately in the next sub sections.

Lecturers' experiences and practices in practical work teaching

This section asked lecturers to indicate what they normally do during laboratory classes in the cell biology course. Six of 11 lecturers indicated that they were able to teach in [a fully/adequately equipped] laboratory once a week while five said that they had this opportunity two times a week. Regarding the use of their laboratory as a classroom, five lecturers said that they used the laboratory as a classroom while six said that they did not do so. Ten of the eleven lecturers indicated that the average size of their practical classes ranged from 25 to 30 students per session, which is considered to be high, taking into account the need to give individual attention to all the students concerned. Below are some of the comments showing the negative impact of the current practices in laboratory classes in cell biology:

L1 said that:

> The practicals on Marine Ecology subject should have been conducted at the Marine Biological Station for investigation; however, there are funding constraints, which do not allow the performance of such practicals…it has negative consequences on the teaching and learning process in the Biology Department

L2 asserted that:

> The quality of laboratory instruction is undesirable; the lecturers do what they can do and not what they must do…due the serious lack of equipment and chemicals.

L3 claimed that:

> There are many students…they should be 10-15 per laboratory class; the physical space is not enough and also the funding to buy materials is limited.

The comments above do not differ significantly from those that have been reported in the literature in terms of the lack of laboratory materials, chemicals, appropriate working conditions, large number of students, poor conditions of designing an experiment, use of inappropriate assessment instruments, and predominance of 'cookbook' experiments (Hodson, 1992; Tamir & Lazarowitz; 1994, Lunetta, 1998; Kapenda et *al*., 2001). In fact, the current practices in terms of practical work at EMU appear to be an obstacle in the way of accomplishing the aims of cell biology practical work and other laboratory-oriented courses. In general, the practical work at EMU is conductedin inadequate conditions and it affects, to some extent, the lecturers' ability to confidently carry out the teaching of practical tasks

Lecturer's uses of practical work in biology course

This section comprised three questions (4, 5 and 6). The lecturers were asked to indicate the frequency of use of different kinds of practical work taking place in the cell biology course. Table 4.36 shows the number of the respondents using each type of practical work in cell biology course relative to questions 4 which states, "(Indicate the frequency of use of different types of practical work in cell biology course)".

The results in Table 4.36 below emerged after the respondents ranked the 'frequency of use' of the indicated types of practical work in five categories: never used, rarely used, occasionally used, used and frequently used.

Table 4.36: Frequency of use of different kinds of practical work.

Kinds of practical work	Never or Occasionally used N	Frequently Used N
Those demonstrations that verify facts and principles	4	7
Experiments by students or lecturer to illustrate or reinforce concepts and theories taught in tutorials	1	10
Practical work set primarily to familiarise students with the use of important instruments, equipment, and techniques	4	7
Practical work that enables the teaching of procedures or skills training, or to teach skills in experimental design	4	7
Practical work which motivate students to develop positive attitudes towards the subject	10	1
Practical work that introduces students to the world of scientists	5	6
Problem-solving or discovery experiments (by lecturer or student) designed to answers a question raised during a theoretical work	10	1
Investigations projects-problems work out by student(s); not necessarily connected in direct way with the theoretical course.	8	3

N =11

Grouping the first three rankings as "Never or occasionally use" the last two as "Frequently used," it is evident that to some extent there is agreement among the lecturers in the use of different kinds of practical work. In this regard, (the range of the frequencies between ten and six respondents), "the experiments by students or lecturers to illustrate or reinforce concepts and theories taught in tutorials" was indicated to be the most frequently used (10) followed by "demonstrations to verify facts and principles" (7); "practical work set primarily to familiarise students with the use of important instruments, equipment, and techniques" (7), "practical work done to enable the teaching of procedures or skills training", and to "teach skills in experimental design or to introduce students to the world of scientists" (6). However, ten respondents indicated that the "practical work done to motivate students developing positive attitudes towards the subject" as being the least used. This position is somehow surprising compared with other studies conducted in this area. For example, the study carried out by Swain *et al*. (2000) on teachers' attitudes toward the aims of practical work shows that the aim to develop a critical attitude was highly rated by their subjects. This form of practical work is supposed to motivate students to want to perform more investigative work rather than repeat standard exercises.

Looking back at the results in Table 4.36, the problem-solving or discovery experiments and investigations project-problems work are the aims that lecturers used least. Certainly, this might be the reason why the lecturers did not regard the use of practical work as a means to motivating students who in turn would develop critical attitudes towards practical work. Another reason might be linked to the difficulty and complexity involved in the teaching of problem-solving. Teaching towards problem-solving requires an active involvement in the design and planning of investigations rather then following the 'cookbook practical work'

Question 5 required the lecturers to indicate the frequency of which they or their students do practical work of any kind. The lecturers' responses to this question suggested that the use of different kinds of practical work was rather limited. This might not be unrelated to the several economic constraints impacting on the activities of the Biological Science Department. Another factor that might have prevented the lecturers from using different kinds of practical work is time constraints (2 hours per week) for laboratory lessons, among other constraints listed in the previous section. In addition, the lecturers' comments on this issue revealed that the use of different kinds of practical work is confined to the subject orientation in terms of content and also to the available time for the completion of laboratory activities.

Question 6 asked the lecturers to report on the 'frequent use' of laboratory fieldwork. Four of the eleven respondents said that they never used laboratory fieldwork whilst three and four respondents respectively said that they used it once a month and once a semester, respectively. Among others, the most serious constraint mentioned by the lecturers in carrying out laboratory fieldwork was the lack of financial resources and transport. For instance, one of the respondents asserted that, "there are many ideas for laboratory fieldwork; but the growing number of students per class and lack of financial conditions is limiting factors". On the other hand, another respondent said "We never used fieldwork in the true sense of the word but…some simulations are done in a natural environment". Although the last statement suggests a way to make up for the deficiencies in resources, it is still a vicarious experience. Although the simulations allowed the lecturers to become more creative in order to conduct fieldwork, this cannot be an adequate substitute for a real fieldwork. Early studies in this regard reported on irregular use of different types of practical work. For instance, Bekalo & Welford (1999) and Fessehatsion (2003) report that only a few teachers used frequently demonstrations in their schools. The teachers ignored other types of practical work by using the excuse of unconducive practical working conditions. Similarly, the study conducted by Kerr (1963) in UK with science teachers showed inconsistency in the use of different kinds of practical work. It was found that teachers used experiments more frequently to the detriment of demonstration work. In this study irrespective of the constraints experienced by the lecturers in implementing laboratory activities it was found that in general, the lecturers were varying the types of practical work in their laboratory sessions on a regular basis.

Lecturers' views of the aims of practical work in cell biology

The last section of the LEQ was concerned with the importance placed on the aims of practical work in cell biology course. Lecturers were required to rate each of the ten aims of practical work in biology in order of importance from one to ten. The most important aim was ranked '1' and the least important aim '10'. The ten aims were adapted from a set of 20 aims produced by Beatty & Woolnough (1982). In order to make the respondents' preferences more meaningful, means and standard deviations were calculated as illustrated in Table 4.37. From the results illustrated in Table 4.37 it is clear that the respondents were not always consistent in their views about the role of practical work.

Table 4.37: Lecturer rankings of the importance of ten aims for practical work

Aim order	Description of the aim	Aim n°	Mean	SD
1	To verify or clarify facts and principles already taught in tutorials explaining their relationship	3	2.5	2.1
2	To make biological phenomena more real through actual experience	5	3.4	1.9
3	To promote the understanding of scientific methods or techniques	8	4.1	2.8
4	To promote a logical reasoning method of thought in solving problems	2	4.5	3.0
5	To elucidate theoretical work as an aid to comprehension	4	4.7	2.9
6	To provide students with opportunities to practice the necessary procedures or skills	10	4.9	2.6
7	To develop specific manipulative skills	6	5.7	2.4
8	For finding facts and arriving at new principles	9	7.1	2.9
9	To encourage accurate observations and descriptions of objects	1	7.4	2.5
10	To arouse and maintain interest in the subject	7	7.5	2.1

The results in Table 4.37 show that the lecturers rated the first five aims of practical work in order of importance as follows: (i) to verify or clarify facts and principles already in tutorials explaining their relationship (mean 2.5); (ii) to make biological phenomena more real through actual experience (mean 3.4); (iii) to promote the understanding of scientific methods or techniques (mean 4.1); (iv) to promote a logical reasoning method of thought in solving problems (mean 4.5); and (v) to elucidate theoretical work as an aid to comprehension as the most important (mean 4.7). The least rated aims were 8, 9 and 10 with mean scores of 7.1, 7.4 and 7.5 respectively.

In this study, the five most important aims differ to some extent from those indicated by the teachers in the studies of Swain *et al*. (1999), Ghebremariam (2000) and, Fessehation (2003). For example, in the Swain *et al*. (1999) study, the Korean teachers indicated the five most important aims as follows: (i) for finding facts and arriving at new principles; (ii) as a creative activity; (iii) to verify facts and principles already taught; (iv) to elucidate theoretical work as an aid to comprehension and; (v) to help remember facts and principles. The aim: 'elucidating theoretical work as an aid to comprehension' showed the smallest difference with UK teachers while the aim on 'creative activity' shows the largest difference from the UK teachers (Swain *et al*., 1999). It seems that the aims indicated by the Korean teachers were more content focused, while the UK science teachers appear to be offering a view that is more investigation oriented. The Mozambican lecturers showed the tendency towards both content and investigative components.

In confronting the lecturers' thoughts on the importance of different aims of practical work with the most preferred kinds of practical work in Table 4.36, it seemed that lecturers were not consistent in relating both aims and kinds of practical they frequently use. They, for instance, demonstrated a mismatch between the aim "for findings facts and arriving at new principles" and the kinds of practical work on "those demonstrations that verify facts and principles". It could be that, in this case, the lecturers had misinterpreted the relationship which may exist between aims and kinds of practical work in science (Woolnough & Allsop 1985). In addition, the constraints already listed in the previous sections by the lecturers such as: lack of laboratory equipment, shortage of time allocated for practical work activities and financial conditions, might also have contributed to lecturers not seeing some of the aims as being important. Furthermore, it can be associated to the way practical work is carried out at university level where there is a tendency toward predominantly 'cookbook practicals'. Many studies, in this regard, have shown that the practical work carried out in many schools, even at university level, does not provide the students with the opportunities to perform their own observations, making decisions about the way of describing what occurs, as well as to perform their own investigations and experiments to arouse interest in the subject (Tamir, 1991; Woolnough, 1991; Hofstein & Lunetta, 2003). This may be one of the reasons lecturers regarded aims 8, 9 and 10 as least important. In this regard, Swain *et al*. (2000) point out that there is a need to provide students with the opportunities to observe and discuss their observations during experiments. This can enable them to make sense of the observations and consequently, develop a more critically thinking approach, reason in a logical way when solving problems and hence develop positive attitudes towards these aims by prioritising them.

In this regard, the lecturers suggested that in order to make the process of teaching and learning cell biology more significant at EMU, there is a for the aims of practical work to focus on the development of high order cognitive skills and manipulative skills. In this way students can consolidate attitudes and values and the spirit of collaborative work as well as employ creativity in performing their own investigations. On the other hand, they caution that this will only happen if the institutions that offer laboratory-oriented courses assume the responsibility in minimising the financial restrictions on doing science practical work. After all, practical work activities are important in conducting real science.

In conclusion, the results of the LEQ indicated clearly that the lecturers shared a common understanding about the current practices taking place during laboratory classes in the cell biology course. The lecturers referred to a number of constraints (including financial restrictions, classroom size, inadequate laboratory equipment and lack of chemicals, among other constraints) as being responsible for their infrequent use of a certain kinds of practical work. They considered these factors as having a negative impact on the accomplishment of the laboratory activities with more emphasis on fieldwork. The frequent use of different kinds of practical work was regarded as being influenced by the subject orientation in terms of its content and time allocated for completion of laboratory activities. However, the lecturers' views about the aims of practical work were somehow incongruent with what has been frequently mentioned in the literature (for example, Kerr, 1963; Swain *et al*., 1999). In this regard, to highlight is the little use of the problem-solving or discovery experiments and investigations project-problems work by the lecturers contributing to lecturers not seeing the importance of practical work to develop positive attitudes towards science. It is assumed that promoting a culture of educational research at the Biological Science Department would help to clarify the objectives of practical work in the promotion of students' understanding of science as well as investigative skills.

4.6 Summary

This section summarizes the data discussed in this chapter in the perspective of the framework and context underpinning this study. As indicated by several authors in conducting a case study it is pertinent to take into account the context in which a particular case or phenomenon being studied is taking place (Patton, 1990; Wiersma, 2000; Cohen *et al*., 2000; Neuman, 2003). The authors regard the context as being a powerful determinant of both causes and effects by providing in-depth investigations. In this study, the context was characterized by the following factors: the way lecturers plan or design laboratory activities, the way Headmaster or course coordinator support lecturer and/or provide laboratory materials and facilities, the way students interact with lecturer to construct their knowledge, the way informal environment, national priorities, student background, and social economic status and so on influenced the current practices of practical work at EMU.

Bearing in mind the current situation of practical work at EMU one could assume that the results of this study were, to some extent, influenced by the socio-cultural context within the process of teaching and learning cell biology course took place at EMU. As indicated in the literature, the making-sense process results from the social interactions that occur within a socio-cultural context. It is in this process that the learner has the opportunity to actively construct their own knowledge using their existing knowledge to make sense of their new experiences (Hewson, 1993; Taber, 2001).

Overall, the results of the Cell Biology Test at the stage of pre-and post-test and interviews showed that the cell biology practical work shifted in a positive direction the students' conceptual level of understanding of the cell division concepts on the four themes (see sections 4.2 and 4.3). However, the students continued to show poor knowledge concerning the basic concepts needed to understand the whole process of mitosis and meiosis divisions after instruction through laboratory. Most of the students' difficulties were similar in nature with those reported in the literature review. The typical difficulties encountered by the students were related to the chromosome structure, chromosome number, events in prophase I of meiosis, distinction between mitosis and meiosis processes (Kindfield, 1991; Kindfield, 1994; Lewis & Wood-Robinson, 2000; Chinnici, *et al*., 2004). Several factors might have caused this cognitive dissonance among the students. According to the results reported in this study, the background of the students attending the cell biology course was heterogeneous in terms of their knowledge and skills. These students were drawn from several secondary schools across the country some of them without any conditions to conduct laboratory sessions. Other factors that might have negatively influenced the results of this study were associated to: (i) time allocated for the laboratory sessions (2 hours per week); (ii) number of the students in the laboratory; (iii) lack of well maintained laboratory equipment and materials; (iii) lack of basic knowledge and skills to operate a light microscope to make accurate observation of the specimens; use of a cookbook practicals and so on.

In relation to these factors that affected the students' understanding of the basic cell division concepts, the literature suggests that, in fact, the way practical is mostly conducted in many schools is confused and unproductive. This results in little understanding of what goes on the laboratory classes and consequently, contributing little to the students' learning or understanding of science in a meaningful way (Cossa, 2002; Bekalo & Welford, 1999; Hodson, 1990; Kapenda, Marenga-Kandejeo, Kasanda, & Lubben.; 2001; Lazarowitz & Tamir, 1994; Tamir, 1991; Watson, 2000). Yet, in this regard, a criticism is done concerning the way lecturers plan or design, conduct and test laboratory activities. For instance, the use of cookbook practicals to perform laboratory experiments and activities is criticized for not providing the students with opportunities to plan investigations and perform their own experiments so that they can construct their own knowledge of the scientific phenomena (Hodson, 1996; Domin, 1999; Shiland, 1999). On the other hand, the instruments used to assess laboratory activities (e.g.: written laboratory reports and paper-and-pencil tests) are considered as being inadequate as it fails to assess students' skills to manipulate equipment, perform observations and plan and perform investigations (Johnstone & Wham 1982; Solomon, 1988, Cossa, 1998).

In order to reverse this situation, several authors (e.g.: Sanders, 1988; Tobin, 1990; gunstone, 1991, Calloids, *et al*., 1997) defends a use of a learning experience in which the consideration of prior theories and the exploration of the existing ideas can contribute for the effectiveness of practical work. There is also a need to equip the learners with adequate theoretical understanding, that is, real understanding of ideas, and the development of physical manipulative skills. Only in that way the learner will be able to make appropriate observations and practical work can contribute to promote meaningful learning (Hodson and Reid, 1988). For instance, the data yielded through classroom observation suggested that the nature of the background of most students and the lack of knowledge and skills to operate a light microscope correctly might have influenced negatively the students' understanding of the basic concepts needed to learn cell division processes in a meaningful way. In this regards, as suggested by the literature, in planning and designing practical activities it is important to start first from where the learners are. Important here, is to provide them with more opportunities to carry out their own experiences in the laboratory so that their can construct their own knowledge enhancing in this way their investigative experiences (Tsaparsilis & Gorezi, 2005). In this study, it is assumed that the use of a constructivist approach in teaching laboratory activities can help the teacher in designing laboratory activities, and hence increase learning. As suggested by the literature, constructivism can contribute to promote the acquisition of process skills and the understanding of science itself (Shiland, 1999).

This study demonstrates also that the way lecturers viewed the role of practical work might have negatively influenced the teaching and learning process of cell biology course. For instance, they showed inconsistencies regarding the relationship between the types and aims of practical work. Contrary to the students, lecturers regarded practical work as not contributing to development of positive attitudes towards science. Accordingly, the literature indicates that this problem can be associated to the fact that in many science schools, teachers lack as a whole the perception that laboratory activities can be the main vehicle in enabling students to achieve science knowledge in a meaningful way by engaging them in laboratory activities that promote the development of scientific concepts (Hofstein & Lunetta, 2003). In addition, the way practical work is conceptualized and recognized by the teacher educators attached to the lack of the necessary practical skills to organize, carry out and evaluate investigative science activities by the tutors themselves contribute to teachers not seeing practical work as an important tool to teach science at schools even when the laboratory conditions and resources are available (Hodson, 1998; Bekalo & Welford, 1999). This kind of teaching approach is regarded as not contributing to students construct their own meaning of the scientific concept in a meaningful way because it fails to engage them in the thinking that precedes an experimental investigation (Hodson, 1998)

Despite that, the results of this study revealed that lecturers showed awareness of the need to focus the aims of practical work so as to ensure the development of high order cognitive skills and manipulative skills, particularly the use of the light microscope to accurately make observations and descriptions of the specimens. They believed that this would help students to consolidate their attitudes and values, and spirit of collaborative work as well creativity in performing their own investigations making the process of teaching and learning cell biology become more meaningful at EMU. The next chapter presents and discusses the main findings, draws conclusions, presents limitations and suggests recommendations for teaching and further research.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study was based on the premise that practical work does contribute to students' understanding of cell biology. It was hoped that findings from the study would provide useful insight to attempts directed at teaching and learning of cell biology at the university level. This chapter summarises the main findings of the study. The study attempted to explore the nature of practical work in cell biology and the type of lecturer-student-material interactions that occurred in the laboratory. Further it examined whether or not students' poor conceptions of mitotic and meiotic cell divisions was related to the method and content of teaching and learning cell biology at the Eduardo Mondlane University, Mozambique.

In pursuance of the aim above lecturers and students involved practical cell biology were observed and interviewed. The purpose was to: (1) ascertain the laboratory environment in terms of the quality of instruction, behaviour of the lecturers and students in the laboratory; (2) listen to the voices of participants in the laboratory and then to pull their views together in a way that could inform practice.

Based on the observations and the interviews the conclusions presented in the next sections were reached.

5.2 Summary of the main findings of the study

The main findings are summarized in the light of the four research questions elaborated for this study. The summary is presented separately according to the sequence of the research questions.

5.2.1 What are the students' conceptions of cell division before and after undertaking practical work in cell biology?

Overall, the results of this study indicate that there was a noticeable shift in the students' conceptual understanding of cell division from the pre-test (Mean 19.00, SD = 5.93) to the post-test (Mean 26.73, SD = 5.44; t-value = 30.12; $p<.05$). These results suggest that the cell biology practical work must probably enhanced the students' conceptions of cell division, the mean gain at the post-test being 7.73. Cohens' D-value of 1.303 was obtained which indicates a large practical effect between the pre-and post-test scores.

The results of this study show that, in general, most students improved their level of understanding of cell biology as shown in Sections A to D below. The level of understanding was determined in terms of three categories: (1) poor 'no answer or lack of basic understanding'; (2) fair 'distorted answer or partial understanding'; (3) good 'correct answer or hold basic understanding'.

A: Processes in the cell cycle

A high percentage (70%) of the students demonstrated increased understanding of the processes in the cell cycle after instruction through practical work compared to 46%

before the instruction. The majority of the students improved their understanding by 24% from a fair to a good level of understanding of the processes in the cell cycle. Although most of the students gained awareness of the scientific concepts (content knowledge) about processes and events occurring during the cell cycle, some of them continued to experience difficulties in applying the knowledge gained through laboratory instruction consistently to correctly differentiate the structure of the chromosomes or to read and interpret cell division graphs. This finding is consistent with evidence from other research studies namely, that students lacked the ability to integrate their knowledge of cell structures with their understanding of corresponding function and chromosome structure (Driver *et al*., 1994; Kindfield, 1994). For instance, Lewis & Wood-Robinson (2000) found that poor understanding of the processes by which genetic information is transferred or is replicated in living organisms is connected to the lack of the basic knowledge about the structures involved (e.g. gene, chromosome, cell). This causes students to confuse the DNA quantity (replicated and unreplicated) with the events involved in cell division.

B: Characteristics and events of mitosis

In this theme it was found that 88% of students showed a good understanding of the characteristics and events of mitosis after instruction through practical work compared to 78% before instruction, that is, an increase of 10%. As in the first theme, most of the students who improved their understanding of the former moved from a fair to good level of understanding. This suggests that cell biology practical work enhanced the students' understanding of characteristics of mitosis and associated events. Despite this, it is important to mention that those students who remained in the poor or fair levels of understanding might have experienced difficulties in understanding the structure of the chromosomes and its corresponding functions to correctly identify the names of the mitotic phases. This finding is consistent with those indicated in the literature in terms of the type of the difficulties demonstrated by the students (e.g. Chinnici, *et al*., 2004; Kindfield, 1991). These authors found in their studies that the misconceptions demonstrated by the students were associated to their inability to differentiate: (1) chromatids from chromosomes; (2) replicated chromosomes with unreplicated chromosomes; (3) chromosome structure with chromosome number. In view of this and considering the complexity of teaching cell division topic it is assumed that the use of different types of teaching aids such as photographs of chromosomes at different stages of division, film and video, simulations, role-play methods as well as build chromosome models can be a remedy for reducing the difficulties in learning cell division. It is assumed that group activities such as role-playing mitosis and meiosis can make concepts more memorable and understandable for students and consequently enhance their understanding of cell division (Chinnici, *et al*., 2004, Stavroulakis, 2005).

C: Characteristics and events of meiosis

In general, the findings on this theme reveal that a considerable percentage of the students shifted from a fair to good level of understanding after instruction through practical work. Before the practical work, 55% of the students demonstrated a good understanding of the theme compared to 75% after instruction, that is, an increase of 20%. As in other themes, these findings suggest that practical work in cell biology enhanced the students' understanding of characteristics of meiosis and associated events. However, there is evidence that students did not consistently apply their knowledge about the basic characteristics of meiosis in order to correctly name its phases and describe the events in prophase I even after instruction through practical work. For instance, 10% and 22% of the students scored at the poor and fair level respectively with respect to phases in meiosis while 35% scored at the fair level relative prophase I even after the instruction through practical work. Linking these findings with the literature, it can been shown that the first part of meiotic division, especially chromosome movement during the prophase phase has usually been the hardest part of meiotic division to explain to students (Kindfield; 1994; Yip; 1998; Öztas *et al*., 2003). For instance, the most salient difficulties seemed to be coupled with the poorly developed understanding of chromosome structure and the specific events that occur during meiosis such as crossing-over that is, what has been called "event-specific process misunderstanding", the importance of the order and timing of events or the so called "whole-process misunderstanding" (Kindfield, 1994). Öztas *et al*. (2003) associate this problem with the way this subject matter is taught during the teachers' higher education. There is a general belief that topics such as cell division and the DNA-chromosome relationship are not well-taught to prospective teachers and consequently, their poor understanding of such topics are reflected in their subsequent teaching. In this regard, a review of the teaching methodology of topics such as cell division at higher education level warrants closer attention in order to provide prospective teachers with adequate level of knowledge.

D: Differences between mitosis and meiosis

According to the results on this theme, nearly two-thirds of the students (65%) at the post-test showed a good level of understanding of the basic differences between mitosis and meiosis compared to 50% at the pre-test. However, a rather small percentage (16%) of the students shifted their level of understanding from poor to fair and to a good level of understanding regarding the types of cells in metaphase and anaphase I. For instance, 42% of the students scored at a fair level of understanding. This shows that a considerable percentage of the students encountered difficulties in identifying the types of cell division and its phases as well as interpreting and representing drawings of cells division even after instruction through practical work. Evidence from some studies show a similar trend. Kindfield (1991) and Kindfield (1994) studying the models of mitosis and meiosis found that the kind of difficulties experienced by the students were not peculiar to novices alone. It was also a challenge for experts. These difficulties might be linked to the fact that the experts regard the processes of mitosis and meiosis at an intuitive level not in terms of its complexity. This suggests that in teaching the cell division topic it is crucial to address the levels of complexity as scientific concepts have different levels of understanding and cannot be dealt with the same way (Flores *et al.*, 2003). Another important factor to consider is the lack of clarity in the terminology used in most textbooks and by the instructors themselves. For example, often the word chromosome is used to mean chromatids or chromatin. Also the status of the chromosomes is poorly associated with haploid or diploid chromosomal number. This implies the development of instruction that clearly defines the origin and differences underlying these concepts right at begin of cell division topic. It is assumed that, by doing so, students will be able to verbalize their conceptions about chromosomes and to represent chromosomes in drawings (Kindfield, 1991).

The answer to research question 1 was expanded through the post-laboratory and post-course interviews. The interviews were used to complement the students' responses obtained through the pre-and post-tests. Likewise the interviews attempted to go deeper in determining the extent to which practical work contributed to students' understanding of the basic concepts of mitosis and meiosis. The qualitative data yielded through the interviews were considered under the following categories: (i) function of mitosis; (ii) identification and description of mitotic phases; (iii) function of meiosis; and (iv) identification and description of meiotic phases.

The six students involved in the interview indicated that the laboratory instruction brought changes in their conceptual understanding of the basic concepts of mitotic and meiotic cell division. Despite this, the findings of the interviews reveal that even after the instruction through practical work, some of the students continued to experience difficulties in the area of: cell division concepts; meaning of haploid and diploid chromosomal number; structure of the chromosomes in order to correctly differentiate, identify and describe mitotic and meiotic events as well as representing and interpreting drawings and pictures about mitotic and meiotic events. Some of the reasons and evidence for students continued difficulties in understanding these concepts even after the instruction through practical work and tutorials are outlined under the next research question.

5.2.2 How do the laboratory activities enhance the students' understanding of cell division?

To answer this question the data were collected during classroom participant observation. This data set provided valuable information about the teaching and learning practices during the laboratory sessions on cell division. However, practical difficulties such as using the light microscope hampered the clarity of what the students actually observed and consequently their understanding of cell division as a whole. In analysing the qualitative data gleaned from observations in form of field notes the following results emerged:

1. Most of the difficulties encountered by the students during practical work were linked to the poor knowledge and skills to operate the light microscope correctly in making accurate observations and descriptions of the microscope slides on mitosis and meiosis. As mentioned in Chapter 3, most of the students came from disadvantaged backgrounds. Hence they studied biology without practical work and consequently lacked basic knowledge and skills. Some of these students saw and operated a light microscope for the first time during university practicals. This must have contributed to their poor understanding of cell division during the laboratory sessions. To grasp this basic knowledge and skill the students had to familiarize

themselves with the operation of the light microscope – this would have been taken for granted in well-resourced schools.

2. Due to the nature of the difficulties showed by the students, a lecturer-centred approach was predominant during the first part of all laboratory sessions. The lecturer used this approach frequently to explain and demonstrate the activities to be performed. For example, he spent a considerable time explaining and demonstrating on the blackboard the steps needed to observe the microscope slides and which parts of the onion apex and pollen mother cells were to be observed. He had to explain repeatedly by demonstrating what cells look like in different stages of mitosis and meiosis using different objective lenses.

3. In most cases, students did not even know what they were supposed to observe. In doing so, they could not transfer what they observed in the microscope field [which is what you observe when looking into the microscope] to a drawing. The number of the students (20-25) in the laboratory was high and the lecturer was unable to attend to all individual students' needs. Students indicated that the time allocated to observe the microscope slides and make drawings was not enough.

4. Most of the students were unable to identify some of the phases of the mitosis and meiosis due the status of the microscopes in use in the laboratory; for example, the higher magnification objective lens was not working in some of the microscopes. Two or more students were required to share the same microscope.

5. Despite the above constraints, during the execution of the laboratory activities, students were given the chance in pairs or groups of three to four to discuss and

compare their views about their observations. In such instances the lecturer appeared to have moved to a learner-centred approach by providing students with sufficient time and opportunities for interaction and reflection. In other words, such activities allowed the students to share meanings and to support each other to gain a fuller understanding of a given concept in mitosis or meiosis. This approach accords with the social constructivist instructional framework in that it encourages students to learn from each other and to express their views without being intimidated as is often the case in a lecturer dominated instructional setting. When students freely interact with lecturers and their peers they tend to gain confidence, they develop conceptually and also develop attitudes and values which they ultimately need to work within a community of practice (Hewson, 1993; Hodson, 1996; Saunders, 1992; Taber, 2001; Tsaparlis & Gorezi, 2005).

6. As a participant observer, I took the chance to interact with some groups of students during the laboratory sessions. I asked the students to explain what they were doing. In such conversations they seemed to possess a good understanding of cell division. However, they were shy to admit the fact it was their first experience observing various phases of mitosis and meiosis under the microscope. However, drawing accurately what they observed under the microscope was a big challenge for them. Again visual skills and methods required for such a task do not arise in a vacuum. They arise out of practice, that is, through direct experience with the learning materials (Calloids *et al*., 1997; Hodson & Reid, 1988; Millar *et al*., 1999, Tamir *et al*., 1992).

7. I asked the lecturer to express his opinion concerning the kinds of activities carried out during the laboratory sessions on mitosis and meiosis. He recognized that, in fact, practical work helped the students to improve their level of understanding.

However, he complained that most of the students lacked good backgrounds to use the microscope correctly in order to make accurate observations and descriptions of the specimens. Hence, most of the time was spent teaching them the steps needed to operate a light microscope in a logical sequence. As mentioned earlier, the students' backgrounds are varied. In so doing, it would be more practical to first provide the students with sufficient time and opportunities to familiarize themselves with the laboratory equipment in particular, the light microscope. This will force the students to take charge of their own learning and to learn how to operate the light microscope correctly to accurately observe the specimens.

5.2.3 What are the students' perceptions of the role of practical work in the learning of cell biology?

To answer this question, the students' perceptions were examined under three categories relating to the aims of practical work: (i) acquisition of knowledge and intellectual skills; (ii) acquisition and development of procedural knowledge and investigation skills and; (iii) acquisition of positive attitudes towards practical work. Overall, the results of this study indicated that the students' opinions regarding the role of practical work were highly consistent. They shared a common understanding that practical work in cell biology helped to promote their levels of learning in terms of acquiring and developing conceptual knowledge and intellectual skills, procedural knowledge and investigations skills, as well as acquiring positive attitudes towards practical work.

Furthermore, the results of the interviews in this regard, indicate that the cell biology practicals contributed significantly to students' ability to manipulate laboratory equipment (e.g. light microscopes). It also enhanced their observational skills and consequently their ability to explain mitotic and meiotic events by linking theory and practice. The implications of these findings are that in organizing practical work sessions it is important to provide students with opportunities to acquire direct experiences which in turn will foster their sense of success, motivation and control in learning science (Tamir *et al*., 1992; Dekkers, 1997; Guzman, 2000). Likewise, this will serve as a means to increase their interest, curiosity as well as their confidence in learning cell biology. In general, the findings of this research question are consistent with what is reported in the literature (Hofstein & Lunetta, 1982; Kaptein, 1987; van den Berg & Giddings, 1992; Hodson, 1993; Parkinson, 1994: Griffin, 1998), in terms of the functions of practical work in the teaching and learning science.

5.2.4 What are the lecturers' practical work teaching experiences and views about the cell biology practical work?

To answer this question data were collected using a Lecturer Experience Questionnaire. The results obtained through this questionnaire suggest that the lecturers shared a common understanding about the current practices taking place during laboratory classes in cell biology courses. The lecturers referred to a great extent to constraints such as financial restrictions, classroom size, inadequate laboratory equipment and lack of chemicals among other constraints (Hodson, 1992; Tamir & Lazarowitz; 1994, Lunetta, 1998; Kapenda et *al*., 2001). They considered these factors as having a negative impact on the accomplishment of the laboratory activities especially fieldwork.

Furthermore, the findings of this study indicate that the lecturers regarded the frequent use of any kind of practical work as being influenced by the subject orientation in terms of its content and time allocated for the completion of laboratory activities. The lecturers perceived the importance of the aims of practical work in cell biology differently from the way it has been constructed in other studies (e.g., Swain *et al*., 1999; Ghebremariam, 2000; Fessehation, 2003). For instance, the five aims rated by these lecturers showed two components: content and investigation whereas the aims indicated by the Korean teachers were more content focused. For the UK science teachers the emphasis was on investigation (Swain *et al*., 1990). Furthermore, the lecturers involved in this study used less problem-solving or discovery experiments and investigations or project work. It seemed that these lecturers did not appreciate the importance of practical work in the development of positive attitudes towards the subject. The implications of this, according to the lecturers, is that the aims of practical work should concentrate on the development of high-order cognitive and manipulative skills so that the students can acquire attitudes and values and the spirit of collaborative work as well creativity in performing their own investigations. They contend that only in this way could the teaching and learning of cell biology become more authentic and useful. In view of this statement, developing high-order practical activities would imply the use of the more 'sophisticated' practical work and consequently the use of different types of practical work or methods (open-ended practicals, projects, skill training practicals, inductive and deductive approaches) to replace the 'cookbook practicals' traditionally used at EMU. Several authors have regarded the use of a 'cookbook practicals' as encouraging rote learning rather than inquiry oriented learning promoting in this way the development of low-order cognitive and manipulative skills (for example, Domin, 1999; Hodson, 1996; Shiland, 1999).

5.3 Conclusions

The main findings reported in this study have provided important information concerning the role of practical work in the teaching and learning cell biology at the EMU. Specifically, these findings have provided insight into the contribution of the cell biology practical work in enhancing students' understanding of concepts in mitotic and meiotic aspects of cell division. Furthermore, the findings have provided useful insight into the students' perceptions of the role of practical work in improving the acquisition of the specific process skills as well as the development of positive attitudes towards science. Additionally, the findings have increased our awareness of the importance placed on the role of cell biology practical work.

The findings obtained from the tests and interviews have shown that the students' level of understanding cell division concepts improved significantly after laboratory instruction. However, despite this, the findings indicate that some students continued to experience difficulties, particularly in some of the basic concepts (e.g.: DNA replication, chromosomal number (haploid and diploid), chromosome structure and movement of chromosomes) considered as important for the understanding of cell division mechanisms.

The findings of the classroom observations seemed to indicate that the activities carried out during the laboratory sessions on mitosis and meiosis enhanced the students' understanding of cell division. However, due the nature of the backgrounds of most the students attending the cell biology course one cannot assume these results as conclusive. It seems that the lack of knowledge and skills displayed by most of the students in using the light microscope correctly in order to make accurate observations and descriptions of the specimens negatively influenced the envisaged aims of practical work on cell division.

Regarding the students' perceptions of the role of practical work in the learning of cell biology, the findings revealed that most of the students shared a common understanding that practical work in cell biology helped to improve their level of learning in terms of: (1) acquiring and developing conceptual knowledge and intellectual skills; (2) developing procedural knowledge and investigations skills; (3) positively changing their attitudes towards practical work; (4) using laboratory equipment; and (5) developing the ability to observe, understand as well as link theory to practice.

The findings have revealed a common understanding among the lecturers of cell biology course. They seemed to be convinced of the benefits of a constructivist instructional approach whereby students have ample opportunities to interact with one another and the learning materials. Furthermore, the lecturers seem to appreciate the need to determine the students' backgrounds before introducing them to new learning materials or equipment. They became more aware of the inadequacy of the laboratory materials critically required to perform practical work in cell biology. Despite this, increased awareness among the lecturers about the unsatisfactory conditions in the laboratory they did not seem to fully grasp the importance of problem-solving activities, open inquiry or project work in the development of critical scientific attitudes and values. For instance, the lecturers' responses to the questionnaire indicated that 91% of the lecturers used this kind of practical work to a lesser extent in favour of experiments performed by the students. The lecturer also illustrated or reinforced concepts and theories taught in tutorials during practical sessions.

5.4 Limitations of the study

Although this study has provided insight into the contribution of the cell biology practical work in ameliorating students' levels of understanding of cell division, some limitations were encountered that may have influenced the results of this study.

Translation of English versions of instruments to Portuguese

The language was a major problem faced in this study. As a Portuguese speaker, it was difficulty to express myself fluently in English. Thus, a considerable amount of time was used in developing and translating the instruments from English to Portuguese or vice-versa to meet the requirements of the study conducted in Portuguese while the thesis is translated into English for my supervisors. Navigating back and forth between the two languages was costly in terms of time and energy on my part. In the final analysis, the onus was on me to make the most of the situation. How well I managed the tension caused by the need to transverse this epistemological chasm is a matter warranting a detailed analysis beyond the scope of this thesis. Despite my deficiency in the English language, I made a concerted effort to present the thesis as clearly as possible.

Sample of the study

This study comprised only a sample of one first-year biology class. This sample is small and extending the sample would have given more reliable results. Therefore, it was difficult to state to what extent the findings of this study would be generalizable. In this regard, the major concern will be for the reader to determine to what extent the findings of this study are applicable to their particular situation (Guba & Lincoln, 1993). In fact, the aim of the study was not to generalize but to provide data and an analysis thereof which other investigations in the area might find useful and applicable to their own particular setting.

Period of the study

The study was restricted to only the first semester (February to June 2005) of the biology course at EMU. This was because the cell biology course runs within that period and plans to extend the period of the study would have implied selecting other biology courses with laboratory components. Another limitation linked to the period of the study was the frequency of the cell biology laboratory sessions that were run once per week for two hours per session. In view of the sample of the sample of this study it was not possible during the laboratory sessions to gather richer information and evidence to show if laboratory activities enhanced the students' understanding of the cell division concepts. More time would be needed to collect richer data through classroom observations.

Design of the study

My initial plan was to conduct this study in secondary schools (pre-university level). However, as it was indicated in Chapter 3 most of the secondary schools in Mozambique did not and still do not offer practical work at all for the natural science subjects. Conducting this study at secondary schools would have allowed me to increase the sample as well carrying on a comparative study instead of using a pre-experimental design.

5.5 Recommendations

This study has provided some insights into the need to provide students with more opportunities to carry on laboratory activities as a means to help them develop valid understanding the cell biology. Thus, the recommendations below are given in the light of the findings and context of this study.

5.5.1 Recommendations at the pedagogical level

1. Students should be given more opportunities to carry on laboratory activities as means to improve their conceptual understanding of the cell division concepts in practical work can help them link theory with practice.

2. Students enter the university courses with different experiences and knowledge bases. As such new teaching approaches need to be developed so that students can be provided with more opportunities to construct their knowledge through practical work. In view of the findings of this study a constructivist instructional approach which facilitates student-student interactions followed by reflection on the part of each student is highly recommended.

3. The concept of cell division concepts is considered difficult topic for both teachers and students at all educational levels. Therefore, there is a need to adapt mechanisms to review the teaching methodology of the concept of cell division at higher education in order to provide teachers with adequate level of knowledge for their

subsequent teaching. Bearing in mind the prevalent unsatisfactory instructional environment in Mozambican classrooms, I would recommend the development of professional development programmes for secondary and university staff so that they can discuss strategies on how to approach the concept of cell division as well as update their content and pedagogical knowledge in the same area.

4. Most of the difficulties experienced by the students during practical work on mitosis and meiosis were linked to the poor knowledge and skills to operate the light microscope correctly so as to make accurate observations and descriptions of the microscope slides on mitosis and meiosis. Therefore, I would recommend that students should be given sufficient time and opportunities to learn how to operate the light microscope correctly before staring with practical work on mitosis and meiosis.

5. The university should adapt a policy of expanding the time allocated for practical work taking into account the levels of preparedness of the students attending the cell biology course as well the number of the students in the laboratory. This will allow the lecturer to attend to all individual students' needs.

6. Practical work sessions should be organized in such a way that they can provide students with opportunities to acquire direct experiences and for students to foster a sense of success, motivation and control in learning science. This will allow them to increase their interest, curiosity as well as their confidence in learning cell biology concepts.

7. The Ministry of Education and other stakeholders should adopt a policy to provide schools and universities with financial and material resources needed to conduct

laboratory activities. Due to the shortage of funds, laboratory equipment and learning materials are in short supply. Consequently, lecturers tend to organize laboratory activities rather than sparingly or regard practical work as not being important to promote positive attitudes towards science.

5.5.3 Recommendations for further research

1. The results of this study have revealed that students need to be given sufficient time and opportunities to perform laboratory activities so that they can link theory with practice and hence increase their understanding of cell biology. The question that arises here is how to organize practical work that can in fact enhance the level of the students' understanding of cell biology concepts taking into account the context in which laboratory sessions are conducted in Mozambique. In this regard, it is suggested that more in depth research be carried out to explore the lecturers' views of the aims of practical work and how they relate these aims with different kinds of practical work in their respective science subjects at the university level. This kind of research is likely to make the curriculum developers based at the Ministry of Culture and Education, Ministry of Science and Technology and all the stakeholders to become aware of the importance of practical work in the acquisition of knowledge, development of process skills as well promotion of positive attitudes towards science.

2. In this study one of the prevalent issues that emerged is related to the poor knowledge and skills to operate the light microscope correctly obstructing to some extent the students' understanding of cell division. Bearing in mind the students' origin and their difficulties, the teaching approach itself stands in need of further

research in order to address the relevance of using laboratory to teach cell division at university. A further investigation to explore the applicability of other laboratory teaching approaches, for example, open-inquiry activities or problem-based learning or their combination with expository laboratory is recommended in that it would help students to development higher-order cognitive and manipulative skills and hence improve their conceptual framework in learning cell division.

3. The results of this study revealed also that most of the difficulties experienced by students even after laboratory instruction could be linked to the inability of students to distinguish between the basic concepts (e.g. replicated and unreplicated DNA; haploid and diploid chromosomal number; chromatids and chromosomes; synapsis and disjunction) important to understand cell division mechanisms. A possible investigation would be the exploration of the effectiveness of varied learning aids for mitosis and meiosis, for example: playing cards to simulate meiosis, role-playing mitosis and meiosis, hands-on exercises, videos etc. on students' understanding of cell division events.

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Appendix A: Cell Biology Test (CBT)

Special Instructions:

1. This test contains 8 pages with 17 main questions. Check that you have all pages and questions.

2. You have 90 minutes to finish the test.

3. Write all answers on the test paper.

4. Write your personnel information on this question paper.

Name: __________________ Province/School of origin: ___________________

Age: _________Gender: Female □ Male □ Year nr in the course: ___________

Question 1

Bellow statements about processes occurring during cell cycle are listed. Place an X against the alternative which you think is ***wrong***.

a) It consists of mitosis and interphase.

b) The cell's DNA replicates during G1.

c) A cell can remain in G1 for weeks or much longer.

d) Most proteins are formed throughout all the subphases of interfaphase.

e) Histones are synthentized primarily during the S phase.

Explain why you chose the answer you did.

Question 2

The figure bellow shows modifications in the form of the chromosome during cell division. Which phases of the cell cycle give the chromosomes represented in 1 and 2, respectively?

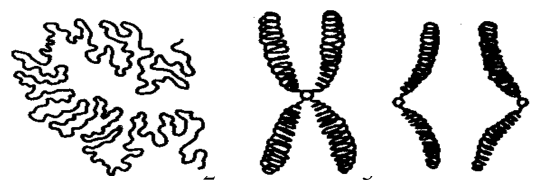
a) Interphase, metaphase.

b) Interphase, anaphase.

c) Interphase, telophase.

d) Prophase, anaphase.

e) Prophase, telophase.



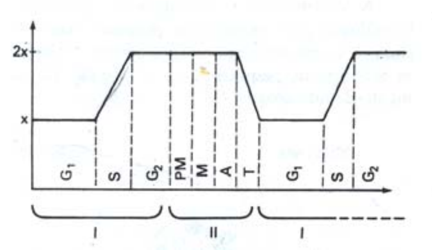
Cell cycle

Cell cycle

Explain why you chose the answer you did.

Question 3

Interpreting the graphic presented bellow, which of the following statements indicate the correct answer about the events that occur during cell cycle?



DNA quantity/nuclei

a) I indicate the interphase.

b) II indicates the mitosis.

c) I and II represent the meiosis.

d) I and II represent a cell cycle in a somatic cell.

e) II indicates the meiosis.

Explain why you chose the answers you did.

____

____

Question 4

Bellow is a picture of a plant meristem tissue showing different phases of mitosis division. Which of the following alternatives indicate the correct sequence of mitosis process?

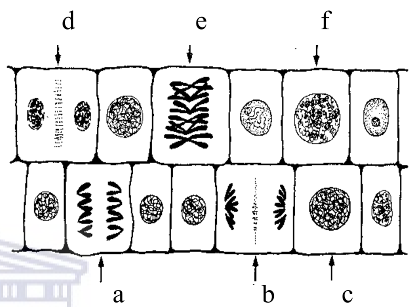
a) a→b→c→d→e→f

b) c→f →e→a→b→d

c) f→b →a→e→d→c

d) e→f →c→a→b→d

e) f→e →c→b→d→a



Question 5

Use the picture on **Question 4** to answers this question. Identify the name of each phase illustrated in the above picture.

a______________________

b______________________

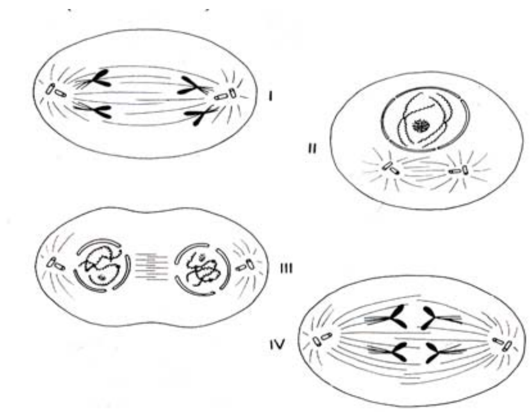
c______________________

d______________________

e______________________

f______________________

Question 6



The diagrams above represent phases of mitosis indicated by Roman numerals. Indicate, in the options bellow, the correct sequence of the phases of this type of cell division.

a) I, IV, III, II

b) IV, II, I, III

c) I, IV, II, III

d) II, IV, I, III

e) II, III, I, IV

Question 7

Match each stage of mitosis with the following key events.

_____Metaphase	a. Sister chromatids of each chromosome separate and move to opposite poles.
______Prophase	b. Threadlike chromosomes condense and a microtubule spindle forms
_____Telophase	c. Chromosomes decondensed, daughter nuclei re-form.
______Anaphase	d. All chromosomes become aligned at spindle equator.

Question 8

Which of the following statements are typically characteristic of meiosis?

a) A **2n** cell originates two cells also with **2n**.

b) A **2n** cell originates, through one division, four cell with **n** chromosomes and genetically distinct between them and from the original cell.

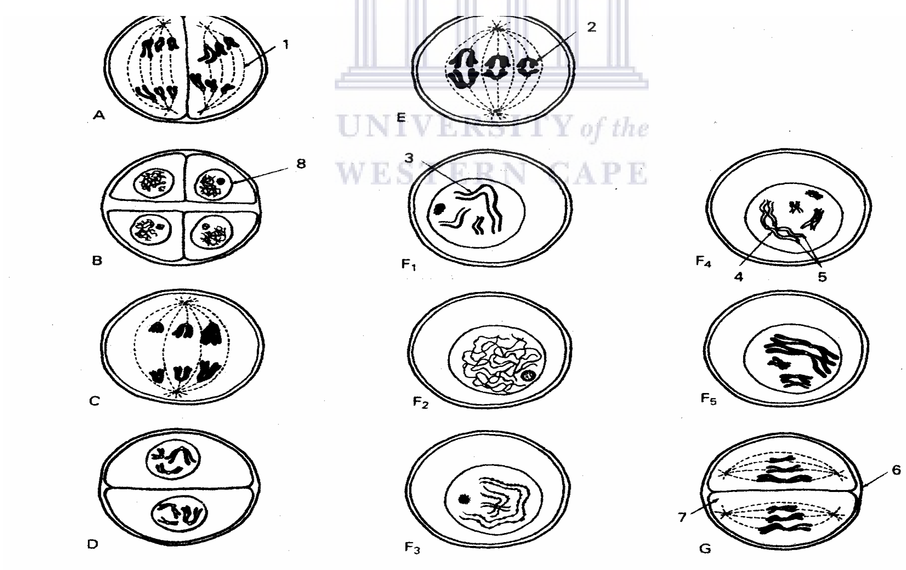
c) A **2n** cell, through two consecutive divisions, originates four haploid cells, genetically distinct between them and from the original cell.

d) A **2n** cell, through two consecutive cell divisions (reductional and equational), originates four haploid cells identical between them and from the original.

e) A **n** cell originates four haploid cells and identical between them and from original.

Question 9

The diagrams illustrated bellow, represent different phases of meiosis in a plant cell. Indicate, in the options bellow, the correct sequence of the phases of this type of cell division. Place **X** against the alternative which you think is correct.



a) $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow F_1 \rightarrow F_2 \rightarrow F_3 \rightarrow F_4 \rightarrow F_5 \rightarrow G$

b) $C \rightarrow G \rightarrow E \rightarrow A \rightarrow F_2 \rightarrow F_1 \rightarrow F_5 \rightarrow F_3 \rightarrow F_4 \rightarrow B \rightarrow D$

c) $F_2 \rightarrow F_3 \rightarrow F_4 \rightarrow F_1 \rightarrow F_5 \rightarrow E \rightarrow C \rightarrow A \rightarrow D \rightarrow G \rightarrow B$

d) $F_2 \rightarrow F_3 \rightarrow F_4 \rightarrow F_1 \rightarrow F_5 \rightarrow E \rightarrow C \rightarrow D \rightarrow G \rightarrow A \rightarrow B$

e) $F_2 \rightarrow F_4 \rightarrow F_3 \rightarrow F_5 \rightarrow F_1 \rightarrow A \rightarrow E \rightarrow B \rightarrow D \rightarrow C \rightarrow G$

Question 10

Use the diagrams on **Question 9** to answer this question.1 to identify the names of each phase illustrated in these diagrams.

A________________________

B________________________

C________________________

D________________________

E________________________

F_1________________________

F_2________________________

F_3________________________

F_4________________________

F_5________________________

G________________________

Question 11

Consider the following events of cell division:

I – Separation of the chromatids.

II – Paring of homologous chromosomes.

III – Exchange of the segments between chromatids.

IV – Division of the centromer.

In prophase I of meiosis occurs only:

a) I and II.

b) I and III.

c) I and IV.

d) II and III.

e) II and IV.

Question 12

In the following statements:

I. Through *crossing-over*, homologous chromatids exchange segments, originating new gene combinations.

II. Crossing-over occurs during the prophase of meiosis I.

III. At the end of interphase, in the metaphase and anaphase of mitosis, the chromosomes are, respectively, singles, duplicated, singles.

IV. Gametes with 14 chromosomes are formed from somatic cells with 28 chromosomes.

Indicate if:

a) All the statements are correct.

b) Statements I, II and III are correct.

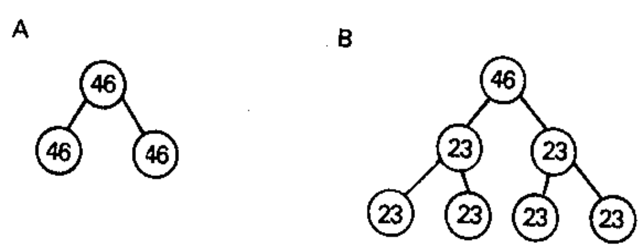
c) Statements I, III and IV are correct.

d) Statements I and II are correct.

e) Statements I, II and IV are correct.

Question 13

Mitosis and meiosis are cell divisions that occur in the cells of living organisms, each one with special characteristics. Relate the diagrams bellow with these processes and indicate which one occurs in the germ cells.



Explain why you chose the answer you did.

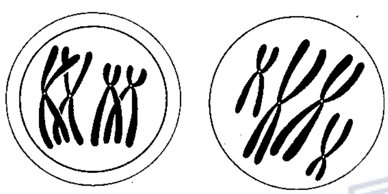
____

____

Question 14

The drawings bellow represent cells division in the same animal whose diploid number of the chromosome is 4 (2n = 4). Identify the type of division and the phase illustrated in each cell.

A B



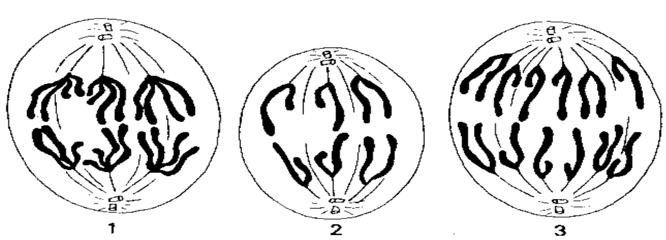
Type	Phase	Explain why?
Cell A		
Cell B		

Question 15

Consider that a diploid animal cell whose chromosomal number is equal to n = 3 is in division. Make two drawings showing the following phases:

a) A mitotic metaphase **b) An anaphase I of meiosis**

Question 16



These drawings above represent 3 cells in anaphase of cell division of an organism whose diploid chromosomal number is equal to 6 (2n = 6). Cells 1, 2 and 3 are, respectively, in:

a) Mitosis, meiosis I and meiosis II.

b) Meiosis I, meiosis II and mitosis.

c) Meiosis II, mitosis and meiosis II.

d) Meiosis I, mitosis and meiosis II.

e) Meiosis II, meiosis I and mitosis.

Explain why you chose the answer you did.

Question 17

The table bellow gives you the main differences between mitosis and meiosis. Combine the two events and place **X** against the alternative which you think is ***wrong***.

MITOSIS	**MEIOSIS**	**YOUR ANSWER (PLACE AN X)**
a) Forms two new diploid cells.	Forms four new haploid cells.	
b) There is a reduction of chromosome number.	No reduction of chromosome number.	
c) No exchange of the genetic information.	There is exchange of the genetic information.	
d) Occurs in somatic cells.	Occurs in germ cells.	
e) There is chromosome duplication for one cell division.	There is chromosome duplication for the two cell divisions.	

Appendix B: Calculations for internal-consistency for the post-test scores

Formula: $KR21 = 1 - \frac{0.8\bar{x}(k - \bar{x})}{ks^2}$

where: $\bar{x}$ = mean of the test score

k = number of items in the test

s^2 = variance of the score on the test

Calculus:

$$KR21 = 1 - \frac{0.8x26,73171(39 - 26,73171)}{39x29,6048}$$

$$KR21 = 1 - \frac{21,385368x12,26829}{1154,5872}$$

$$KR21 = 1 - \frac{262,36189638072}{1154,5872}$$

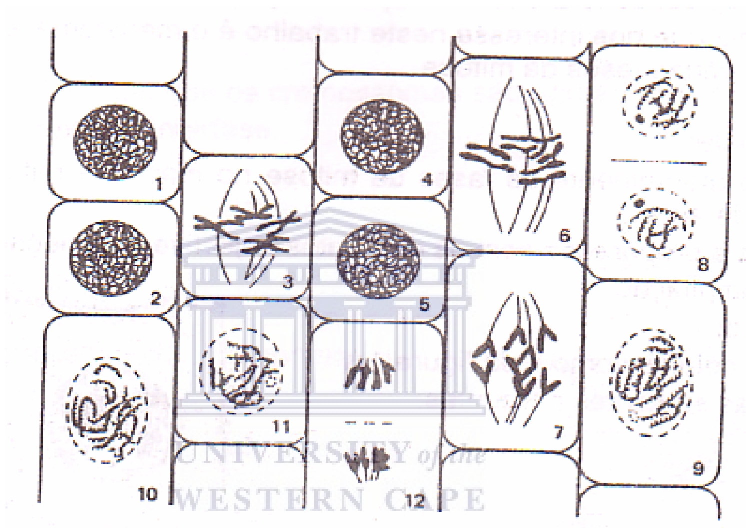
$$KR21 = 1 - 0,22723471194$$

$$KR21 = 0,78$$

Appendix C: Ficha de Trabalho Laboratorial em Mitose

Identificação da sequência de acontecimentos da mitose

A figura que se segue representa um corte longitudinal da região de crescimento de uma raíz. As células dessa região sofrem mitoses contínuas que garantem o crescimento desse orgão.



Baseando-se na figura, responda as seguintes questões:

1. Que células estão em divisão?
2. Que estruturas podem ser identificadas nessas células?
3. Que células estão no início da divisão?
4. Em que células a mitose está a terminar?
5. Que célula está em fase mais adiantada da divisão: a 3 ou a 6?
6. Que célula está em fase mais adiantada da divisão: a 6 ou a 7?
7. Que célula está em fase mais adiantada da divisão: a 7 ou a 12?
8. Das fases representadas na figura, qual sucede a fase da célula 12?

Observação microscópica das diferentes fases da mitose

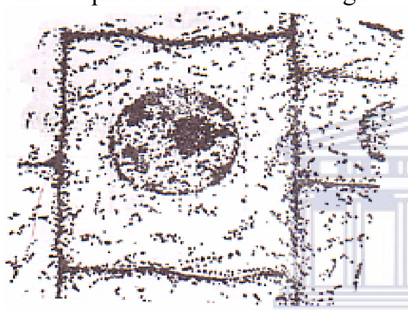
A coifa é um orgão constituido por células dispostas frouxamente que protege o meristema apical da raíz e facilita a penetração da raíz no solo.
A parte da raíz que nos interessa neste trabalho é o meristema, onde podemos encontrar as várias fases da mitose.

Procedimento

1. Observe atentamente as fases da mitose no mapa da mitose pendurado na sala de aulas.

2. Observe as preparações com as diferentes objectivas, começando com a de menor ampliação.

3. Interfase:
   Identifique células como a da figura abaixo e responda as seguintes perguntas:



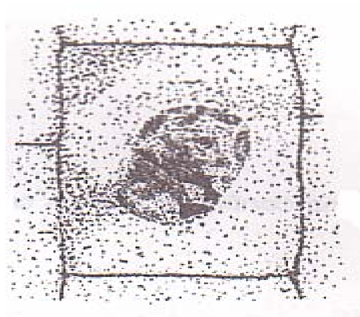
   a) Descreva o conteúdo do núcleo durante a interfase.

   b) É possível observar o nucléolo e a membrana nuclear?

   c) Os coromossomas são ou não observáveis com facilidade?

   d) Os cromossomas são ou não visíveis durante a interfase?

4. Prófase:
   Identifique células como a da figuraa abaixo e responda às seguintes perguntas:

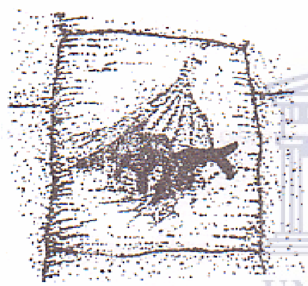


a) Os cromossomas são ou não visíveis durante a prófase?

b) Descreva as mudanças que o nucléolo e a membrana nuclear sofreram da interfase até a prófase.

c) Explique porquê é que os cromossomas são agora visíveis e não eram durante a interfase.

5. Metáfase:
Identifique células como a da figura abaixo e responda as seguintes perguntas:



a) Descreva a disposição dos cromossomas na célula.

b) Identifique o sítio através do qual os cromossomas se ligam às “fibras”.

c) Identifique o conjunto de “fibras” formadas durante esta fase.

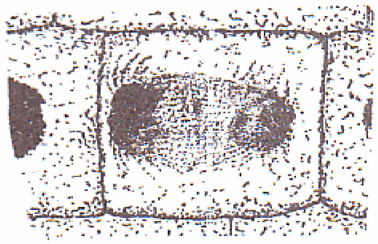
6. Anáfase:
Identifique células como a da figura abaixo e responda às seguintes perguntas:

a) Como confirmar que os cromossomas contêm a informação duplicada?

b) Qual é a estrutura responsável pelo movimento dos cromossomas?

7. Telófase:

Identifique células como as da figura abaixo e responda asseguintes perguntas:

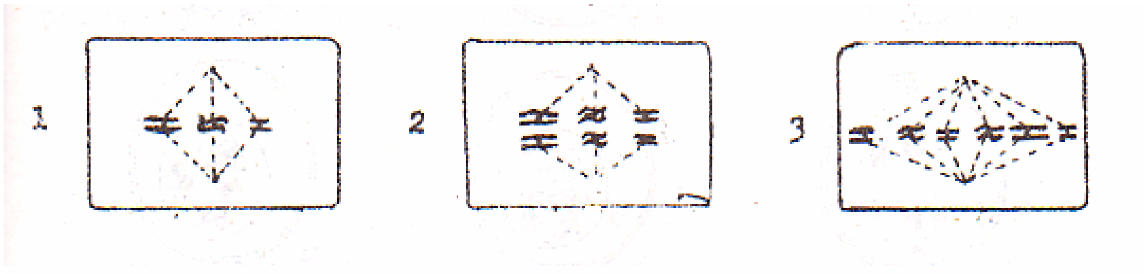


a) Quais são as estruturas celulares que surgiram de novo durante esta fase?

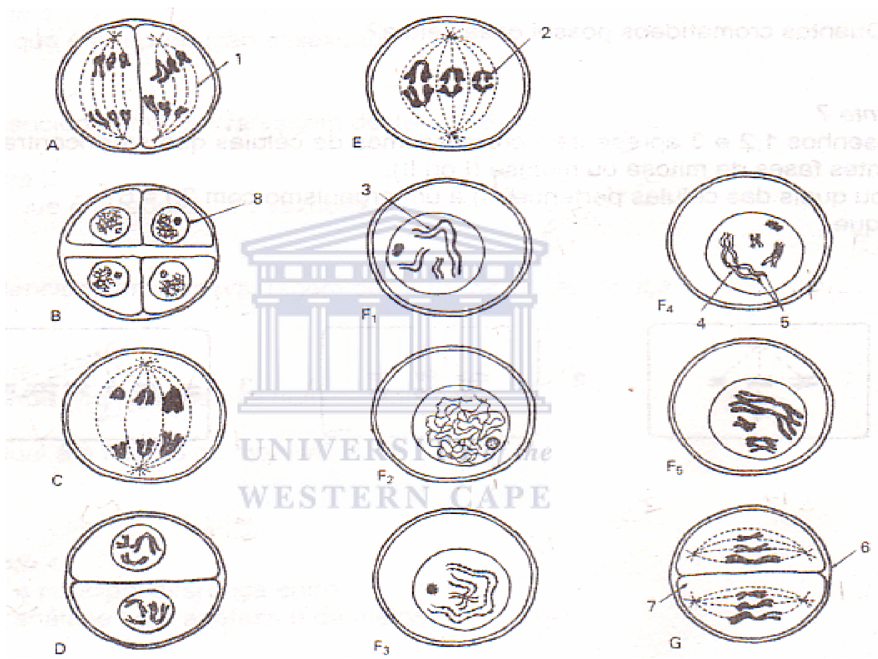
b) Desenhe nos rectângulos seguintes as diversas fases da mitose que observou ao microscópio.

Appendix D: Ficha de Trabalho Laboratorial em Meiose

1. O que é a reprodução a assexuada?
2. Mencione uma desvantagem deste tipo de reprodução.
3. O que é a reprodução sexuada?
4. Mencione uma desvantagem deste tipo de reprodução.
5. Onde ocorre a meiose num organismo?
6. Qual é a função da meiose?
7. Qual é a principal diferença entre a anáfase I e a anáfase II da meiose?
8. E entre a anáfase II da meiose e a anáfase da mitose?
9. O núcleo do espermatozóide do porco contém 20 cromossomas. Quantos cromossomas contém o núcleo duma célula do estômago do porco? Justifique.
10. Num organismo com 2n = 8, uma célula está em metáfase I. Quantos pares de cromossomas homólogos apresenta a célula?
11. Quantos cromatídeos possui essa célula?
12. Os desenhos 1, 2 e 3 apresentam cromossomas de células que se encontram em diferentes fases de mitose ou meiose (I ou II). Qual ou quais as células pertence(m) à um organismo com 2n = 6? Justifique.



13. Na figura embaixo estão representadas esquematicamente as diversas fases da meiose numa célula vegetal.



Analise atentamente a figura e responda a seguintes questões:

a) Identifique cada uma das fases representadas nos diagramas.

b) Começando com a letra (símbolo) que identifica o diagrama com o início da meiose, ordene as fases na sua sequência lógica.

c) Faça a legenda da figura (números 1 à 8).

d) Indique, justificando, em quais diagramas há evidências do fenômeno de recombinação.

e) Para cada um dos diagramas, qual é a quantidade (n, 2n, 3n,) de DNA.

Appendix E: Students' Perceptions Questionnaire (SPQ)

This questionnaire is intended to find your perceptions in relation to the role of practical work in the learning of cell Biology. You are kindly asked to fill in the questionnaire. Your opinion is important, as it will be helpful to improve the quality of teaching-learning process of Biology course.

SECTION A

Please write your personal details in the following item:
Name: ____________________School of origin: ____________________ Province: ____________
Age: ____________ Gender: Female □ Male □Years nº in the course: _________________________

SECTION B

Please provide your opinion about each of the following statements if you think practical work they do helps you learn cell biology. Use the following scoring rate key and tick (✓) the most appropriate response: strongly disagree (SDA) = 1; disagree (DA) = 2; don't know (DK) = 3; agree (A) = 4; strongly agree (SA) = 5.

Item	SDA	DA	DK	A	SA
1. Practical work helps in learning basic cell biology concepts.					
2. Practical work helps in learning cell biology events and facts.					
3. Practical work helps in understanding and accepting new scientific concepts about cell.					
4. Practical work in cell biology enables one to apply theory to practice.					
5. Practical work in cell biology helps make phenomena more real through experience.					
6. Practical work can help to clarify the principles and theories discussed in cell biology tutorials.					
7. Practical work helps in making cell biology abstract concepts to become real.					
8. Practical work helps verify facts and principles already taught in cell biology tutorials.					
9. Practical work can help in identifying common and different characteristics of cell structures and events.					
10. Practical work can help in learning experimental techniques used in cell biology.					
11. Practical work can help in learning how to use practical equipment and common measurement instruments.					
12. Practical work in cell biology helps to develop skills to plan and perform experiments in practical conditions.					
13. Practical work in cell biology can help in understanding scientific ideas.					
14. Practical work in cell biology can help in learning skills to record and organize data obtained from observations and experiments.					
15. Practical work in cell biology helps to develop skills to apply the results of observations and experiments in new situations.					
16. Practical work in cell biology helps present science as an investigative process.					
17. Practical work in cell biology can help in learning skills to analyse and interpret results of observations and experiments.					
18. Practical work in cell biology can encourage the positive attitudes towards biology.					
19. Practical work in cell biology can facilitate the development of logical reasoning.					
20. Practical work in cell biology can encourage the development of creativity.					
21. Practical work can encourage the development of skills to make accurate observations and descriptions to determine characteristics of cell structures and events.					
22. Practical enables to diagnose and dispel misconceptions about cell biology.					
23. Practical work helps arouse and maintain interest in biology subject.					
24. Practical work helps develop critical ways of thinking and analysis in problem-					

	solving.					
25.	Practical work can help to explain a relationship between cell structures.					

Please, answer the next question in writing.

26. What do you think should be done so that the practical work can contribute effectively to the teaching and learning of cell biology?

Appendix F: Lecturers' Experience Questionnaire (LEQ)

This questionnaire is intended to find your experiences in relation to the role of practical work in the teaching of biology course. Kindly fill in the questionnaire.

Your opinion is important, as it will be helpful to improve the quality of teaching-learning process of biology course.

Section A

Please write your personal details in the following item:

Subject (s) you teach: ____________________________________ Nr of the years teaching: _____

Age: ____________ Gender: Female □ Male □ Qualifications: BSc □ Honour □ MSc □ Dr □

Section B

This section asks you about some of the current practices taking place during laboratory classes in biology course.

How many periods per week are you required to teach Biology in a room provided with laboratory equipment, materials (chemicals, water, specimens, etc?)

2. Is your laboratory used as a form (class) room? Yes…..... No…….

3. What is the average size of your practical classes? Number of students……………….

Any other comments on the current practices taking place during laboratory classes in Biology course?
………
……

Section C

This section is about the kinds of Practical work in biology. Practical work in Biology courses refers to the laboratory activities that include demonstrations by lecturers, observations or manipulations of real objects and materials by students and fieldwork laboratory.

4. Place a tick (✓) in the Appropriate column to indicate 'frequency of use' of the following types of practical work using the key bellow:
1 = never used; 2 = rarely used; 3 = occasional used; 4 = used; 5 = frequently used

Kinds of practical work	**1**	**2**	**3**	**4**	**5**
1. Those demonstrations that verify facts and principles					
3. Experiments by students or lecturer to illustrate or reinforce concepts and theories taught in tutorials					
4. Practical work set primarily to familiarise students with the use of important instruments, equipment, and techniques					
5. Practical work to enable the teaching of procedures or skills training, and to teach skills in experimental design					
6. Practical work to motivate students developing positive attitudes to the subject					
7. Practical work to introduce students to the world of scientists					
8. Problem-solving or discovery experiments (by lecturer or student) designed to answers					

a question raised during a theoretical work					
9. Investigations projects-problems work out by student(s); not necessarily connected in direct way with theoretical course					

5. How often did your students see or do practical work of any kind in your biology subject this semester? Please tick only the one applicable (✓) frequency of use for the following items:

a) About once every lesson ( )
b) About once in two lessons ( )
c) About once a week ( )
d) Rarely ( )
e) Never ( )

Any other comments:
………
………
………..

6. How often did your students do fieldwork?

a) About once a week ( )
b) About once a month ( )
c) About once a semester ( )
d) About once a year ( )
e) Never ( )

Any other comments?
………
………
…….

Section D

In this section, ten most important aims of practical work in biology are listed below. Please, rank these aims in order of importance from 1 to 10. The most important aim should be ranked '1', followed by the next important '2'… and '10' for the least important aim.

Aims of biology practical work	**Rank**
1.To encourage accurate observations and descriptions of objects	
2. To promote a logical reasoning method of thought in solving problems	
3. To verify or clarify facts and principles already taught in tutorials explaining their relationship	
4. To elucidate theoretical work as an aid to comprehension	
5. To make biological phenomena more real through actual experience	
6. To develop specific manipulative skills	
7. To arouse and maintain interest in the subject	
8. To promote the understanding of scientific methods or techniques	
9. For finding facts and arriving at new principles.	
10. To provide students with opportunities to practice the necessary procedures or skills	

Please, add some general comment, if any, on the values of practical work in cell biology course.
………
………
………
………