THE IMPACT OF THINKING MAPS TO ENHANCE THE DEVELOPMENT OF CRITICAL THINKING SKILLS AMONG FIRST YEAR PRE-SERVICE LIFE SCIENCE TEACHERS

Francois Gysbertus Minnie

B.Sc. (UFS), B.Sc. Hons. (UFS)

A dissertation submitted in fulfilment of the requirements for the degree

MAGISTER EDUCATIONIS

in

Learning and Teaching

Faculty of Humanities

North-West University

(Vaal Triangle Campus)

Vanderbijlpark

Study Leader: Prof. MM Grösser

2017

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

It all starts here ™

DECLARATION

I, FRANCOIS GYSBERTUS MINNIE, solemnly declare that this work is original and the result of my own labour. It has never, on any previous occasion, been presented in part or whole to any institution or board for the awarding of any degree.

I further declare that all information used and quoted has been duly acknowledged by complete reference.

SIGNATURE **DATE**

Rita van Wyk

Language Practitioner
Taalpraktisyn

084 5484177
rieviera@mweb.co.za

DECLARATION

28 October 2016

I herewith declare that I was responsible for the language editing of the dissertation:

The impact of thinking maps to enhance the development of critical thinking skills among first year pre-service life science teachers, by Francois Gysbertus Minnie.

M. J. van Wyk

M.J. van Wyk
BA (Unisa)
Advanced Dipl. in Translation and Interpreting (UFS)
Accredited member of the SA Translators' Institute

DEDICATION

This dissertation is dedicated to all the people who challenged, inspired and encouraged me to commence the study and supported me throughout the course of the study: especially my wife, Rentia, who offered me love and support throughout the course of the study.

ACKNOWLEDGEMENTS

I thank the following people for their advice, guidance, motivation and support during this study:

- My support system at home: My wife Rentia and children, Rinis and Niël, for their love, support and understanding during the completion of this study.
- My mother, Jeanette Minnie, and mother-in-law, Ina de Jager, and all my family and friends for their love and support.
- My study leader, Professor M.M. Grösser, for her guidance, advice, patience and helping me to focus, and especially for believing in me.
- Mrs. Aldine Oosthuyzen for the capturing of the data, her assistance in the statistical analysis, advice, support and the technical editing of this dissertation.
- Mrs. Rita van Wyk for the professional language editing of the dissertation.
- Mrs. Martie Esterhuizen of the Vaal Triangle Campus library, for helping me to find the literature needed for my research.
- Mrs. Daphne Strauss who assisted during the recruitment of students and supervision during the pre- and post-tests.
- My colleagues at the School of Educational Sciences for their valued advice and support.
- All the LIFE 111 students of 2016 who participated in this research study.
- The University of North-West for allowing me to conduct this study.

SUMMARY

The National Curriculum and Assessment Policy Statement (CAPS) Grades R-12 continues to support teaching and learning that should nurture critical thinking skills among learners[1]. This research investigated the impact of Thinking Maps as a teaching strategy to enhance the development of critical thinking skills among first year pre-service Life Science[2] teachers at a university in South Africa.

The literature review explains the multidimensional nature of critical thinking that involves the development of cognitive and metacognitive skills and strategies, dispositions/behavioural traits, intellectual traits, as well as universal intellectual standards of reasoning that are applied to the elements of thought. The importance of critical thinking for teacher training was explored by emphasising its importance to cope with the challenges of the 21st century. Moreover, the development of critical thinking skills stands central to achieving the objectives of CAPS. Nationally and internationally, the development of the critical thinking skills of pre-service teachers appears to be fragile, and political, educational, personal, behavioural, cultural and language factors seem to play an important role in influencing the development of critical thinking skills. A number of commercially available tests exist to assess the development of critical thinking skills. As none of these tests focus on assessing critical thinking in subject content, the researcher decided to construct his own closed multiple choice test, strengthened by open questions, to assess the application of the critical thinking skills analysis, synthesis and evaluation in the context of Life Sciences.

In order to identify a suitable theoretical framework for developing the Thinking Maps intervention that was implemented in the study, important learning theories and related teaching styles, teaching methods and teaching strategies were clarified. It appeared that teaching framed within a cognitive and constructivist approach would be more apposite for enhancing the development of critical thinking, as these approaches provide opportunities for active and social construction of knowledge and problem-solving that hold benefits for the development of critical thinking.

The role and importance of visual learning, in particular Thinking Maps, for enhancing the development of critical thinking were clarified by means of a literature review. Thinking Maps is

1 In the context of the study, “learners” will be used in the context of school-level teaching, and “students” in the context of teaching at higher-education level.

2 The term “Life Sciences” will be used when referring to the subject Life Sciences. In all other instances reference will be made to “Life Science” teachers/classrooms/content/students (Department of Basic Education, 2011:6, 17).

a programme that consists of a set of eight visual tools designed to help students[3] develop critical thinking processes and habits in a multidisciplinary and an integrated fashion, such as describing, comparing, categorising, identifying cause and effect relationships, sequencing and ordering, analysing part-whole relationships and seeing analogies. In the context of the study, the researcher employed the Circle Map, Tree Map and Multi-Flow Map to enhance the development of the critical thinking skills' analysis, synthesis and evaluation, that are central to achieving the objectives of Life Science subject content.

The empirical research design employed in the study comprised a quantitative, quasi-experimental research design in which a Thinking Maps intervention was implemented on a rotation basis in two experiments with experimental and control groups with a purposively selected group of first year pre-service teachers (n = 56) at a South African university. The twelve-week Thinking Maps intervention programme, also presented on a rotational basis, was underpinned by cognitive and constructivist learning theory and implemented Thinking Maps as a teaching strategy that supported the facilitation of independent teaching and learning. The study aimed to determine if a Thinking Maps intervention could enhance the development of critical thinking.

Descriptive and inferential statistical procedures were employed to analyse pre-test and post-test data, and data obtained through the Thinking Maps constructed by the students. The pre-test results obtained for Experiment 1 and Experiment 2 revealed that the students' critical thinking skills to analyse, synthesise and evaluate, were in need of development. After a twelve week Thinking Maps intervention with Experimental group 1 and 2 on a rotation basis, the latent potential for enhancing critical thinking skills through Thinking Maps was observed. Normal lecturing apparently also contributed to some extent to enhancing the development of the critical thinking skills. Although some improvement in the application of the participants' critical thinking skills was noticed, the students still appeared to be beginning thinkers with an average ability to apply critical thinking. More continuous and purposeful development of the critical thinking skills seem to be necessary to sustain the development and application of the skills to enable the students to become master thinkers. Moreover, the universal intellectual standards of reasoning involved in critical thinking apparently did not benefit from the Thinking Maps intervention. The study is concluded with recommendations to further enhance the development of critical thinking.

---

[3] In the context of this research, first year prospective education students will be the focus of the study, and will therefore focus on using the term "students". The information provided in the study could however also include "learners" at school.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION AND STATEMENT OF THE PROBLEM

1.1 INTRODUCTION AND STATEMENT OF THE PROBLEM

In this research the researcher determined the impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers at a university in South Africa.

According to the pioneers in the field of critical thinking research, critical thinking is multidimensional in nature (Ennis, 2001:44; Facione, 2009:5, 6; McPeck, 1981:20; Paul, 1993:58). Critical thinking comprises the development of core critical cognitive skills and metacognitive strategies, dispositions/attitudes/habits of mind/behavioural traits, intellectual traits, and universal intellectual standards of reasoning that are applied to the elements of thought (Ennis, 2001:44; Facione, 2009:5, 6; McPeck, 1981:20; Paul, 1993:58) (*cf*. 2.2). The cognitive skills involve, among others, problem-solving, formulating inferences, decision-making, logical and cohesive reasoning, analysis, synthesis, questioning, evaluation/judgement, identifying assumptions and inductive and deductive reasoning. The metacognitive strategies involve self-regulation of thought and explanation (Dewey & Bento, 2009:335). The dispositions/behavioural traits, attitudes or habits of mind comprise intellectual curiosity/inquisitiveness, scepticism/seeking the truth, desiring to obtain the best understanding of a given situation, being open-minded, analytical, systematic and judicious, and having self-confidence in reasoning, desiring to obtain the best understanding of a given situation and being open-minded to allow others to voice opinions (Ennis, 2001:44; Facione, 2009:8; Grosser, 2016a:68; Halpern, 2007:10; Paul & Elder, 2006:14, 14). The intellectual traits refer to the unique qualities and patterns of thinking that include humility, courage, empathy, autonomy, integrity and perseverance (Paul & Elder, 2006:13, 14).

In the context of the research, the researcher mainly focused on three core critical thinking skills which stand central to the mastering of learning content in B.Ed. Life Sciences at school and at first year pre-service teacher-training level, namely: **analysis, synthesis** and **evaluation** (Department of Basic Education, 2011:14-18). In addition, although not the main focus of the study, the researcher also explored whether the universal intellectual standards of reasoning could benefit from the Thinking Maps intervention.

The development of critical thinking skills has been on the agenda of South African education since 1997. The new National Curriculum and Assessment Policy Statement (CAPS) Grades R-12 continues to support teaching and learning that should nurture the cognitive and metacognitive processes as well as intellectual dispositions that are important for critical thinking. Learners should be able to:

- identify and solve problems and make decisions using critical and creative thinking;
- work effectively as individuals and with others as members of a team;
- organise and manage themselves and their activities responsibly and effectively;
- collect, analyse, organise and critically evaluate information;
- communicate effectively using visual, symbolic and/or language skills in various modes;
- use science and technology effectively and critically, showing responsibility towards the environment and the health of others; and
- demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation (Department of Basic Education, 2011:4, 5).

Against the background of the aforementioned CAPS objectives, it seems reasonable to assume that teachers should be key role-players in ensuring that learners at school develop good critical thinking skills. Completed national and international research studies, however, report the opposite. These studies point to the fact that the development of critical thinking skills among pre-service teachers appears to be fragile and deficient (Allamnakhrah, 2013; Hashim, 2010; Lombard & Grosser, 2008; Scholtz *et al*., 2008; Zascavage, 2010). The likelihood of pre-service Life Science teachers lacking effective critical thinking skills is therefore a reality. The researcher argues that developing and/or improving the application of critical thinking skills among pre-service teachers in Life Sciences is important, as teachers first have to possess critical thinking skills before they can teach and develop the skills among learners at school.

The use of Thinking Maps as a teaching strategy to develop critical thinking processes dispositions/behavioural traits, intellectual traits and universal intellectual standards of reasoning is highlighted in the literature as a programme that consists of a set of eight visual maps (Hyerle & Yeager, 2007:2). Each map is designed to represent a specific cognitive process that can be used in a multidisciplinary and integrated fashion across age groups in any subject field (Hudson, 2013:9).

Qualitative and quantitative research projects on improving critical thinking skills by means of intervention programmes with various teaching strategies have been conducted nationally and internationally among a variety of participants at all school levels, learners with special needs, and undergraduate students. The focus areas of the completed research include Technology (Arencibia, 2013:2), special needs (Boucher, 2010:9), Life Sciences (Avia, 2010:1), Natural

Sciences (Naidoo, 2011:1), Mathematics (Slater, 1995:1), Web Design (Botha, 2004:1), Physical Sciences (Galyam, 2004:1), and Computer Science (Jordaan, 1998:1). None of the aforementioned studies evaluated the impact of Thinking Maps for enhancing the development of critical thinking skills among pre-service Life Science teachers.

Only three research studies conducted internationally (Hudson, 2013; Russell, 2010; Sunseri, 2011) that determine the effectiveness of Thinking Maps could be located. Mixed method research by Russell (2010:4) determined the impact of Thinking Maps on the reading comprehension of elementary fourth and fifth grade learners. The findings revealed there was no statistical significant difference between the groups receiving Thinking Maps and those not receiving Thinking Maps instruction.

Two quantitative research studies by Hudson (2013:10) and Sunseri (2011:8) respectively, determined the impact of Thinking Maps on fourth and fifth grade students' expository texts. According to Sunseri (2011:99), the main findings indicate that Thinking Maps do not have a statistically significant impact on improving students' writing. Secondly, research by Hudson (2013:3) determined the effect of Thinking Maps on fifth grade Science achievement, and the findings suggest that the students who did not use Thinking Maps performed better than those who used Thinking Maps (Hudson, 2013:3).

Furthermore, many research studies related to the development and improvement of the critical thinking skills of pre-service teachers have been conducted. Various intervention studies document the effects of specific teaching strategies on the development of critical thinking skills of pre-service teachers. The implementation of inquiry-based learning (Qing *et al.*, 2010), philosophy of inquiry (Daniel, 2001), active learning (Burbach *et al.,* 2010), blended learning (Akyüz & Samsa, 2009), cognitive apprenticeship (Osana & Seymour, 2004), discussion-forums (Umar & Ahmad, 2010) and cooperative learning (Goyak, 2009; Grosser, 1999) have all delivered advantages and gains in terms of promoting the development of critical thinking skills among pre-service teachers. However, despite these efforts, the critical thinking skills of pre-service teachers still appear to be fragile and in need of development.

Statement of the problem

Teachers play an important role in developing critical thinking skills among learners in order to achieve the outcomes of the CAPS. It is however clear from completed research that the critical thinking skills of pre-service teachers seem to be fragile and not well-developed. As it is reasonable to assume that teachers have to possess critical thinking skills themselves before they can cultivate these skills among learners, eductors-training is faced with a challenge to develop critical thinking skills among pre-service teachers. It is clear from the completed research studies cited above that none of these involved pre-service Life Science teachers and did not establish the effects of Thinking Maps on enhancing the development of critical thinking in the context of first year pre-service teachers. This research therefore wished to address a **contextual gap** by focusing on pre-service teachers in South Africa, as well as a **theoretical gap** by establishing the merits of Thinking Maps as teaching strategy for enhancing the development of critical thinking.

The significance of conducting a study that would determine the impact of Thinking Maps for enhancing critical thinking among pre-service Life Science teachers can be motivated as follows:

- The CAPS (Department of Basic Education, 2011:5) aims to produce learners who are able to identify and solve problems and make decisions using critical and creative thinking. Therefore, student teachers need to be equipped with strategies to enable them to achieve the stated aim.
- Thinking Maps are visual representations that provide a framework for students to construct meaning and enhance the development of their critical thinking skills. Becoming acquainted with the application of Thinking Maps can benefit the development of the students' critical thinking and provide them with a strategy to use that could enhance the quality of their own teaching practice.
- Suggestions flowing from this research could influence the future training of Life Science teachers to become capable of applying a teaching strategy like Thinking Maps to enhance critical thinking during their own teaching.
- Findings related to the implementation and use of Thinking Maps could help schools in adopting an effective instructional strategy that could assist teachers in achieving the cognitive objectives of the CAPS curriculum.

Based on the introduction and formulation of the problem, the researcher formulated the purpose of the study.

1.2 PURPOSE STATEMENT

The purpose of this quantitative, quasi-experimental study was, firstly, to determine how effective first year pre-service Life Science teachers were at applying the critical thinking skills to analyse, synthesise and evaluate information. Secondly, based on the pre-test results, the researcher determined how a Thinking Maps intervention can enhance the development of deficient and fragile critical thinking skills. By means of pre-testing and post-testing, and the construction of Thinking Maps, improvement in the application of the deficient and fragile critical thinking skills was established.

Based on the aforementioned discussion, the researcher conceptualised the study as follows:

1.3 CONCEPTUAL FRAMEWORK

The key concepts that stood central to the study was **critical thinking** and **Thinking Maps**. The researcher briefly clarifies the conceptualization for both concepts as they relate to the context of the study, in the following sections, and extends the clarification in sections 2.2 and 3.5.

1.3.1 Critical thinking

Since the days of Socrates, Plato and Aristotle, critical thinking has been an important item on the education agenda. Since the 1980s, pioneers in the field, Beyer (1983:45), Ennis (1985:46), Norris (1985:42) and Paul (1988:50), have defined critical thinking. In general, these definitions view critical thinking as the application of cognitive processes that are reflective and evaluative in nature. Critical thinking skills have also been conceptualised according to the viewpoints of more recent pioneers in the field of critical thinking research, namely Duron *et al.* (2006:160), Paul (1985:37) and Paul and Elder (2006:4). According to Duron *et al.* (2006:160), Paul (1985:37), and Paul and Elder (2006:4), critical thinking is, among other things, the ability to answer questions of analysis, synthesis and evaluation about information. Critical thinkers raise vital questions and problems, formulate them clearly, gather and assess relevant information, use abstract ideas, think open-mindedly, and communicate effectively with others (Duron *et al*., 2006:160).

1.3.2 Thinking Maps

Thinking Maps were conceptualised according to the viewpoint of Hyerle and Yeager (2007:1-7). Thinking Maps is a teaching strategy consisting of a set of eight visual tools designed to help students develop critical thinking processes and habits (Hyerle & Yeager, 2007:2). The eight graphic organisers and the cognitive skills they address are summarised in Figure 1:1

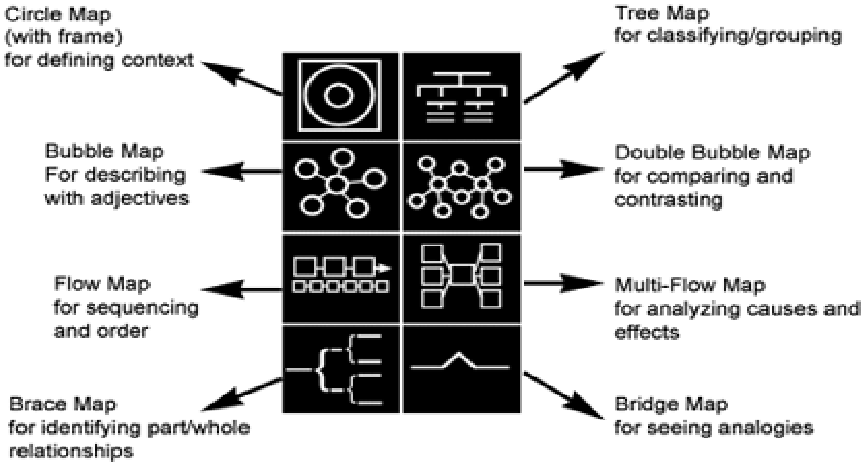


Figure1.1: Thinking Maps and associated thought processes

In this research, the researcher concentrated on the following maps: the Circle Map, the Tree Map and the Multi-flow Map, as these maps provided opportunities for acquiring the skills to analyse, synthesise and evaluate (*cf*. 3.5).

1.3.3 Other concept clarifications

A brief definition of other concepts central to the study is provided below.

- **Pre-service teacher –** a student teacher who has not yet completed training.
- **Life Sciences** – the subject Life Sciences is "the scientific study of living things from molecular level to their interactions with one another and their environments" (Department of Basic Education, 2011:8). According to the CAPS, Life Sciences, Grades 10-12 have three broad subject-specific aims which relate to the purpose of learning science, namely knowing the subject content, doing science or practical work and investigations and understanding the applications of Life Sciences.

To achieve the aforementioned aims, learners must be able to apply the following critical thinking skills:

- organise or reorganise knowledge (analyse and synthesise);
- develop flow charts and diagrams (synthesise);
- recognise patterns and trends (analyse);
- evaluate and categorise information;
- use information in a new way (synthesise);
- analyse and synthesise information/data;

- recognise relationships (analyse); and
- hypothesise and identify variables (analyse and synthesise).

It is clear from the aforementioned that the critical thinking skills to analyse, synthesise and evaluate are particularly important. This research focused on the interrelated applicaton of these three critical thinking skills, that are briefly defined below.

- **Analysis** – Analysis is the ability to identify and infer relationships among facts, ideas, concepts, information and opinions (Facione, 2009:5).
- **Synthesis –** Synthesis is defined as combining a number of different parts, ideas or pieces of information to come up with a new idea or theory. Synthesis thus requires original or creative thinking in order to recognise new problems and develop new strategies to solve them or to create new plans, models and hypotheses (Nieman & Pienaar, 2010:81).
- **Evaluation** – Evaluation is the ability to determine the significance, worth or credibility of statements, perceptions, experiences, judgements, beliefs or opinions, and to assess the logical strength of an argument, statement or description (Facione, 2009:5).

The following three Thinking Maps were used in the intervention to enhance the critical thinking skills, and the choice is briefly defined according to Hyerle and Yeager (2007:24-60).

- **Circle Map** – The Circle Map consists of two circles, a small inner circle and a larger outside circle. Words, numbers, pictures, signs or symbols defining or trying to understand the object, person or idea, are written in the inner circle. Context information that define the idea or concept are written in the larger outside circle. The Circle Map enables one to organise and reorganise knowledge, thus applying the skills of analysis and synthesis (*cf.* Figure 1.1, Figure 3.5).
- **Tree Map** – The Tree Map focuses on the skills to analyse and synthesise information by means of classification. The category name or main idea is written on the top line with a connecting line down to individual sub-categories or supporting ideas. Details for the sub-categories or supporting ideas can be added to the Tree Map (*cf*. Figure 1.1, Appendix D).
- **Multi-Flow Map** – The Multi-Flow Map is used for analysing and evaluating cause and effect relationships. An important event is written in the middle rectangle, with the causes of this event written on the left side of the event and the effects on the right side. All arrows must point to the right, indicating how the causes lead into the event and the effects lead out of the event (*cf*. Figure 1.1, Figure 3.11).

1.4 THEORETICAL FRAMEWORK

The theoretical framework that underpinned the design and implementation of the Thinking Maps intervention to enhance the development of critical thinking skills was cognitivism and cognitive constructivism (*cf.* 2.7.1.3), according to which the teacher becomes a cognitive and metacognitive guide of a student's learning and not the transmitter of knowledge only (UNESCO, 2004).

Based on the discussion on the introduction and statement of the problem as well as the conceptual framework, the researcher formulated the following research questions:

1.5 RESEARCH QUESTION

The central question that drove the execution of the study was two-fold in nature.

1.5.1 Central question

To what extent are pre-service Life Science teachers effective at applying the critical thinking skills to analyse, synthesise and evaluate information, and if not, how can a Thinking Maps intervention enhance the development of the critical thinking skills' analysis, synthesis and evaluation among first year pre-service Life Science teachers?

Within this central question, the following secondary questions unfolded:

1.5.2 Secondary research questions

- What does the development of effective critical thinking skills entail?
- Which critical thinking skills are important for Life Sciences?
- What are Thinking Maps?
- How can the use of Thinking Maps enhance the development of critical thinking skills in Life Sciences?
- How effective are first year pre-service Life Science teachers at applying the critical thinking skills of analysing, synthesising and evaluating?
- To what extent will a Thinking Maps intervention have an impact on the development of the critical thinking skills (analysis, synthesis, evaluation) of first year pre-service Life Science teachers?
- To what extent will there be a difference in the pre- and post-test results of an experimental and control group first year Life Science teachers regarding the application of critical skills

(analysis, synthesis, evaluation) after a Thinking Maps intervention, and in the absence of a Thinking Maps intervention, respectively?

- To what extent will a Thinking Maps intervention contribute to the development of the universal intellectual standards of reasoning involved in critical thinking?

The last question was not a main focus of the study, but the researcher wanted to obtain initial data for a future study in relation to whether students could apply the intellectual standards of reasoning to the motivations they provide for test answers.

Based on the research questions, the following main aim and objectives were formulated:.

1.6 AIM AND OBJECTIVES OF THE STUDY

The main aim of the study was to determine to what extent first year pre-service Life Sciences teachers are effective at applying the critical thinking skills to analyse, synthesise and evaluate information, and if not, to establish how Thinking Maps can enhance the development of the critical thinking skills analysis, synthesis and evaluation among first year pre-service Life Science teachers.

The main aim was operationalised in the following objectives.

- To determine what the development of critical thinking skills entails by means of a literature review.
- To determine which critical thinking skills are important for Life Sciences by means of a literature review.
- To explain what Thinking Maps are by means of a literature review.
- To investigate how Thinking Maps can enhance the development of critical thinking skills in Life Sciences by means of a literature review.
- To determine how effective first year pre-service Life Science teachers are in applying the critical thinking skills of analysing, synthesising and evaluating by means of a pre-test.
- To examine to what extent a Thinking Maps intervention can develop the critical thinking skills of analysing, synthesising and evaluating among first year pre-service Life Science teachers by means of a post-test, and the Thinking Maps constructed by the pre-service teachers during the intervention.
- To examine to what extent there will be a difference in the pre- and post-test results of an experimental and control group regarding the application of critical skills, after a Thinking

Maps intervention, and in the absence of a Thinking Maps intervention, respectively, by comparing the pre-and post-test results of the different groups.

- To establish to what extent a Thinking Maps intervention would contribute to the development of the universal intellectual standards of reasoning involved in critical thinking by means of open pre-test and post-test questions.

As the study would be determining cause and effect relationships, the following tentative hypotheses guided the execution of the study.

1.7 HYPOTHESES AND VARIABLES

The following tentative research hypotheses regarding the impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers were proposed:

H^0_1: There will be no statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after completion of the Thinking Maps intervention.

H^a_1: There will be a statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after completion of the Thinking Maps intervention.

H^0_2: There will be no statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after normal classroom teaching/lecturing (in the absence of teaching with Thinking Maps).

H^a_2: There will be a statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after normal classroom teaching/lecturing (in the absence of teaching with Thinking Maps).

In the context of the study, the interrelated application of the critical thinking skills analysis, synthesis, evaluation, was regarded as the dependent variable (Creswell, 2012:115) and the Thinking Maps intervention as the treatment or independent variable (Creswell, 2012:116, 117). Moreover, biographic variables such as gender, home language, culture and type of school attended could be regarded as control variables (Creswell, 2012:117) that could have influenced the research results. The various subgroups of the biographical variables however did not contain sufficient participants for statistical analyses (*cf.* 6.3). It was therefore not possible for the researcher to control for the influence of these variables (McMillan & Schumacher, 2006:129).

The researcher explains the empirical research design that was employed in the study in the next section.

1.8 EMPIRICAL RESEARCH

1.8.1 Literature study

A literature study was undertaken to identify and define critical thinking skills, as well as the meaning and value of Thinking Maps to enhance critical thinking. The literature study informed the conceptual and theoretical frameworks of the study and guided the construction of the pre-tests and post-tests used for data collection and the design and development of the Thinking Maps intervention.

1.8.2 Research paradigm

The research was framed within a positivistic paradigm as the researcher gathered numerical data objectively from the research participants (Jansen, 2010:21). Positivistic paradigms are concerned with measurement, numerical data and statistical analysis (McMillan & Schumacher, 2008:254). Chapter 4 explains the research paradigm in detail (*cf.* 4.2).

1.8.3 Research design

The researcher used a quantitative, quasi-experimental research design in this research, as manipulation of a dependent variable (critical thinking skills) took place with a group of participants who were not randomly selected (Creswell, 2012:307). The research was structured and planned, and numerical data were collected and statistically analysed (Creswell, 2009:145, Maree & Pietersen, 2010a:145). The quantitative, quasi-experimental research design is further explored in detail in sections 4.4.1 and 4.4.2.1.

1.8.4 Research strategy

In this research the researcher used the non-equivalent groups (assignment to groups was not random) pre-test-post-test control and comparison group design as strategy of inquiry in a double experiment (Experiment 1 and Experiment 2) that was conducted on a rotation basis. Chapter 4 of this research elaborates on the research strategy (*cf*. 4.4.2).

1.8.5 Research participants

In the context of the study non-probability, convenient and purposive sampling of the 2016 first year Life Science pre-service teachers (n = 56) at a South African university was utilised. The sampling procedure is further explored in Chapter 4 (*cf*. 4.4.4).

The next section briefly refers to the methods of data collection applied in this research.

1.9 METHODS OF DATA COLLECTION

1.9.1 Tests

To generate data, the researcher used pre- and post-testing as a primary measure of data collection to determine the extent to which the participants acquired the skills to execute critical thinking (analysis, synthesis, evaluation) in Life Sciences content prior to and after a twelve-week Thinking Maps intervention. The tests were norm-referenced, as comparisons were drawn between the achievements of participants within and across the experimental and control groups in Experiment 1 and 2. The tests were piloted and refined before being administered to the study participants. Chapters 2 (*cf*. 2.5) and 4 (*cf*. 4.4.3.1) of this research outline discussions pertaining to the construction of tests, with specific focus on multiple-choice questions, supported by open questions, as well as the nature of the tests, respectively. The open questions were included to provide some initial insight into the participants' application of the universal standards of reasoning, and was not regarded as a primary data collection method.

1.9.2 Student Thinking Maps

Based on the pre-test results, the Thinking Maps intervention was developed to address the deficiencies noted in the pre-test results at the onset of the first six weeks (Experiment 1) and second six weeks of the first semester of 2016 (Experiment 2). During the implementation of the intervention, the student participants worked independently to select and construct relevant Thinking Maps that would synthesise the subject content dealt with during lectures and to complete activities or solve problems in Life Sciences. The researcher assessed (*cf*. Table 3.2, Table 3.3) the student generated Thinking Maps (*cf.* 3.5), which allowed him to monitor and gauge students' progress in becoming familiar with the application of the critical thinking skills on which the study focused.

How the researcher adhered to quality criteria during the execution of the research is elucidated in the following section.

1.10 QUALITY CRITERIA: VALIDITY AND RELIABILITY

1.10.1 Validity

Validity refers to the accuracy of research data (McMillan & Schumacher, 2006:134-142). In the context of the study, the researcher considered criteria to uphold the validity of the research design, the data collection instrument and the experimental research strategy.

1.10.1.1 Validity of the quantitative research design

The validity of the quantitative research design was ensured by adhering to criteria for internal, external, construct and statistical conclusion validity (Creswell, 2012:162; Leedy & Ormrod, 2013:89-103; McMillan & Schumacher, 2008:134). How the researcher complied with each of these aspects is clarified in Chapter 4 (*cf*. 4.4.6.1).

1.10.1.2 Validity of the tests

Validity of the test items was guaranteed by addressing various forms of validity, namely face, content, construct and criterion validity (Delport & Roestenburg, 2011:173; Leedy & Ormrod, 2013:89; Pietersen & Maree, 2010c:217). How the researcher adhered to the aforementioned criteria is discussed in Chapter 4 (*cf.* 4.4.6.1).

1.10.1.3 Validity of the experimental research strategy

To ensure validity of the experimental design, criteria for internal and external validity were adhered to (Cohen *et al*., 2007:156-159; Lodico *et al.,* 2010:244-249). How the researcher dealt with these criteria is explained in Chapter 4 (*cf*. 4.4.6.1).

1.10.2 Reliability

To ensure reliability of the tests, a range of measures was applied.

The researcher ensured that:

- The tests were bilingual.
- As part of a pilot study, three experienced colleagues in the field of Life Sciences verified the content of the tests in terms of suitability to assess critical thinking as well as the difficulty level of the content. The researcher incorporated their suggestions and recommendations in the final versions of the tests used to collect data.
- Marking, adding and transfer of marks were double-checked by a colleague.
- He was the only marker, to avoid problems with interrater reliability.
- Objective tests were used to avoid inconsistency in marking.
- He avoided the Halo effect by not giving participants who did well or badly in one assessment undeserved favourable or unfavourable assessment in a follow-up assessment. The double-checking of the marking of tests by an independent person avoided the influence of the Halo effect (Cohen *et al*., 2007:159).

Reliability measures are further explained in Chapter 4 (*cf*. 4.4.6.2).

The following section pays attention to the procedures used for analysing data.

1.11 DATA ANALYSIS

The data gathered by means of the tests and the Thinking Maps were analysed by means of descriptive and inferential statistics.

1.11.1 Tests

The data analysis of the tests made use of both descriptive and inferential parametric statistics (Creswell, 2012:182; Leedy & Ormrod, 2013:279; Pietersen & Maree, 2010a:183; Pietersen & Maree, 2010b:198). The explanations of the statistical procedures follow in Chapter 4 (*cf*. 4.4.5). The open questions used in the tests enabled the participants to motivate and explain their answers to the closed questions. The open responses were merely checked for the application of the universal intellectual standards of reasoning, namely clarity, logic, depth, breadth, accuracy, significance and precision in thinking.

1.11.2 Thinking Maps

Descriptive statistical procedures were used to analyse the Thinking Maps that the student participants constructed during the intervention.

1.12 ETHICAL CONSIDERATIONS

All the various ethical considerations pertaining to the research are discussed in detail in Chapter 4 (*cf.* 4.4.7). The various ethical considerations that the researcher adhered to were:

- Ethical issues in the research problem.
- Ethical issues in the purpose of research.
- Ethical issues in data collection.
- Ethical issues in data analysis and interpretation.
- Ethical issues in writing and disseminating research (Creswell, 2009:88-91; Strydom, 2011a:113-126).

The chronological execution of the data collection process is highlighted in the following section.

1.13 DATA COLLECTION PROCESS

The data collection process took place as follows:

- Ethical clearance was firstly sought from the Ethics Committee of the North-West University (NWU), Vaal Triangle Campus. The study was approved and received an ethical clearance number: NWU-HS-2015-0194 (*cf.* Appendix A).
- Written consent was obtained from all the participants in the research (*cf*. Appendix B).
- A literature review on critical thinking skills and Thinking Maps was conducted and guided the setting of pre-test 1 and 2 and post-test 1 and 2 as well as the design and implementation of the Thinking Maps intervention (*cf.* Appendix C).
- A pilot study was conducted to determine the reliability and validity of the tests.
- Experiment 1 commenced with pre-test 1, based on the Life Science content that the student participants dealt with at Grade 12 level. The data were analysed, and based on the data, the Thinking Maps intervention was compiled to address the deficiencies noted during pre-test 1.
- The Thinking Maps intervention (*cf.* Chapter 5) was implemented during the first semester of 2016 with the experimental group of Experiment 1 for a period of six weeks, after which post-test 1 was written to determine the impact of the intervention. The intervention focused on the application of critical thinking to content that emphasised working according to the scientific method and problem-based learning. Post-test 1 was based on the content covered with the implementation of the Thinking Maps intervention during the first six weeks of semester 1. During this time, the control group received normal classroom lecturing for six weeks, and also wrote post-test 1 to determine the impact of normal classroom lecturing on the application of their critical thinking skills. The student participants who received the Thinking Maps intervention, generated Thinking Maps during classroom lecturing and after classroom lecturing for homework. Post-test 1B, a repetition of pre-test 1, was written simulatenously with post-test 1.
- Pre-test 2, based on the Life Science content of semester 1, that mainly emphasised the application of critical thinking to problem-based content and content related to working according to the scientific method dealt with in the first six weeks of the semester, was administered during week 7 (start of semester 2). Based on the data, the Thinking Maps intervention for Experimental group 2 was developed, linked to the problem-based content and content related to working according to the scientific method, that would be dealt with in weeks 7 – 12 of the 1st sememster. Thereafter, Experiment 2 followed, where the control group (the experimental group of Experiment 1) received normal classroom lecturing for six weeks, and the experimental group (the control group of Experiment 1) received the Thinking Maps intervention. On completion of the Thinking Maps intervention, post-test 2 followed to determine the impact of the Thinking Maps intervention. Post-test 2 only focused

on the application of critical thinking to content involving problem-based learning dealt with in weeks 7-12 of the intervention. Post-test 2B, a repetition of pre-test 2, was written simulatenously with post-test 2.

- The repetition of pre-test 1 and pre-test 2 served the purpose to establish transfer and retention of the skills acquired during the Thinking Maps intervention to different subject content.
- The data obtained by the pre-tests and post-tests and the Thinking Maps constructed by the student participants were captured by an independent statistician at the NWU, Vaal Triangle campus, and analysed and interpreted with the assistance of the independent statistician and the researcher's study leader.
- The open questions in the pre-and post-tests were checked by the researcher to gather initial data for a future study on the application of the universal intellectual standards of reasoning involved in critical thinking (*cf.* 6.7).

1.14 THINKING MAPS INTERVENTION

The six stages of the intervention research model are described in Chapter 5 (*cf*. 5.2.3). In the context of the study, the researcher implemented four stages, namely problem analysis and project planning; information gathering and synthesis; design, and early development and pilot testing.

The twelve-week intervention programme (*cf*. 5.3.2) was underpinned by the cognitive and constructivist learning theory (*cf*. 2.7.1.3), and utilised the independent teaching method (*cf*. 2.7.2.3) with Thinking Maps as a teaching strategy to enhance the development of critical thinking through problem-solving and inquiry-based learning (*cf*. 2.7.2.3)

1.15 CHAPTER DIVISION

The layout of this research is as follows:

Chapter 1: Introduction and statement of the problem.

Chapter 2: Literature review: Critical thinking in Life Sciences: A concept clarification.

Chapter 3: Literature review: Developing critical thinking in Life Sciences through visual learning: The role of Thinking Maps.

Chapter 4: Empirical research design.

Chapter 5: The Thinking Maps intervention programme.

Chapter 6: Data analysis and interpretation.

Chapter 7: Summary, findings and recommendations.

Bibliography

Appendixes

1.16 CHAPTER SUMMARY

This chapter began with a brief discussion to clarify what critical thinking is, and emphasised its importance to achieve the objectives of the South African CAPS and the subject Life Sciences. Completed national and international research studies reported that the development of critical thinking skills among pre-service teachers appears to be fragile and deficient. The use of Thinking Maps as a teaching strategy seemed to be a possible solution to enhance the critical thinking development of pre-service teachers (*cf.* 1.1). The focus of this research dealt with critical thinking and Thinking Maps as a teaching strategy to enhance critical thinking; therefore a number of research studies was consulted to verify research on the topic of critical thinking and Thinking Maps as a teaching strategy for enhancing critical thinking. Completed research in the field of enhancing critical thinking skills has not yet established the effects of Thinking Maps on enhancing the development of critical thinking among pre-service Life Science teachers. Therefore, a gap in terms of specific research linked to Life Sciences as well as Thinking Maps for enhancing critical thinking was identified (*cf*. 1.1).

The research question and secondary research questions of the study were formulated and aligned with the aim and objectives of the study, which entailed determining to what extent pre-service Life Science teachers are effective at applying the critical thinking skills to analyse, synthesise and evaluate information, and if not, to investigate to what extent a Thinking Maps intervention could enhance the development of critical thinking skills among first year pre-service Life Science teachers (*cf*. 1.5).

The research for this research was framed within a positivistic paradigm (*cf***.** 1.8.2), and employed a quantitative, quasi-experimental research (*cf.* 1.8.3) with a non-equivalent, pre-test-post-test control group strategy of inquiry in a double experiment (*cf*. 1.8.4). The research participants and sampling (*cf*. 1.8.5) were also addressed and involved non-probability convenient and purposive sampling of first year pre-service Life Science teachers (n = 56) at a South African university. Data were collected by means of researcher-developed pre-tests and post-tests based on the content of first year Life Sciences (*cf*. 1.9.1), that comprised closed and open test items, and the Thinking Maps generated by the student participants during the intervention and for homework (*cf.* 1.11.2).

Criteria for upholding reliability of the research were adhered to (*cf*. 1.10.1), and the validity of this quantitative research design was secured by complying with the four aspects of internal, external, construct and statistical validity (*cf*. 1.10.1.1). The tests were subjected to criteria for validity, and focused on ensuring face, content, construct and criterion validity (*cf.* 1.10.1.2). The validity of the experimental research design was ensured by adhering to criteria for internal and external validity (*cf*. 1.10.1.3).

The data analysis procedures involved descriptive and inferential statistics (*cf.* 1.11.1). Based on the pre-test and post-test results comparisons were made within and across experimental and control groups to establish the effect of the Thinking Maps intervention to enhance the development of critical thinking skills. Only descriptive statistics were used to analyse the Thinking Maps constructed by the student participants (*cf.* 1.11.2). The answers to the open test questions were checked for the application of the universal intellectual standards of reasoning (*cf.* 1.11.1). Throughout the research principles for conducting ethical research were upheld (*cf.* 1.12).

The following chapter, Chapter 2, focuses on a conceptualisation of critical thinking, its importance in Life Sciences, factors that could influence the development of critical thinking, and an overview of suitable teaching and learning theories, teaching methods, and teaching strategies to enhance the development of critical thinking in Life Sciences.

CHAPTER 2

CRITICAL THINKING IN LIFE SCIENCES: A CONCEPT CLARIFICATION

2.1 INTRODUCTION

This chapter aims to provide a comprehensive overview of what critical thinking entails, and how it could be enhanced. The chapter addresses the following issues:

2.2 Critical thinking: A concept clarification

- The nature of critical thinking
- Core critical thinking skills
- Critical thinking dispositions/behavioural traits
- Universal intellectual standards
- Elements of thought
- Intellectual traits

2.3 The importance of critical thinking

- The importance of critical thinking at school level: The CAPS Curriculum
- Critical thinking and teaching and learning in the 21st century
- Critical thinking as a life skill
- Critical thinking and its role in Life Sciences

2.4 The critical thinking abilities of pre-service teachers

- An international perspective
- A national perspective

2.5 Assessing critical thinking skills

- Introduction
- Multiple-choice tests
- Open-ended information assessment
- Commercially available critical thinking tests
- Assessing the development of critical thinking in the context of the research

2.6 Factors influencing the development of critical thinking

- Political factors
- Educational factors
- Personal and behavioural factors
- Cultural factors
- Language factors

2.7 Teaching for critical thinking

- Teaching and learning theories and their relation to the development of critical thinking
- Teaching methods and strategies to develop critical thinking
- Researcher's view of classrooms conducive to the development of critical thinking

2.8 Chapter summary

The first section in this chapter provides an extended discussion of what critical thinking entails. As this research focused on the development of critical thinking skills, it is necessary to provide a conceptualisation of critical thinking, in order to clearly delineate the focus of this research.

2.2 CRITICAL THINKING: A CONCEPT CLARIFICATION

2.2.1 The nature of critical thinking

The development of critical thinking has been regarded as an important outcome and ideal of education since the days of Socrates, Plato and Aristotle (Grosser, 2016a:68). Critical thinking in this research is conceptualised according to the viewpoints of pioneers in the field of critical thinking research. In 1933, John Dewey (1933:15) argued that the purpose of education is to learn and think critically. Beyer (1983:45) continued by asserting that critical thinking involves the assessment of the authenticity, accuracy and worth of any claims made about knowledge/information. Norris (1985:42) emphasised the metacognitive nature of critical thinking by concluding that critical thinking refers to the application and the evaluation of one's own thinking. Ennis (1985:46) formulated the definition that most widely characterises critical thinking, as thinking that is reasonable and reflective thinking, and Paul (1988:50) added that critical thinking involves the ability to reach sound conclusions based on observations and information. According to Duron *et al.* (2006:160), Paul (1985:37), and Paul and Elder (2006:4), critical thinking involves the ability to analyse, synthesise and evaluate information. Analysis, synthesis and evaluation are defined as critical thinking skills focusing respectively on parts of information and their functionality in the whole, putting parts together to form a new and original whole and valuing and making judgements based upon information (Brookhart, 2010:40; Ijaiya *et al.*, 2010:383). In addition, critical thinkers raise vital questions and problems, formulate the questions and problems clearly, gather and assess relevant information, use abstract ideas, think open-mindedly, and communicate effectively with others (Brookhart, 2010:40; Duron *et al*., 2006:160; Ijaiya *et al*., 2010:383).

In essence, the researcher is of the opinion that all the cited definitions emphasise that critical thinking entails the application of reflective and evaluative thinking processes. For the purpose of this research the conceptualisation of critical thinking mainly supported the viewpoints of Facione (2009:4) and Paul and Elder (2006:4) that will be elucidated below.

Facione (2009:5-6) describes critical thinking as being multidimensional in nature. Critical thinking comprises the development of the following elements: **cognitive skills and metacognitive strategies**, **dispositions/attitudes/habits of mind**/**behavioural traits**, **intellectual traits**, and **universal intellectual standards of reasoning** that are applied to the elements of thought (Ennis, 2001:44; Epstein & Kernberger, 2006:10; Facione, 2009:5, 6; McPeck, 1981:20; Moore, 2011:508; Paul, 1993:58; Paul & Elder, 2006:5; Vieira *et al.,* 2011:45).

According to Paul and Elder (2006:21), good "critical thinkers routinely apply the intellectual standards to the elements of reasoning in order to develop intellectual traits". A second opinion held by Facione (2000:64) and Profetto-McGrath (2003:572), indicate that dispositions are prerequisites for the application of critical thinking skills, as there must be a willing mental effort to apply the skills. Dispositions are regarded as crucial for critical thinking and according to Facione (2000:64) and Profetto-McGrath (2003:572), critical thinking will not take place or will be inferior if these dispositions are not regarded as important. The researcher however has a different opinion, and argues that the core cognitive skills, metacognitive strategies, dispositions, intellectual traits and universal intellectual standards of reasoning have to be applied in unison, to qualify thinking as good critical thinking, as illustrated in Figure 2.1.

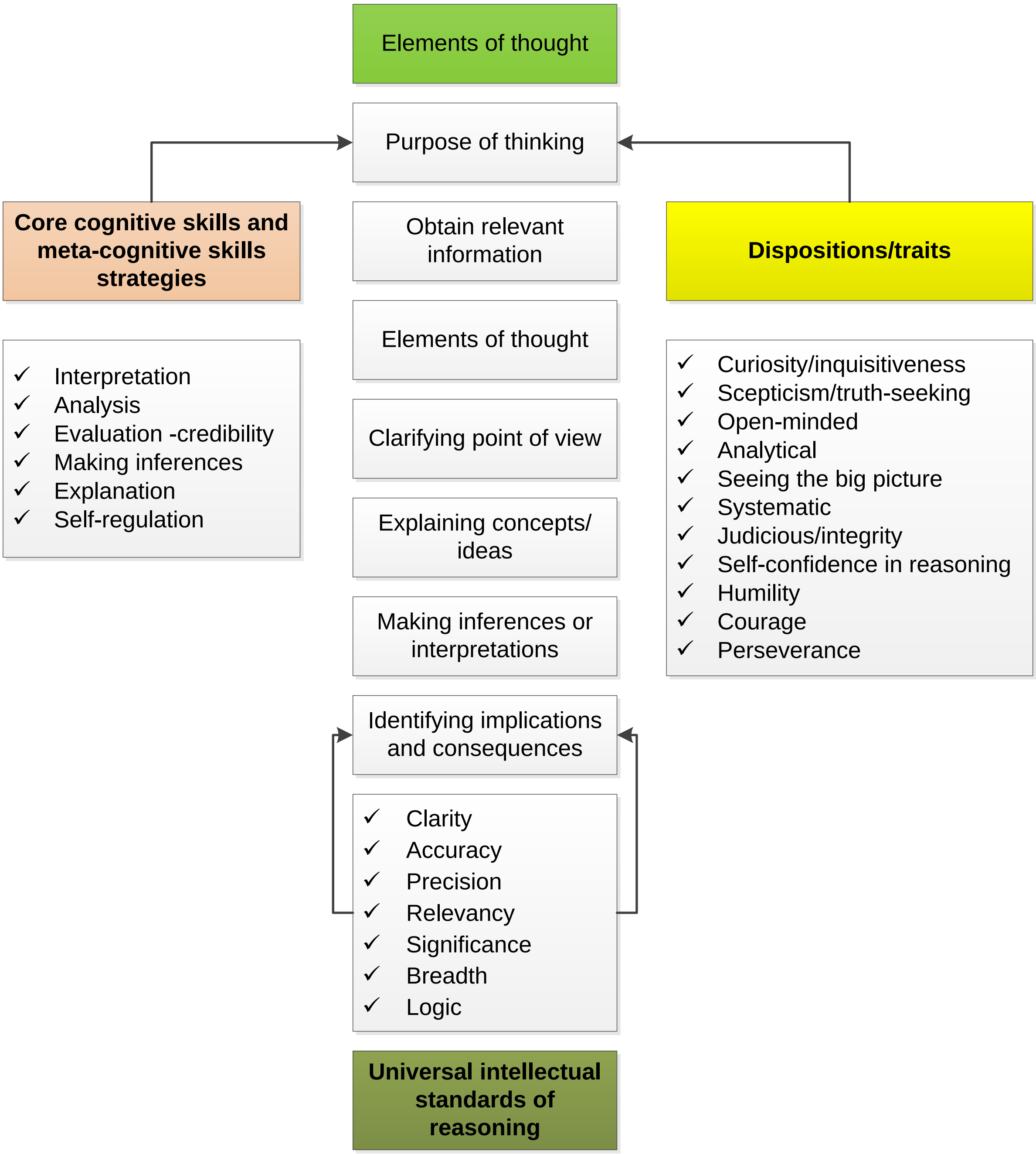


Figure 2.1: Good critical thinking (Adapted from Grosser, 2016b (in press); Paul & Elder, 2006:21)

Figure 2.1 illustrates the argument of the researcher that supports the interrelated application of all the elements of critical thinking when engaged in the elements of thought. For example, during problem-solving that focuses on a number of elements of thought (*cf*. Figure 2.1), the effectiveness of the problem-solving process will not only depend on the application of the cognitive critical thinking skills and the metacognitive critical thinking strategies. Dispositions such as accuracy and persistence and intellectual traits such as open-mindedness and perseverance, and universal intellectual standards of reasoning, such as precision, clarity and relevancy will also play a role in ensuring that the problem is solved effectively.

The various elements that comprise good critical thinking are elucidated below.

2.2.2 Core critical thinking skills and metacognitive strategies

According to Brookhart (2010:40) and Facione (2009:5, 6) the cognitive skills at the very core of critical thinking are: interpretation, analysis, evaluation, synthesis and inference.

- Interpretation refers to understanding and expressing the meaning or significance of experiences, situations, data, events, judgements, conventions, beliefs, rules, procedures or criteria.
- Analysis focuses on identifying relationships among information and comparing information to identify similarities and differences.
- Evaluation involves judging the value of statements, beliefs, opinions, situations or experiences; making claims about the worth of something and explaining reasons for or motivating making claims.
- Synthesis involves breaking down information into parts and joining different pieces of information together to constitute a new whole.
- Inference involves drawing conclusions flowing from data, statements, principles, evidence, judgments, beliefs, opinions, concepts, descriptions, questions, or other forms of representation.

Metacognitive strategies comprise the following:

- Explanation refers to the ability to present in a coherent way the results of one's thinking.
- Self-regulation involves reflection and is defined to mean self-monitoring and evaluating one's own thinking in order to confirm or rectify it.

According to Arsal (2015:141) and Facione *et al.* (2000:61), critical thinkers not only possess cognitive skills and metacognitive strategies, but also have affective dimensions of critical thinking or dispositions, such as a "willingness to suspend judgement and being open-minded, self-confident and analytical and willing to engage in sustained critical thinking". In this research, the researcher focused on the interrelated application of three core critical thinking skills, namely analysis, synthesis and evaluation.

2.2.3 Critical thinking dispositions/behavioural traits

Most researchers agree that in addition to the core critical skills and metacognitive strategies critical thinking also involves dispositions (Facione, 2009:8). Facione *et al.* (2000:61) define critical thinking dispositions as "a person's constant internal motivations to act toward, or respond to, persons, events, or circumstances in habitual, yet potentially malleable ways." A close analysis of the dispositions, behavioural traits and intellectual traits reveals many areas of overlapping between the two (Costa, 2009:54). When we use everyday language when talking of dispositions, we think of traits such as open-mindedness or reflectiveness as marking trends but not strict laws. The dispositions, also referred to as attitudes, habits of mind (Costa & Kallick, 2014:84) or behavioural traits comprise intellectual curiosity, to be systematic, judicious, analytical, sceptic, confident in reasoning, desiring to obtain the best understanding of a given situation and being open-minded to allow others to voice opinions with which one may or may not agree (Ennis, 2001:44; Facione, 2009:5, 6). Facione (2009:8) suggests that "a strong disposition toward critical thinking, specifically an inclination toward intellectual curiosity and inquisitiveness, is indicative of one's ability to think critically and act intellectually." Tsui (2002:743) asserts that critical thinking behavioural habits are enhanced by volunteering answers, posing questions, challenging statements, identifying and analysing arguments, querying evidence, conjecturing alternatives, stating results, justifying procedures and presenting arguments. Open-mindedness would call for respect of others' opinions, as well as being alert to alternatives and the consequences of decisions (Facione, 2011:5,6). Inquisitiveness or intellectual curiosity (Facione, 2011:7) is necessary to obtain background information for solving problems for which a systematic approach is needed (Fradkin *et al.,* 2010:37), and focused and persistent working ways are required to complete the problem-solving process (Ricketts *et al.,* 2003:59-62). Moreover, distinguishing between important and unimportant facts (Facione, 2011:7), as well as reflecting on the decisions made to solve problems are important dispositions that could affect the successfulness of the outcome of the problem-solving process. Judiciousness as disposition drives the evaluation of decisions to solve problems (Facione, 2011:7). The researcher concurs that if students do not work systematically, are not open-minded and do not seek the truth, it will be difficult for them to apply the higher order thinking skills required in Life Sciences (such as to gather, analyze, organize and evaluate information).

Costa and Kallick (2014:84) refer to the dispositions as habits of mind, defined as 16 different dispositions employed skilfully and mindfully by characteristically intelligent people when confronted with problems, to which the solutions are not immediately apparent (Anderson, 2010:14; Costa, 2009:15). Habits of mind build learners' creativity, capacity for teamwork and ability to become life-long, self-regulated learners, and emerge in dispositions such as thinking interdependently, striving for accuracy, persistence, being open to continuous learning, communicating with clarity and precision, and taking responsible risks.

Researchers such as Ennis (2001:44), Facione (2009:5, 6), Halpern (2007:3) and Perkins *et al*. (2000:270) tend to identify similar sets of dispositions as relevant to critical thinking. For example, the most commonly cited critical thinking dispositions include

- open-mindedness;
- fair-mindedness;
- the propensity to seek reason;
- inquisitiveness;
- the desire to be well-informed;
- flexibility; and
- respect for, and willingness to entertain others' viewpoints. (Ennis, 2001:44; Facione, 2009:5, 6; Halpern, 2007:3; Perkins *et al*., 2000:270).

According to Arsal (2015:141), dispositions can be intentionally taught to become powerful intellectual resources that demonstrate good critical thinking.

Critical thinking also involves the development and application of a number of universal intellectual standards of reasoning, which are explained below.

2.2.4 Universal intellectual standards of reasoning

According to Paul and Elder (2006:10), intellectual standards must be applied to critical thinking so as to enhance it and therefore be infused in the development of students' critical thinking through consistent use by the teacher. To think critically, students must have a good command of the following intellectual standards:

Clarity is an important gateway standard to clarify statements by improved elaborations or expressions. **Accuracy** is needed to check if something is really true. If a statement is clear and accurate but lacks **precision**, specific detail will be missing. **Relevance** is needed to determine whether information is connected or applicable to a question. Without **significance,** the central idea or consideration of the most important problem will be lost. The **depth** refers to the complexities or difficulties of a question, while **breadth** is important to get another viewpoint or perspective of the problem. Finally, if ideas that are put together make sense, then the thinking complied with the intellectual standard of **logic** (Paul & Elder, 2006:12).

All thinking (including critical thinking) is always applied to a particular element of thought. The elements of though are explained in the next section.

2.2.5 Elements of thought

The above-mentioned intellectual standards should be applied to the following **elements of thought** (Paul & Elder, 2006:6):

- **Purpose:** Good thinking always has a significant and realistic purpose which is stated clearly. During thinking/reasoning one should check constantly, and monitor whether one is on track to reach the purpose.
- **Question:** Good thinking always involves questioning to figure out something and to solve problems.
- **Assumptions:** Clearly identified assumptions should underpin good thinking and one should determine whether they are justifiable in shaping one's point of view.
- **Point of view:** Good thinking requires a point of view and the consideration of others' points of view; their strengths as well as weaknesses. It involves being open- minded in evaluating all points of view.
- **Information:** Good thinking is built on solid, sufficient, clear, accurate and relevant information.
- **Concepts and ideas:** Involvement in thinking requires the identification of key concepts and ideas and using them with care and precision. Thinking and reasoning are always expressed through concepts and ideas. Consideration of alternative concepts or definitions of concepts is necessary to shape one's thinking.
- **Inferences or interpretations:** All inferences or interpretations made during thinking should be based on evidence gained and from the interpretations, conclusions drawn and meaning given to the information.
- **Implications and consequences:** Consideration should be given to all possible consequences, negative or positive, that may arise from one's reasoning (Paul & Elder, 2006:6, 7).

Good critical thinking also involves the development of a number of intellectual traits that are briefly explained below.

2.2.6 Intellectual traits

The following section clarifies the **intellectual traits** (Paul & Elder, 2006:16, 17) that qualify good critical thinking:

- **Intellectual humility:** Intellectual humility implies having a consciousness of the limits of one's knowledge.

- **Intellectual courage:** Displaying intellectual courage means to be active and critical when information is presented and to see some truth in ideas that are regarded as dangerous or absurd and to recognise one's own misleading beliefs.
- **Intellectual empathy:** Having intellectual empathy refers to the ability to reconstruct accurately the viewpoints and critical thinking of others and to reason with viewpoints other than one's own. This trait correlates with a willingness to remember times when one was wrong despite one's own convictions.
- **Intellectual autonomy:** Intellectual autonomy refers to learning to think for oneself and having command over one's thought processes.
- **Intellectual integrity:** Displaying intellectual integrity means to stand by one's own thinking and to be true to one's own beliefs.
- **Intellectual perseverance:** Intellectual perseverance implies being conscious of the necessity to use intellectual insights and truths in spite of problems one may encounter.
- **Confidence in reasoning:** Good critical thinking reflects characteristics of autonomy, confidence and courage to come to one's own conclusions and to formulate rational viewpoints.
- **Fair-mindedness:** When involved in thinking/reasoning, one has to adhere to intellectual standards without reference to one's own feelings or viewpoints (Paul & Elder, 2006:16, 17).

In the context of the research, the researcher focused on enhancing the development of the core critical thinking skills analysis, synthesis and evaluation purposively, and did not attempt to enhance the development of the dispositions/behavioural traits, intellectual traits or the universal intellectual standards of reasoning purposively. The researcher however assessed the work of the student participants during the implementation of the intervention with the purpose to establish whether the Thinking Maps intervention would sensitise student participants to become more aware of applying the universal intellectual standards of reasoning as well, when involved in tasks that required the application of critical thinking.

2.3 THE IMPORTANCE OF CRITICAL THINKING

> *"By becoming a critical and inspiring teacher expects a figure that is able to motivate and to inspire the students, so that students are able to optimize the potential of their critical thinking that is useful for the future"* (Uksw, 2014:161).

The aforementioned quote underscores the importance of teachers who need to have well developed critical thinking skills before they can enhance the development of these skills among their learners. The following section explores the importance of critical thinking at school-level and teacher-training level with specific reference to Life Science teachers.

2.3.1 The importance of critical thinking at school level: The CAPS Curriculum

The development of critical thinking skills has been on the agenda of South African Education since 1997. The new CAPS Grades R-12 continues to support teaching and learning that should nurture the elements of critical thinking. In addition, Du Plessis (2013:3) asserts that: *"CAPS are encouraging an active and critical approach to learning, rather than rote and uncritical learning of given truths."*

The following table provides the objectives of the CAPS Grades R-12 and explains the link between the objectives and the researcher's view on how the various elements of critical thinking that are implied in achieving the objective.

Table 2.1: Objectives of the CAPS Grades R-12 and links to the elements of critical thinking

Objectives of the CAPS	**Elements of critical thinking implied in achieving the objectives (*cf.* 2.2)**
Identify and solve problems and make decisions using critical and creative thinking	Intellectual curiosity and autonomy, analyticity, systematicity, self-confidence, questioning, interpreting, evaluating, making inferences; accuracy, logic, relevancy, breadth.
Work effectively as individuals and with others as members of a team.	Being: open-minded, self-confident, analytical, purposeful, sceptical and judicious; demonstrating intellectual humility and courage
Organise and manage themselves and their activities responsibly and effectively.	Being systematic, thinking logically and being relevant when reasoning.
Collect, analyse, organise and critically evaluate information.	Being relevant, analytical, logical and systematic when evaluating information.
Communicate effectively using visual, symbolic and/or language skills in various modes.	Being explanative, clear, self-confident; and having a point of view.
Use science and technology effectively and critically showing responsibility towards the environment and the health of others.	Having intellectual empathy and integrity.

Objectives of the CAPS	Elements of critical thinking implied in achieving the objectives (*cf.* 2.2)
Demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation.	Being analytical, reflective, having intellectual empathy.

(Department of Basic Education, 2011:4, 5).

Given the aforementioned objectives, it is clear that prospective teachers need to be trained in order to know how to enhance the development of the different elements that comprise critical thinking in order to ensure that they will be able to achieve the objectives as indicated by the CAPS.

As critical thinking is also regarded as an important life skill to cope with the challenges of the 21^{st} century, the importance of its development cannot be underscored.

2.3.2 Critical thinking and teaching and learning in the 21^{st} century

Ijaiya *et al*. (2010:385) state that the world faces many paradoxes; on the one side is knowledge explosion in science and technology and on the other side are countries getting poorer economically with less peace. Globalisation, technology, migration, international competition, changing markets, population expansion, poverty, famine and transnational environmental and political challenges add a new urgency to develop the critical thinking skills students need for success in dealing with challenges in the 21^{st} century context (Saavedra & Opfer, 2012:2).

Crockett (2015:2), Saavedra and Opfer (2012:5) and Wagner (2008:17) propose that students need the following survival skills to be prepared to deal with the 21^{st} century life challenges as mentioned above. It is noteworthy that many of these survival skills comprise the elements of critical thinking.

- Critical thinking and problem-solving: Students who can apply higher order thinking to provide solutions to real-world problems might be more successful than those who are not effective at critical thinking and problem-solving.
- Collaboration and leadership: Students need the ability to connect and collaborate with others; which is essential to their learning, but also to their mental and emotional health.
- Ethics, action and accountability: Students need to be well-rounded and responsible global citizens who act responsibly towards creating a better world for everyone.

- Effective oral and written communication: Students need to communicate visually and with text and speech to enable them to interact and pass information to others with clarity and precision.
- Accessing and analysing information: Students need the ability to think analytically, which includes proficiency when comparing, contrasting, evaluating and synthesising information.
- Creativity: Students need to be able to think and work out of the box in both digital and non-digital environments to develop unique and useful solutions (problem-solving).

According to Saavedra and Opfer (2012:6), there are compelling economic and civic reasons for education systems to develop students' 21st century skills. Firstly, the economic rationale is that computers and machines can cost-effectively do the jobs that people with only routine knowledge and skills can do. This implies that fewer people with only basic skills are employed and more people with higher-order thinking skills are required. Furthermore, there is increasing competition for the supply and demand of people who can add value through applying non-routine, complex thinking and communication skills to new problems and environments.

Secondly, a civic rationale for education institutions is to increase their focus on developing students' 21st century skills, because although students need a foundation of basic knowledge, they also need to learn how and why to be engaged citizens who think critically, so that they can, for example, analyse news items, identify biases, evaluate current issues, and propose solutions in an educated way. Students need to be able to solve problems so that they can propose or review policies to address social challenges (Saavedra & Opfer, 2012:6). In this regard, Gardner (2010:9-31), argues that the 21st century learner will need five kinds of minds to function effectively, namely:

- the disciplined mind that refers to the mastery of information;
- the synthesising mind that implies the ability to integrate ideas from different disciplines into a coherent whole and to communicate the integration to others;
- the creating mind that holds the capacity to uncover and clarify new problems and questions;
- the respectful mind that involves an awareness and appreciation of differences among people; and
- the ethical mind that refers to the fulfilment of one's responsibilities as worker and citizen with integrity.

The development of the above-mentioned minds clearly points to the importance of developing critical thinking skills, such as creating and synthesising, as well as dispositions and intellectual traits such as respect, responsibility and ethical conduct.

According to Pink (2006:49), we need to prepare our students, whose lives are controlled by automation, increasingly developing technologies, abundance in some areas and at the same time poverty in others, for the conceptual age (21st century). Pink (2006:49-67) provides an alternative to the teaching and learning of the 21st century. According to Pink, there has been an evolution from the agricultural age to the current conceptual age, as illustrated in Figure 2.2 below.

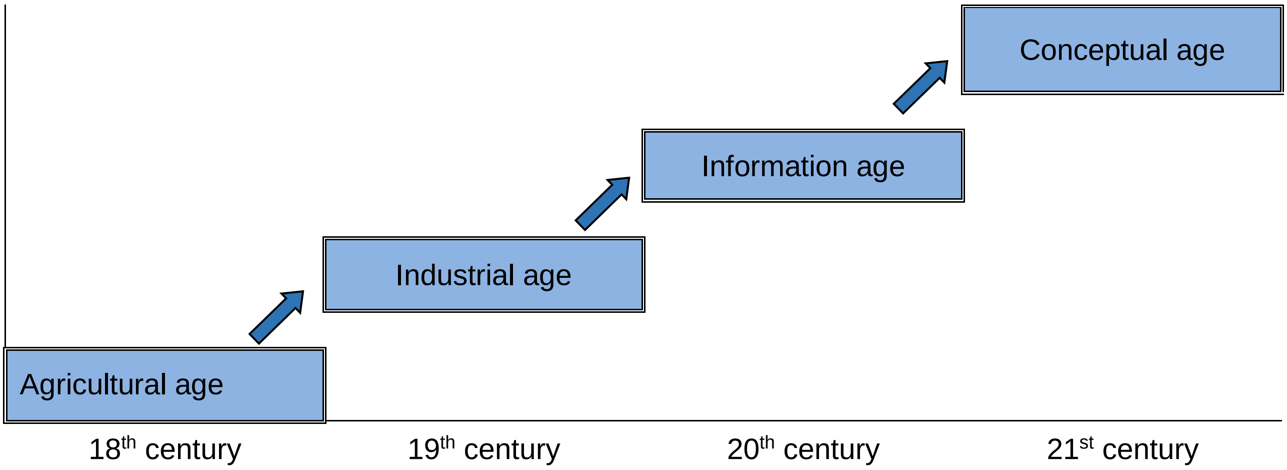


Figure 2.2: From the agricultural age to the conceptual age (Pink, 2006:49)

Figure 2.2 indicates a progression in development that took place from farmers to creators and empathisers. Pink (2006:49) argues that this progression involves the left brain and increasingly the right brain as well. In the context of Pink's arguments, one could argue that the left brain refers to the development of the core critical thinking skills and metacognitive strategies, and the right brain to the development of the critical thinking dispositions/behavioural traits and intellectual traits.

According to Pink (2006:61), the left brain associated with "high-concept aptitudes" (higher order thinking skills: function, argument, focus, logic, seriousness, argument), remains necessary but is no longer sufficient and should be complemented by students' right brain in order to obtain "high-touch aptitudes" (design, story, symphony, empathy, play, meaning) that have become essential for the 21st century. Pink (2006:61) explains the balance between these six high-concept and six high-touch senses as follows:

- **Not just function but also design**: In order to create a cleaner and better environment, it is essential to create something beautiful engaging one's emotions instead of merely creating functional items.
- **Not just argument but also story**: In order to use the abundance of information, students need to use effective communication skills to rebut a good argument with persuasive counterpoints.
- **Not just focus but also symphony**: In order to use the automation and abundance of technology available, students not only need to analyse but also synthesise, combining a number of different parts, ideas or pieces of information to come up with a whole new idea or theory.
- **Not just logic but also empathy**: In order to use the information and analytic tools available, students cannot use logic alone, but have to take their fellowmen into consideration in building relationships and taking care of others.
- **Not just seriousness but also play**: Laughter, light-heartedness and humour have proven to be advantageous to one's health, and there should be a balance between work and play.
- **Not just accumulation but also meaning**: Although we live in a world of extremes, wealth does not necessarily result in health and one should pursue spiritual growth (Pink, 2006:65-67).

Pink (2006:65-67) concludes that the above-mentioned six senses that include the application of the cognitive skills and metacognitive strategies as well as critical thinking dispositions/behavioural traits and intellectual traits involved in critical thinking, will increasingly influence our lives and shape our world, resulting in a whole new mind. Critical thinking could therefore also be regarded as an important life skill, which will be clarified in the following section.

2.3.3 Critical thinking as a life skill

Thinking is a natural process, but when left to itself can often be biased, distorted, partial, uninformed and potentially prejudiced. Excellence in thought must be systematically cultivated and enhanced (Duron *et al.,* 2006:160; Paul & Elder, 2006:4). The quality of our life and that of what we produce, make, or build depends precisely on the quality of our thought. Shoddy thinking is costly, both in money and in quality of life. Facione (2009:6) states that good critical thinkers are not only able to interpret, analyse, evaluate and infer, but can also explain what they think and how they draw conclusions by applying self-reflection and judgement on their own opinions and improve on their previous opinions.

Brookhart (2010:5), Hager and Kaye (1992:27) and Jacobson (2014:31) provide the following reasons why people need to acquire critical thinking as a life skill.

- People will be better equipped to compete for opportunities and jobs and perform better at the work place.
- Critical thinking is seen as a prerequisite for good citizenship, to enable people to distinguish between lies and truth.
- The ability to think well contributes to a person's psychological well-being and good critical thinkers are more likely to be well adjusted.
- As a society that faces some complex and threatening problems, we must learn to be better thinkers in a broader sense, to contribute to the solution of problems.
- Thinking is at the heart of what it means to be human, and failure to develop one's thinking potential is to preclude the full expression of humanity.

Furthermore, as Beyer (1995:28) and Brookhart (2010:5) state, critical thinking enables individuals to make decisions and evaluate information related to personal, social, economic and political issues. Brookfield therefore argues that "critical thinking is a survival skill that you need to make your way through life" (cited by Johanson, 2010:27).

In order for critical thinking to become a life skill, students have to develop through different phases, namely **unreflective thinkers** who are unaware of problems in their thinking, **challenged thinkers** who are faced with significant problems in their thinking, **beginning thinkers** who try to improve their thinking with regular practice, **practicing thinkers** who recognise the need to regularly practice thinking, **advanced thinkers** who keep on practicing thinking, and finally **master thinkers** who have developed good habits of thought that become second nature (Paul & Elder, 2006:19).

In the context of teacher training it is acknowledged that the teacher will have a profound influence on a learner's ability to learn and think critically. The following section focuses on the important role of Life Science teachers in nurturing critical thinking.

2.3.4 Critical thinking and its role in Life Sciences

According to CAPS, the subject "Life Sciences is the scientific study of living things from molecular level to their interactions with one another and their environments. To be accepted as a science, it is necessary to use certain methods for broadening existing knowledge, or discovering new things. These methods must lend themselves to replication and a systematic approach to scientific inquiry. The methods include formulating hypotheses and carrying out investigations and experiments as objectively as possible to test these hypotheses. Repeated investigations are carried out and adapted. The methods and results are analysed, evaluated and debated before the community of scientists accepts them as valid" (Department of Basic Education, 2011:8).

By studying and learning about Life Sciences, learners will develop:

- their knowledge of key biological concepts, processes, systems and theories; and
- an ability to critically evaluate and debate scientific issues and processes (Department of Basic Education, 2011:8).

In the process of learning Life Sciences, learners must be able to perform certain skills in mastering the subject content. The next table,Table 2.2, illustrates the skills learners have to acquire and the researcher's view regarding the elements of critical thinking that are implied in acquiring the skills expected in Life Sciences.

Table 2.2 Skills expected from learners in Life Sciences and links to the elements of critical thinking

Life Sciences: Skills	**Elements of critical thinking (*cf. 2.2*)**
Analyse information/data.	Being relevant, analytical, logical, systematic when analysing information.
Recognise relationships between existing knowledge and new ideas.	Being analytical, systematic, relevant; having courage, reasoning with significance.
Critically evaluate scientific information.	To synthesise; being analytical, logical, relevant; reasoning with significance.
Identify assumptions.	Purposeful reasoning, questioning assumptions, making inferences, identifying implications.
Categorise information.	Being relevant, accurate, precise, logical when reasoning.

(Department of Basic Education, 2011:13).

It is clear from Table 2.2 that critical thinking skills and and metacognitive strategies as well as critical thinking dispositions/traits and universal intellectual standards of reasoning play a role when mastering subject content in Life Sciences.

Critical thinking is often compared to the working according to the scientific method (*cf.* Figure 2.5) used in Life Sciences because it involves a systematic and procedural approach to the process of thinking. Just as students learn the process of the scientific method in Life Sciences they must also learn the process of thinking critically (Snyder & Snyder, 2008:92).

If teachers purposively and persistently provide opportunities for learners to practise higher order thinking skills, for example dealing in class with real-world problems, encouraging open-ended class discussions, and fostering inquiry-oriented experiments, there is a good chance for the consequent development of the elements of critical thinking (Stedman & Adams, 2012:9). McCollister and Sayler (2010:42), Pithers and Soden (2000:243) and Qing *et al.* (2010:4598) support the notion that such critical thinking skills can be developed more effectively in the course of teaching subject matter content and concepts.

It is reasonable to assume that teachers themselves need to be good critical thinkers before they can teach students to think critically. In order to establish to what extent pre-service teachers are able to think critically, the following section will explore an international and national perspective regarding the development of critical thinking among pre-service teachers.

2.4 THE CRITICAL THINKING ABILITIES OF PRE-SERVICE TEACHERS

Walsh and Paul (1986:49) state that "critical thinking skills should be thoroughly integrated into all aspects of the teacher education programmes and prepare future teachers to be models of effective critical thinking strategies". The subsequent sections will provide a succinct overview of the status quo in terms of the development of critical thinking among pre-service teachers.

2.4.1 An international perspective

According to Ijaiya *et al.* (2010:383), Africa struggles to improve access to education, mainly due to overpopulation and underfunding of the sector by many communities. This has led to the lowering of standards and many teachers being produced with limited intellectual skills, especially critical thinking skills. This viewpoint is supported by the Finn Report released in Australia, which states that "teachers will have to update and expand their knowledge and critical thinking abilities and modify their pedagogy in quite major ways" (Hager & Kaye, 1992:27).

Many other studies conducted by Mergler (1997), Owu-Ewie (2007), Paul (1997) and Williams (2005) (all cited by Allamnakhrah, 2013:199) in different countries have investigated the development of critical thinking among pre-service teachers. These studies show that the pre-service teachers in the following countries, namely Ghana, California, Australia and the United States of America, lack critical thinking skills. Allamnakhrah (2013:200) argues that the development of critical thinking skills is unlikely unless pre-service teachers and their lecturers are themselves the products of critical thinking.

2.4.2 A national perspective

Grosser and Lombard (2008:1364) found that a significant number of pre-service teachers in South Africa are not yet on Grade 12 level with regard to the functioning and execution of critical thinking skills.

According to Lombard and Grosser (2008:573), prospective teachers have an apparent inability to apply critical thinking which, according to Potterton (2008:15), could be linked to the continuous use of teacher-centered, non-critical approaches to teaching. Lombard and Grosser (2004:213) support this view by stating that teachers themselves are products of a poor education system which did not emphasise cognitive development and the development of critical thinking skills and therefore do not know how to teach these skills.

The problem of developing critical thinking skills at school level is compounded at tertiary level. Lectures have become increasingly one-sided and teacher-centered. There is limited interaction between the teacher/lecturer and learners/students and among learners/students themselves in large classes, and opportunities for questioning and classroom discussions are severely hampered (Uksw, 2014:163).

Based on the aforementioned international and national perspectives one could conclude that school learning apparently does not prepare pre-service teachers to have well-developed critical thinking skills. It is therefore imperative that teacher-training accepts a two-folded challenge, namely to create opportunities to nurture the development of pre-service teachers' critical thinking skills, and to assist them to become effective at nurturing critical thinking among the learners whom they will teach.

As the present study focused on assessing the development of pre-service Life Science teachers' critical thinking skills, it was important for the researcher to familiarise himself with ways in which critical thinking skills can be assessed effectively.

2.5 ASSESSING CRITICAL THINKING SKILLS

2.5.1 Introduction

Having a defensible elaborated definition of critical thinking, assessing these critical skills need a clear idea of the purpose for which the assessment will be used. In order to assess critical thinking skills, a variety of commercially developed critical thinking tests are available. Literature suggests that if the commercially available critical thinking tests are not adequate, one could alternatively compile one's own closed multiple-choice tests or make use of open-ended information-gathering assessment (essay and short-answer testing, interviewing and monitoring classroom discussions) (Norris & Ennis, 1989:101).

The following sections provide information on possible ways to assess the development of critical thinking skills.

2.5.2 Multiple-choice tests

According to Norris and Ennis (1989:101), the following aspects should be adhered to when constructing one's own multiple-choice critical thinking tests:

- **Identifying the purpose of the test**

  Identification of a specific purpose (other than to test critical thinking) is necessary. The following purposes may apply:

  - Testing for transfer: Testing student's critical thinking abilities in subject contexts and other related contexts.
  - Testing for critical thinking in specific subjects: Used to test whether students have learned subject-content.
  - Preparing students for multiple-choice testing: Teachers often use standardised multiple-choice tests to prepare students explicitly for certain types of tests.
  - Judging students versus judging programmes: If students must be appraised, the test must be more reliable and valid for each student as will be the case when programmes must be appraised.
  - Summative versus formative evaluation: Formative evaluations are carried out to establish growth and development while an intervention programme to enhance the development of critical thinking skills is in progress, while summative evaluations are conducted after a programme or course has been conducted.
  - Aspect-specific versus comprehensive testing: If you need to identify students' strengths and weaknesses regarding specific aspects of critical thinking, you need data on each of these aspects. In comprehensive tests, different sections will test specific aspects.
  - Norm-referenced testing versus criterion-referenced testing: A student's scores are compared to those of other students.
  - Testing for grading: Teachers may use multiple-choice tests for norm-referencing and grading (Norris & Ennis, 1989:101).

- **Making a table of specifications**

  After a test purpose has been chosen, the specific aspects of critical thinking on which the focus should be must be included. If the test is subject-specific, certain elements of the subject should be included. The table should reflect the weighting of the different aspects of critical thinking and elements of the subject (Norris & Ennis, 1989:105).

The following table, Table 2.3, indicates how the critical thinking skills were tested by the researcher in all pre- and post-tests.

Table 2.3: Multiple-choice critical thinking tests in Life Sciences (Adapted from Norris & Ennis, 1989:107)

Aspects of critical thinking			Total %
Analysis	**Synthesis**	**Evaluation**	
10%	10%	10%	30%
5%	5%	5%	15%
5%	5%	5%	15%
5%	5%	5%	15%
5%	5%	5%	15%
4%	3%	3%	10%
34%	33%	33%	100%

Table 2.3 illustrates balancing of the critical thinking skills analysis, synthesis and evaluation, in equal proportions, in all the pre-tests and post-tests used in the research.

Norris and Ennis (1989:106) conclude that this table is idealised, since all elements and aspects are interrelated and interdependent. Consequently, one must make judgements based on one's thoughts regarding the predominant emphasis of an item, in order to roughly satisfy the table of specifications.

- **Drafting items**

Following are some guidelines for writing test items, based upon a set of guidelines prepared by Jason Millmans of Cornell University (cited by Norris & Ennis, 1989:108, 109), combined with suggestions from Cohen *et al.* (2007:427).

- Constructing each item with only one correct or best answer.
- Testing for the intended knowledge and abilities.
- Avoiding "none of the above" and "all of the above" as choices.
- Using either a direct question or an incomplete statement as the item stem.
- Writing items in clear and simple language.

- Stating the central problem of the item clearly and completely in the stem.
- Including most of the reading in the stem.
- Basing each item on a single, central problem.
- Constructing options homogeneous in grammatical form.
- Including in the stem any words that would otherwise need repeating in each option.
- Emphasising negative words or words of exclusion and avoiding such words when possible.
- Placing options at the end of the item stem.
- Arranging options in a logical order, if one exists.
- Avoiding unintended hints based on:
  - grammatical consistency or inconsistency between the stem and the option,
  - repetition of key words in the stem and keyed option, or
  - rote or other verbal associations between key words in the stem and the keyed option.
- Avoiding hints based on the:
  - unusual length of the keyed option,
  - degree of qualification stated in the keyed option or use of terms such as "never" and "always" in the unkeyed options,
  - lack of independence and mutual exclusivity of the options,
  - frequency with which the keyed option is placed in a given option position, or
  - pattern of the location of the keyed position.
- Avoiding hints from one item to another.

Multiple-choice questions should be scored with one mark for a correct answer and no mark for an incorrect answer, and must be designed in such a way that higher-order thinking is required (Brookhart, 2010:33).

In the context of the research, the researcher's multiple-choice tests were purposefully developed to test for specific aspects of critical thinking, namely the ability to analyse, synthesise and evaluate when reasoning about an answer, as shown in Table 2.3.

According to Norris and Ennis (1989:127), a major problem answering the multiple-choice questions is differences among participants related to background beliefs and levels of worldly wisdom. In order to take the various background beliefs into account, the researcher included an open-ended question for each of the multiple-choice test items, and student participants had to motivate and defend chosen answers. This provided the possibility to the researcher to gain an initial understanding of the participants' application of the universal intellectual standards of reasoning, and would possibly eliminate guessing (Norris & Ennis, 1989:115).

2.5.3 Open-ended information assessment

Norris and Ennis (1989:129), cite the following advantages that open-ended questions have over multiple-choice critical thinking testing:

- They provide the researcher with the opportunity to consider the effects of different background beliefs and levels of worldly wisdom.
- They provide clearer insight into critical thinking dispositions or intellectual traits and the application of the universal intellectual standards of reasoning.
- They give a better indication of critical thinking in different tasks, making their ecological validity greater.

In designing open-ended critical thinking assessment items the following general guidelines may be used and can be adjusted according to specific situations:

- Piloting the assessment with a sample of students to ensure it provides an interesting context and that the students understand the task or questions in the way intended.
- Asking the students to justify answers as part of the assessment.
- Being generous, but not overly, when student's answers are interpreted.
- Only giving credit when answers are true and relevant.
- Making notes of all strengths and weaknesses within individual responses from students.
- Making inferences on the presence or absence of critical thinking dispositions/traits and universal intellectual standards of reasoning from the students' responses and make notes of them (Norris & Ennis, 1989:131).

Table 2.4 below, summarises the different open-ended approaches for assessing critical thinking, and the researcher indicates which of the critical thinking elements (*cf.* 2.2) could be addressed with open-ended assessment approaches.

Table 2.4: The different open-ended approaches and possible critical thinking outcomes

Open-ended approach	Possible critical thinking outcome
1. Short-answer tests • Suitable for asking students to infer conclusions, make credibility judgments, and to identify assumptions.	Remaining relevant; being analytical, open-minded, judicious, self-confident and sceptic; reason with clarity, make inferences; being able to evaluate and explain.

Open-ended approach	Possible critical thinking outcome
2. Argumentative essays • Display a process of reasoning (thinking) and discussion. • Less useful on specific areas of critical thinking. • Start with the type of critical thinking you want to access.	Reasoning that is inference-related, clarity-related, orderly(logic). Being able to communicate effectively and becoming analytical and judicious when reasoning.
3. Interviews • Acquire very detailed information on critical thinking skills. • Students can express their ideas easier and in a more coherent manner than in written form. • Evaluator has options like asking the student to clarify or explain or defend conclusions. • Some students might feel threatened or embarrassed when being interviewed.	Remaining relevant, being analytical, open-minded, judicious, self-confident, sceptic; making inferences; to evaluate, and explain, reason with clarity.
4 Classroom discussions • Allowing students to take part in extended discussions will encourage students' critical thinking abilities and dispositions. • Used to compare students' progress over time.	Remaining relevant; being analytical, open-minded, judicious, self-confident, sceptic; making inferences; to evaluate and explain; to reason with clarity, and communicate effectively.

(Brookhart, 2010:33; Norris & Ennis, 1989:132-154).

Norris and Ennis (1989:157) conclude that open-ended approaches complement the multiple-choice critical thinking testing as:

- Multiple-choice testing can provide detailed information on specific aspects of critical thinking as it is embedded purposively into the tests but cannot provide information on critical thinking dispositions/traits and the universal intellectual standards of reasoning.
- Open-ended testing can provide information on critical thinking dispositions/traits and the universal intellectual standards of reasoning but not on specific aspects of critical thinking.

2.5.4 Commercially available critical thinking tests (Published tests)

Table 2.5 summarises the available commercially developed tests that focus on assessing the application of critical thinking in general scenarios. Ennis (1993:182) states that existing multiple-choice critical thinking tests do not test directly for all the elements of critical thinking and therefore evaluators should be open-minded when drawing conclusions.

Table 2.5: Commercially developed critical thinking tests

Published test	Aspects of critical thinking assessed
1. The California critical thinking test • Aimed at tertiary students.	Interpretation, argument analysis, appraisal, deductive and inductive reasoning.
2. Cornell critical thinking test, Level X • Aimed at Gr. 4 to tertiary level. • Requires participants to decide whether there is sufficient evidence or reasons to draw certain inferences or conclusions.	Making inferences and conclusions, inductive reasoning, assessing credibility, deductive reasoning and identifying assumptions.
3. Cornell critical thinking test, Level Y • Aimed at gifted secondary, tertiary students and adults. • Requires participants to decide whether there is sufficient evidence or reasons to draw certain inferences or conclusions.	Making inferences and conclusions, inductive reasoning, assessing credibility, deductive reasoning, making predictions and experimental planning, identifying fallacies, formulating definitions and assumption identification.
4. Ennis-Weir critical thinking essay test • Aimed at secondary and tertiary students. • Focuses on argumentation. • Can be used as teaching material. • More comprehensive.	Identifing a purpose; reasons and assumptions, stating one's viewpoint, offering good reasons, and seeing other possibilities and explanations.
5. Watson-Glaser Critical Thinking Appraisal • The inferences and conclusions which participants are asked to examine are drawn from mini-case studies or exercises.	Inductive reasoning, assumption identification; deductive reasoning, judging conclusions, argument evaluation.

(Brookhart, 2010:33; Ennis, 1993:183; Hager & Kaye, 1992:27; Şeker & Kömür, 2008:395)

Based on the aforementioned table and to the best knowledge of the researcher, there is no test commercially available for researchers to determine the impact of Thinking Maps for enhancing critical thinking skills in Life Sciences in the South African context. This lack of subject-specific critical thinking tests is supported by Ennis (1993:182) who states that there are no subject-specific critical thinking tests which primary purpose is to assess critical thinking in a specific subject area. Therefore, the researcher developed multiple-choice tests with closed and open question for pre- and post-test purposes that address Life Science subject content to establish transfer of the application of critical thinking skills to subject content (*cf.* 4.4.5).

2.5.5 Assessing the development of critical thinking in the context of the research

The researcher took into account the following above-mentioned suggestions (*cf*. 2.5.2, 2.5.3) when he developed multiple-choice tests for the research. The tests used in the context of this research adhered to the following criteria:

- Having a purpose:
  - The researcher tested for transfer of critical thinking skills to different subject content contexts, as the pre-tests and post-tests were based on different topics in the Life Science curriculum of the LIFE 111 module (*cf.* 2.5.2).
  - The researcher also tested whether student participants mastered subject-content (*cf.* 2.5.2).
  - Summative evaluation was used after the Thinking Maps intervention.
- Identified test specifications (*cf.* Table 2.3):
  - The tests addressed the Life Sciences (LIFE 111) programme outcomes and subject content.
  - The elements of the subject content and the application of critical thinking skills (analysis, synthesis and evaluation) were addressed in equal proportions.
- Drafting items:
  - The researcher adhered to all the above-mentioned guidelines in 2.5.2 for drafting the test items.
  - Student participants scored one mark for each correct answer (*cf*. 2.5.2).
  - Higher order thinking was required from the student participants (*cf.* 2.5.2).
  - The tests were purposively developed to test for specific aspects, namely the application of skills to analyse, synthesise and evaluate information (*cf*. 2.5.2).
- General:
  - A pilot study was conducted by asking three experienced colleagues in the field of teaching Life Sciences to pre-service teachers to comment on the suitability and difficulty level of the tests in order to enhance the reliability and validity of the tests.
  - In order to take the various backgrounds of students into account, student participants had to provide an open-ended motivation for each test item.

As this research assumed that the applyication of a teaching strategy, namely Thinking Maps, culd enhance the development of critical thinking, it was important for the researcher to identify to what extent teaching practices could be regarded as an important factor that could hamper the development of critical thinking skills. In order to achieve this, a brief overview of all the possible factors which may have a negative influence on the development of critical thinking skills are explored below.

2.6 FACTORS INFLUENCING THE DEVELOPMENT OF CRITICAL THINKING SKILLS

"The most important single factor influencing learning is what the learner already knows"

David Ausubel (1978:58)

Researchers such as Grosser and Lombard (2008:1367), Lun *et al*. (2010:606), Pithers and Soden (2000:241), Snyder and Snyder (2008:92) and, more recently, Illeris (2015:30) have discussed factors which tend to inhibit or enhance the development of students' critical thinking skills. The factors include political, educational, personal, behavioural, cultural and language factors. Each of these factors is briefly elucidated below.

2.6.1 Political factors

According to Ijaiya *et al.* (2010:383), Africa struggles to improve access to education under the yoke of overpopulation and under-funding as education (Colleges of Education and universities) gets commercialised for internally generated revenue. This has resulted in lowering of standards, consequently producing teachers who are limited in knowledge and the application of critical thinking skills.

2.6.2 Educational factors

Research conducted by Ijaiya *et al.* (2010:384) indicated that in many African countries the curriculum lacks emphasis on the development of and promotion of critical thinking skills. In this regard, Snyder and Snyder (2008:92) suggest that the current trend to standardise curricula and focusing on test scores undermine the ability of teachers/lecturers to address and practise critical thinking at school/university level. Other educational factors that inhibit the development of critical thinking include:

- Over-emphasis on knowledge and recall.
- Excessive use of objective questions and lately a shift to computer-based testing which encourages factual questions.
- The belief that assessing critical thinking skills is more difficult than factual knowledge.

- Over-crowded classrooms, which limit useful interaction and questioning that stimulate the development of critical thinking.
- Lack of emphasis of critical thinking skills in subject content. Students do not learn the critical thinking skills because they are not explicitly taught. Students are not familiar with critical thinking skills and lack the ability to practise it.
- Poor knowledge of critical thinking by teachers/lecturers.
- Over-emphasis on certification of learning rather than on the critical skills required for effective learning (Ijaiya *et al.,* 2010:384; Saavedra & Opfer, 2012:7; Snyder & Snyder, 2008:92).

According to Snyder and Snyder (2008:93), time constraints are barriers to integrating critical thinking into teaching. Teaching/lecturing is faster and easier than problem-based or inquiry-based learning. Objective tests that require one correct answer are faster to administer and grade than subjective assessment where students have to provide their own answers and motivate their answers. In the process of lecturing and assessment through objective tests, the practice of critical thinking skills is lost.

The presence of learning barriers (Illeris, 2015:30) can affect the acquisition process of critical thinking skills when intended learning is not understood or understood in a distorted or insufficient way. Illeris (2015:30) identified three dimensions of learning barriers, namely:

- Mislearning: Mislearning is related to subject-content and includes misunderstandings, lack of concentration, lack of prior learning and unclear communication.
- Learning defence: Learning defence is related to rejected or distorted learning and conflicting learning.
- Learning resistance: Learning resistance refers mainly to interaction between teacher/lecturer and student and includes values, preferences and understandings, and the students' personal dispositions and preconditions (*cf.* 2.6.3).

Tsui (2002:742) found that classroom involvement, such as a paper critiqued by an teacher, conducting independent research, working on a group project, giving a class presentation and taking essay exams have a positive effect on academic skills, including the development of critical thinking. To the contrary, according to Saavedra and Opfer (2012:7) and Tsui (2002:742), taking multiple-choice exams and exposure to traditional lecturing (transmission model) through which teachers transmit factual knowledge via lectures and textbooks, are negatively related to the development of critical thinking skills.

2.6.3 Personal and behavioural factors

Teachers/lecturers and students may have preconceptions about the subject content that inhibit their ability to think critically about the subject content. Preconceptions, such as a personal bias, could inhibit critical thinking due to a lack of analytical skills and dispositions such as being fair, open-minded, and inquisitive about a topic/subject matter (Snyder & Snyder, 2008:93).

According to Pithers and Soden (2000:241) and Sternberg (1987:458), the following behavioural patterns in students inhibit good thinking:

- Acting without thinking (impulsiveness).
- Needing help at each step (overly dependent).
- Using inappropriate goals that cannot be reached (not perceiving cause-effect relationships).
- Having difficulty with comprehension (missing meaning).
- Being convinced of the rightness of their beliefs (lack of fair-mindedness).
- Operating within narrow mindsets (being rigid and inflexible).
- Being fearful to voice an opinion (not confident).
- Condemning good thinking as a waste of time (anti-intellectual) (cited by Pithers & Soden, 2000:242).

According to Pithers and Soden (2000:242) the following types of teacher/lecturer behaviours inhibit good thinking:

- Teachers/lecturers who simply agree or disagree without solid arguments to justify their actions.
- Teachers/lecturers who just demonstrate and explain without learner-centered actions.
- Teachers/lecturers who cut off student responses without proper reasoning.
- Teachers/lecturers who use reproof (disapproval) rather than praise.
- Teachers/lecturers who shake the learner’s confidence in the value of new ideas.
- Teachers/lecturers who use only recall types of questions.

2.6.4 Cultural factors

Grosser and Lombard (2008:1364) found that the various cultural backgrounds of pre-service teachers have not prepared them to address and practise critical thinking. This conclusion is supported by Nisbett and Norenzayan (2002:3) who state that cultural differences that exist among different cultures affect peoples' beliefs about the world and the nature of their cognitive abilities. In this regard they assert that cognitive and metacognitive abilities develop from practical activity that is "culturally constrained and historically developing" (Nisbett & Norenzayan, 2002:10). They are of the opinion that variation in cultural cognition arises because of different background and historical development of societies, which lead to different thought processes (Nisbett & Norenzayan, 2002:11).

According to Vygotsky (1986:58), cultural development is the driving force of all development. All things cultural and social construct the understanding of humans' cognition and learning. Research indicates that cognitive actions of people coming from a culture that focuses on collective thought, such as Ubuntu (African culture/lifestyle which emphasises respect and dignity), could stifle critical thinking abilities (Nisbett & Norenzayan, 2002:11). Western culture is characterised by individuals who focus on personal freedom, choice, criticism, debate, open-minded, curiosity, freedom of speech and diversity, who are likely to have analytical and critical thought (Nisbett & Norenzayan, 2002:11).

2.6.5 Language factors

Several international studies (Lun *et al*., 2010:606; Qing *et al*., 2010:4598) have shown that the use of English as a second language may explain cultural differences in critical thinking skills. Students using English as their second language usually possess lower level of English proficiency when using English in tasks requiring critical thinking. Limited English proficiency could influence the understanding of information that could lead to a cognitive overload that results in a temporary decline to be effective at applying thinking skills (Lun *et al*., 2010:606).

The researcher took notice of the above-mentioned factors that could inhibit the development of critical thinking skills during the course of the research. In particular, the researcher focused on how teaching practices could enhance the development of critical thinking skills.

As this research focused on teaching critical thinking skills to pre-service teachers by means of a Thinking Maps intervention, it was important for the researcher to identify a theoretical framework to underpin the application of the Thinking Maps intervention. He therefore familiarised himself with ways in which critical thinking skills could be taught effectively, before constructing the intervention. The researcher wanted to ensure that he created the most effective opportunities for enhancing the development of critical thinking skills. The next section therefore explores a number of teaching and learning frameworks, teaching styles, teaching methods and teaching strategies, in order to identify the teaching framework/s, teaching style, teaching method/s and teaching strategy/ies most apposite for the researcher's intervention.

2.7 TEACHING FOR CRITICAL THINKING

2.7.1 Teaching and learning theories and their relation to the development of critical thinking

Learning is defined as a process that brings together personal and environmental experiences and influences for acquiring, enriching or modifying one's knowledge, skills, values, attitudes, behaviour and world views (Ertmer & Newby, 2013:45; UNESCO, 2004). The major theories that underpin the teaching and learning of knowledge, skills, values and attitudes include, among others, behaviourism, cognitivism, constructivism, transformative learning and experiential learning. Each of these theories is briefly explained below with the aim to clarify how and why the researcher identified a theory or theories that would underpin his Thinking Maps intervention.

2.7.1.1 Behaviourism

The basic idea of behaviourism is that learning consists of a change in behaviour due to the acquisition, repetition and application of associations between stimuli from the environment and the individual's responses to it (McNeeley, 2007:2). Behaviourists are mainly concerned with observable and measurable changes in behaviour, stimuli and responses and the formulation of rules that help to explain the relationships between the observable components and behaviour (Ertmer & Newby, 2013:45). Thorndike, a leading behaviourist theorist, conclude that (1) a response to a stimulus is reinforced when followed by rewarding the student, and (2) a response to a stimulus becomes stronger by exercise and is more likely to recur with repetition (UNESCO, 2004). This view of learning is characterised by the "drill-and-practice" programmes that are still at the order of the day in many educational institutions.

It seems reasonable to assume that behaviourists believe that specific ways of behaving are learned through stimuli and responses that can be reinforced or discouraged by applying respectively reward or punishment. The student is characterised according to his reactions to conditions in the environment and the focus is on acquisition of knowledge (Ertmer & Newby, 2013:48).

Since critical thinking is viewed by researchers like Brookhart, (2010:40), Duron *et al.* (2006:160), Paul (1985:37) and Paul and Elder (2006:4) as the ability to answer questions of analysis, synthesis and evaluation, solving problems and being creative, the researcher argues that one can expect problems when adopting a passive, teacher-centered, behaviourist approach to teaching to enhance the application of critical thinking. This argument is supported by Schunk (2000:118) who states that it is generally agreed that behavioural principles "cannot adequately explain the acquisition of higher level skills" like development of language, solving problems, generating inferences or other critical thinking skills.

2.7.1.2 Cognitivism

Cognitivism focuses on the student as an "active processor of information who is trying to make sense of the information given to him through lecturing and reading text books" (UNESCO, 2004). This viewpoint is supported by Ertmer and Newby (2013:50), who concur that learning is understood to be the acquisition of knowledge where the learner is an information-processor who absorbs information, applies cognitive processes such as thinking, problem-solving, language, decision-making, information processing and concept formation, and stores the information in his memory. The major difference between cognitivists and behaviourists is the locus of control over the learning activity. Learners are equipped with cognitive skills to select, analyse and evaluate information, where behaviourists emphasise the manipulation of the learning environment (Wallace *et al.,* 2007:128).

Cognitive theories provide a clear shift from behavioural stimuli and response theory to people who are regarded as information processors (Pintrich & Schunk, 2002:143; Schunk, 2000:119). This view is supported by McNeeley (2007:4), who argues that cognitive learning theories include thought, previous experience as a foundation to gain and organise new information, and the social environment to acquire and practise new information. This move away from the behaviourists' viewpoint to that of cognitivism, coincides with the emergence of the computer as an information-processing device (Ertmer & Newby, 2013:51).

In the process of conveying knowledge to students, mainly through lecturing and reading textbooks, the instructional design system is used to present procedures for guiding learning and understanding (Greeno *et al*., 1993:19). According to Ertmer and Newby (2013:51), cognitivism is concerned with how students gain and process knowledge, namely by applying higher level critical thinking skills such as being analytical, making inferences, and solving problems.

2.7.1.3 Constructivism

Constructivists argue that students should actively construct their own knowledge and are not merely passive recipients of knowledge. Construction of knowledge should take place by interacting with the environment and through the reorganisation of existing thinking structures (UNESCO, 2004). This view is shared by Ertmer and Newby (2013:55), Illeris (2015:31), McNeeley (2007:6) and Slavin (2003:260), who argue that constructivism is a combination of learning with creating meaning from the acquired knowledge. Students are therefore viewed as sense-makers, not simply gaining information but interpreting it and creating meaning. This view of learning led to the shift from "acquiring knowledge" to "creating meaning" metaphor (Ertmer & Newby, 2013:55).

Both Piaget and Bruner, earlier influential theorists of constructive learning, identified certain stages through which a human's mental development goes from infancy to adulthood (Illeris, 2015:31). Piaget (1969:26) viewed the student's active interaction with the physical and social environment as the most important factor in the stimulation of mental growth and development. According to Duminy *et al.* (1990:270), Bruner proposed the theory of discovery learning where students are given a wide variety of facts and information and are encouraged to discover the answer through underlying rules and principles. The provision of a classroom atmosphere, in which mistakes are seen as learning opportunities and students are encouraged to think creatively to take guesses, solve problems, formulate hypothesis and be analytical, are essential. Both Piaget and Bruner viewed the student as constantly interacting with the environment and the representation of the world by using new information (Illeris, 2015:31).

Bloom's taxonomy of the cognitive domain also underlines this sequence of progressive contextualisation of information. Only when students learn and understand are they able to apply, analyse and then synthesise and evaluate information (cited by Du Preez & Van Wyk, 2006:49).

Two major types of constructivism will be discussed in the following sections, namely socio-constructivism and cognitive constructivism (Powell & Kalina, 2009:241). Both have a student-centered, inquiry-based approach whereby the teacher becomes a cognitive and metacognitive guide of students' learning and not the transmitter of knowledge only (UNESCO, 2004).

Socio-constructivism

According to Powell and Kalina (2009:241), socio-constructivism involves ideas constructed in individuals through a personal process. Knowledge is considered as self-sufficient and independent of the contexts in which it finds itself. According to socio-constructivits, thinking and learning involve interactions between an individual and a situation/context. Knowledge acquisition is therefore considered as a product of the interaction and the situation/context in which it is acquired and utilised. This view gives way to a new metaphor for learning as "participation" and "social negotiation" (UNESCO, 2004).

The theory of socio-constructivism was constructed by Lev Vygotsky, who, although himself a cognitivist, rejected the assumption made by other cognitivists such as Piaget and Perry, who stated that learning can be separated from its social context (GSI Teaching & Resource Center, 2015a:1; Slavin, 2003:61). According to Vygotsky (1978:123), the role of language and culture should be emphasised in human intellectual development and how humans see the world.

Vygotsky (1978:123) argues that language and culture are the building blocks through which students experience, communicate and understand. This co-constructed knowledge by the student depends on the student's internal motivation to understand and promote learning (GSI Teaching & Resource Center, 2015a:3). Vygotsky (1978:84) states that learning is a collaborative process under guidance of teachers or in collaboration (collaborative learning) with fellow students, by giving students opportunities to discover, apply new information and solve problems to enhance critical thinking.

Cognitive constructivism

In cognitive constructivism, ideas are constructed from experience in individuals through a personal process to make meaning for the student, as opposed to social constructivism where ideas are constructed through interaction with the teacher and other students (Powell & Kalina, 2009:241).

Piaget's theory of cognitive constructivism has to do with the individual and how he constructs knowledge (Piaget, 1969:26). Cognitive constructivism implies that humans cannot be given information which they immediately understand and use. Instead, they have to construct their own knowledge based on their existing cognitive structures (GSI Teaching & Resource Center, 2015b:1). This viewpoint is supported by Slavin (2003:64-65), who states that each student interprets experiences and information in the light of their existing knowledge, their level of cognitive development, cultural background and personal history. According to Powell and Kalina (2009:242), Piaget rejected the idea that learning is a passive process where the student assimilates given knowledge. He instead proposed that learning is a dynamic process where students are actively involved by creating and testing their own hypotheses, discovering new information and solving problems through the application of higher order thinking skills.

From the above discussions of constructivism, it is reasonable to assume that learning is much more than memory. To enable students to really understand and learn, they must apply knowledge, work to solve problems and discover information which will lead to the development of higher order cognitive and metacognitive skills.

2.7.1.4 Transformative learning theory

According to Howie and Bagnall (2015:349) and Jarvis (2015:83), the transformative learning theory is a combination of processes throughout one's lifetime whereby the whole person, body (genetic, physical and biological) and mind (knowledge, skills, attitudes, values, emotions, meaning, beliefs and senses) change because of disjuncture, into a more experienced person. Mezirow (1991:167) defines transformative learning as a "process of becoming critically aware of how and why our assumptions have come to constrain the way we perceive, understand and feel"; and a way to change our habits of mind through critical self-reflection and act upon these new understandings and knowledge.

Transformative learning theory postulates that dynamic relationships between teachers/lecturers and learners/students during teaching learning promote learning, personal development and growth. Transformative learning requires an environment that encourages and rewards intellectual openness and open-mindedness to allow others to voice opinions with which one may not agree (McGonigal, 2005:1).

A cooperative teaching and learning environment promotes intellectual openness, as it enhances interaction between teachers and learners, creating opportunities for learners to engage in critical discourse with other students and to evaluate and change perspectives about issues (Brown & Brown, 2015:136). Transformative learning involves the institutions of learning, the students' life situations, the teachers and their situations, how the curriculum might unfold, but also the social systems such as families and peer groups. It involves critical reflection of one's own assumptions and knowledge, using rational interventions, self-examining, justification, but also reflection through discussion and conversation with others about viewpoints and perspectives (Brown & Brown, 2015:136; Howie & Bagnall, 2015:350; McGonigal, 2005:2).

2.7.1.5 Experiential learning

Experiential learning theories build on social and constructivist theories of learning, but situates experience at the core of the learning process, and aims to understand the ways in which experiences, whether first- or second-hand, motivate learners and promote their learning (Killen, 2007:50; Steffens, 2015:41). Therefore, learning is about meaningful experiences in everyday life, that lead to a change in an individual's knowledge and behaviours (UNESCO, 2004:2). In this regard Kolb (1983:38) defines learning as "the process whereby knowledge is created through the transformation of experience".

Kolb's assumptions of learning centres around the following concepts:

- Learning is best conceived as a holistic continuous process of creating knowledge grounded in experience, and not conceived in terms of outcomes.
- Learning requires the resolution of conflicts between dialectically opposed modes of adaption to the world.
- Learning involves transactions between the person and the environment (Kolb, 1983:38-40).

Experiential learning involves the application of information received from the teacher to the student's experiences in real life, also outside the classroom (Steffens, 2015:41-45). The student acquires new knowledge inside and outside the class, but also from other sources. The student learns through the process of testing whereby new information derived in or out of class is tested against the student's accustomed real-life experiences. In the process, the student transforms both the information and the experience into new knowledge (Steffens, 2015:41-45). Mayer, cited by Browne and Freeman (2000:304) states, "The key to developing critical thinking lies in creating conditions for participation rather than passivity, and in providing opportunities for emotional engagement with the materials".

From the above discussions of the learning theories the researcher argues that it is reasonable to conclude that the principles of **cognitivism** and **cognitive constructivism** appear to be the most appropriate to consider when teaching for the development of critical thinking. Cognitivism and cognitive constructivism postulate that students need to be involved in independent meaning-making and thinking that could contribute to better understanding and learning. All of these activities create opportunities for the development of higher order cognitive and metacognitive critical thinking skills and strategies. The social nature of learning as postulated by social constructivism also provides opportunities to develop the important critical thinking skills, strategies, dispositions and intellectual traits. In the context of this research, the researcher however mainly focused on the principles of cognitive constructivism that promote independent meaning-making.

The skill to think critically needs to be strengthened and reinforced by teachers through the teaching methods and strategies that they use during teaching. According to Stedman and Adams (2012:9), the presentation of learning material has a large effect on whether or not critical thinking takes place. Most teachers tend to use a lecture format in their classrooms, but this approach does not encourage or provide learners with the opportunity to master critical thinking (Duron *et al.,* 2006:161). The following section explores different teaching styles, teaching methods as well as teaching strategies, with specific emphasis on the methods and strategies that could develop students' critical thinking skills.

2.7.2 Teaching methods, teaching strategies to develop critical thinking

Against the background of the CAPS objectives (*cf*. Table 2.1), teachers should be key role-players in ensuring that learners at school develop good critical thinking skills, which will imply that teaching needs to become less teacher-centered and more student-centered (Kruger, 2002:109). It is important that teachers have adequate knowledge of a variety of teaching styles, methods and strategies to ensure that they will employ relevant approaches during teaching that would enhance the development of critical thinking.

Grosser (2009:22) asserts that a **teaching style** (transmission-reception style (teacher-centered) or facilitation style (student-centered)), refers to overarching characteristics, or a manner or way of presenting information and knowledge to students. Within each teaching style teachers employ teaching methods, which are procedures the teacher can use when presenting the learning content to students. Within each teaching method a variety of **strategies**, which are regarded as broad plans of action or activities which an teacher designs to ensure that students learn what they are supposed to learn (Jacobs, 2008:72; Mahaye & Jacobs, 2008:175), can be employed.

Figure 2.3 illustrates the different teaching styles and specific methods within each teaching style:

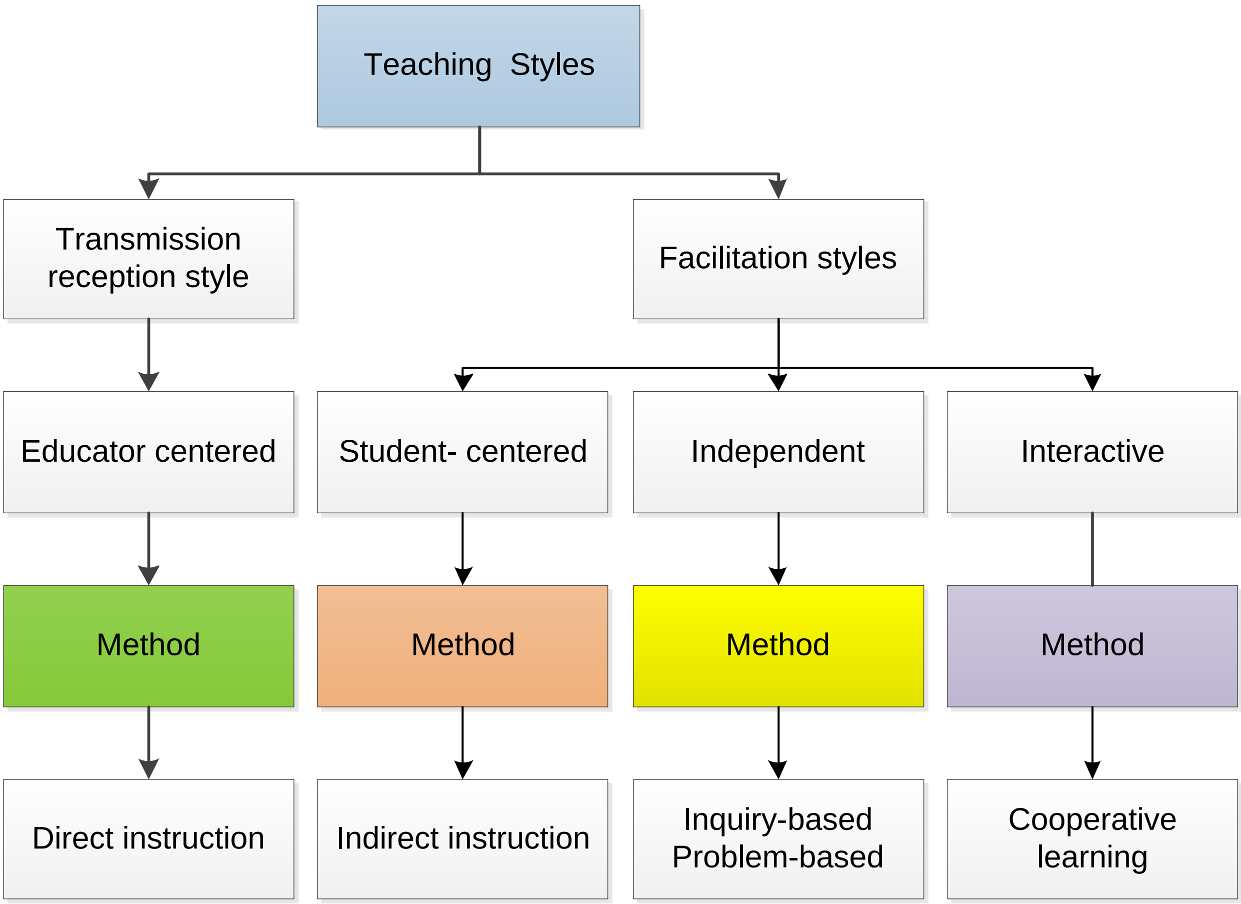


Figure 2.3 Teaching styles and specific methods (adapted from Grosser, 2009:4)

Figure 2.3 illustrates the two main teaching styles, namely the transmission-reception, teacher-centered and facilitation/student-centered styles, and the methods which can be used to teach, through direct, indirect, independent or interactive teaching. The following section explores the four methods of teaching within the two teaching styles, as well as strategies applicable to each of the methods.

2.7.2.1 Direct teaching methods and related strategies

Direct teaching is an teacher-centered approach where the teacher takes a central role, spending most of the time talking, explaining and communicating knowledge. The students normally have to listen passively without given a chance to react, ask questions or discover knowledge for themselves. The students seldom apply or practise their newly acquired knowledge (Arends, 2004:293; Kruger, 2002:109). Burden and Byrd (2010:120) assert that the teacher is in full control of the subject content and skills to be learned. Direct teaching is useful to introduce new skills or concepts in a short time period, therefore direct teaching is behaviouristic in nature (*cf.* 2.7.1.1) academically focused with the teacher controlling the pace and setting the goals (Gunter *et al*., 2003:64). Burden and Byrd (2010:120) support the effectiveness of direct teaching to learn basic skills more rapidly as it tends to increase the academic instructional time during which students attend to the task.

Table 2.6 lists some strategies of direct teaching.

Table 2.6: Direct teaching strategies

Strategies	**Method**
Lectures	Teacher presents lesson with visual aids. Students listen/take notes.
Presentation	Teacher disseminates information, explains difficult concepts, stimulates students' learning or explains tasks.
Demonstration	Teacher presents visual lesson/experiment to examine processes.
Questioning	Teacher guides students by using questions, moving from lower to higher level.
Recitations	Teacher asks students questions on previous work done.
Practice and drill	Teacher goes over material just learned and students repeat information until content is established in their minds.
Reviews	Opportunity for students to look at a topic another time (reteaching).
Guided practice	Students use and practise the knowledge and skills addressed in class step by step through work sheets.
Homework	Students study at home (assignments, work sheets).
Expert presentations	Teacher who specialises in a field provides a lecture as a guest speaker.
Dictation	Teacher reads or speaks and students write down the exact words.

(Burden & Byrd, 2010:120-134; Kramer, 2006:100)

According to Kramer (2006:100), direct teaching is not useful in building higher order skills such as analysis, synthesis, evaluation, problem-solving or understanding, but is effective in teaching cognitive objectives related to recall and knowledge.

It is essential that teachers practise direct teaching strategies to transfer important knowledge or information such as concepts, definitions, morphological and physiological information in order to stimulate students' understanding, because only then will they be able to apply the higher order skills of analysis, synthesis and evaluation.

2.7.2.2 Indirect teaching methods and related strategies

Indirect teaching is a student-centered approach, underpinned by cognitive and constructivist learning theory (*cf.* 2.7.1.2, 2.7.1.3) where students are active participants with a high degree of involvement and the students are more in control of their own learning by observing, investigating and drawing inferences. Moreover, indirect teaching stimulates learners' curiosity and encourage learners to produce alternatives to solve problems (Borich, 2003:94; Kramer, 2006:100; Kruger, 2002:110). Teachers provide students with opportunities to discover facts for themselves and to apply their newly acquired knowledge. Students are asked for input and two-way communication is promoted (Kruger, 2002:110). However, as Grosser (2009:27) asserts, indirect teaching is not effective for learning facts, complex concepts, or processes that need understanding. According to Rüütmann and Kipper (2011:110), indirect teaching involves teaching and learning in which concepts, patterns and abstractions are taught in the context of strategies that include concept learning, inquiry and problem-based learning. Indirect teaching includes the strategies listed in Table 2.7.

Table 2.7: Indirect teaching strategies

Strategies	**Method**
Class activities	Use activities that relate to the real lives of the students.
Bookmark notes	Teacher distributes full-length paper to be used as a bookmark; on which prompts and questions are recorded. Students are required to record notes and observations.
Concept maps	Students create visual, topic-based concept maps (*cf*. 3.4.2).
Harvesting	Students must reflect after an experiment/activity in class on "what" they learned, and what to learn next.
Chain notes	Teacher pre-distributes index cards and they are passed around; students write a brief answer to a question related to the learning.
Case studies	Students are given a real fictitious situation; students answer questions in order to understand facts, principles and concepts.

Strategies	Method
Micro-lessons	Students act as teachers in planning and delivering a micro-lesson.
Posters and collages	Students create an educational poster or collage to illustrate issues related to subject content.
Simulations	Students prepare and simulate situations and characters to enable problem-based learning; students making decisions and facing consequences.
Field trips and site visits	Students undertake practical experiments outside the classroom; students visit authentic sites related to the curriculum.
Chalk and talk	Students assigned to multiple boards around the room to brainstorm answers to an assignment.
Investigations and experiments	Students assigned to develop their own investigation/experiment to investigate a topic/theme.
Interviews	Students gather data from people and specialists on various topics/themes.
Students' self-evaluation	Engaging students in critical evaluation of their own responses and thereby taking responsibility for their own learning.

(Kramer, 2006:101; Rüütmann & Kipper, 2011:110; VanGundy, 2005:169-340)

Real-world activities involve analysis, synthesis, evaluation and decision-making behaviours in the cognitive (thinking) domain, organisation and characterisation behaviours in the affective domain, and articulation and naturalisation behaviours in the psychomotor (doing) domain. These behaviours are not learned by memorising facts and information. Instead, they must be constructed by students' own attempts to use personal experiences and past learning to bring meaning to and make sense out of the content provided. Teaching for higher order thinking requires instructional strategies that represent indirect instruction (Burden & Byrd, 2010:139; Rüütmann & Kipper, 2011:110).

In addition to the direct method of teaching to convey important information, ideas and concepts (knowledge), teachers must make use of several indirect strategies (such as case studies, field trips, experiments, investigations and simulations) that would create opportunities to foster and enhance students' higher order thinking skills.

2.7.2.3 Independent teaching methods and related strategies

Independent teaching methods are those in which students work by themselves and each student relies on his/her own efforts to accomplish a task or an assignment to enhance individual learner initiative, self-reliance and self-improvement (Borich, 2007:17; Philpott, 2009:38). The teacher may be involved in some way in the identification of the problem or observation (Burden & Byrd, 2010:157), but the students must plan and execute the task without close management by the teacher (Borich, 2007:17). According to Grosser (2009:37), the teacher's role in independent teaching is to direct and assist the students. Independent learning is effective in identifying weaknesses students may have and which the teacher may help in solving.

Table 2.8 lists some strategies that promote independent teaching and learning.

Table 2.8: Independent strategies

Strategies	**Method**
Learning centres/stations	Designated area in the class where students go to find and use resources/materials for tasks.
Contracts	Structure that provides the teacher and student to agree on tasks to allow students to work on their own.
Video/movie clips	Students provided with URL/hyperlinks to websites with curriculum-related content; students must provide answers/explanations to given questions.
Blogs	Teachers use blogs to "*push*" questions and discussion prompts to students; students work through problems on their own.
Homework	Students work outside the classroom.
Research projects	Students collect information on a topic; projects must be submitted to get marks.
Report projects	Students perform project (investigation or experiment) outside the classroom and submit a report (example: scientific method).
Interviews	Students conduct interviews and present results in class.
Assignments	Students answer question-related subject content, case studies, experiments etc.
Equipment-assisted learning	Students use computers, mobile phones, iPod etc. for learning; students acquire individual practice of skills.
Worksheets	Students work through investigative/experimental worksheets on their own; students acquire analytic and evaluation skills.
One-on-one debates	Students prepare a topic and discuss with their peers.

(Borich, 2007:17; Burden & Byrd, 2010:157-158; VanGundy, 2005:169-340)

The following sections are devoted to two specific strategies that form part of independent teaching and learning, namely **problem-based learning** and **inquiry-based learning**, which formed part of the subject content in Life Sciences that was addressed during the Thinking Maps intervention.

Problem-based learning

According to Snyder and Snyder (2008:93), critical thinking requires more than engagement; it involves students' personal discovery of information and knowledge. Problem-based learning (PBL) is a heuristic, student-centered method which encourages students to "learn, discover, understand, or solve problems on their own, as by experimenting, evaluating possible answers or solutions, or by trial and error" (Snyder & Snyder, 2008:93). In addition, Hmelo-Silver *et al*. (2007:100) concur that in problem-based learning students "learn content, strategies and self-directed learning skills through collaboratively solving problems, reflecting on their experiences, and engaging in self-directed inquiry" and that it involves hypothetically deductive reasoning.

Figure 2.4 represents the sequence of problem-based learning.

Figure 2.4: The sequence of problem-based learning

Figure 2.4 illustrates ways to solve problems. According to Spence (2001:4), in solving the problem assigned by the teacher, students will be unsure about the proceedings and what new knowledge is needed for a solution. Spence (2001:4) therefore suggests that students must work backwards by starting with an acceptable solution and then search for the necessary knowledge and evidence to support it. Spence (2001:4) asserts that nearly all the experts agree that cooperative learning group work is ideal for solving problems.

The goals of PBL are to help the learners develop flexible knowledge, effective problem- solving skills, self-directed learning, effective collaboration skills and intrinsic motivation (Dostál, 2015; Hmelo-Silver, 2004:235). The following steps apply when doing problem-based learning (*cf.* Table 2.9): (i) learners work in small groups (four learners per group), and firstly have to grasp the nature and scope of the problem and postulate possible explanations for the problem. Each learner plays a specific role in the group in relation to the completion of the task.

Table 2.9 summarises the steps during problem-solving.

Table 2.9: Steps during problem-solving

Steps	Students' reaction
1. Explore the issues.	What do I already know and believe about this topic and how can I share that with my teammates?
2. Define the problem.	What do I think is the problem we have to solve and how can my team agree on a problem statement?
3. Investigate solutions.	What do we have to know and do to solve this problem? Discuss problem statement, their knowledge and experience.
4. Research the knowledge and data that support the solution.	Plan; assign tasks; set deadlines.
5. Write the solution and submit.	Use communication skills to state solution clearly; support solution with plausible arguments and evidence.
6. Review the performance.	Go over your evaluation; as a team note the mistakes made; discuss the mistakes and plan improvements on how to solve the next problem.

(Snyder & Snyder, 2008:96; Spence, 2001:4-5)

PBL does not intend to generate single correct answers or solutions. The ideal is that different appropriate answers might apply. Learners are provided with guidance in solving the problem, but answers to the problem are not provided. Assessment should focus on how the problem was solved and not whether answers are correct. Finally, the solution needs to be communicated.

The role of the teacher is to facilitate learning by supporting, guiding, and monitoring the learning process, building learners' confidence to take on the problem, and encourage the learners, while also stretching their understanding. PBL represents a paradigm shift from a traditional lecture-based teaching and learning philosophy (Schmidt *et al.,* 2011:792-806).

There are four different kinds of problem-based teaching and learning, namely:

Experiments: Experiments are linked to formal curriculum-based problems that require an investigation into a hypothesis.

Case studies: Case studies can be based on real-life events that focus on a problem that needs to be solved.

Role-play and simulations: Role-plays and simulations can immerse learners in teacher-constructed real-life problem situations from which they should learn certain things, for example empathising with people.

Project work: Project work extends over a period, where research or investigations are conducted to collect information, and the information is then presented in a structured and coherent manner (South African Institute for Distance Education, 2013:314, 321).

Spence (2001:3) states that problem-based learning gives students opportunities to examine and try out what they already know; to discover what they need to learn; to develop skills for increased performance in teams; to improve their communication skills (verbally and written); to state and defend sound arguments and to become open-minded about their own beliefs and attitudes. Spence (2001:2) also found that problem-based learning environments increase students' critical thinking skills and knowledge acquisition. The teacher's role is to facilitate the learning process and may provide subject-content knowledge on a "just-in-time" basis (Hmelo-Silver *et al*., 2007:100), to enable students who get stuck to proceed with the problem-solving process.

Problem-based learning is educationally useful to nurture critical thinking because:

- Learners learn to apply cognitive and metacognitive skills and strategies such as interpretation, analysis, evaluation, making inferences, explanation and self-regulation.
- Learners have to make selections from different possible solutions to a problem and justify the selection.
- In finding the most suitable solution to a problem, learners learn to demonstrate the application of a number of dispositions, such as curiosity, truth-seeking, open-mindedness and systematicity.
- Problem-solving activities normally take place in small-group format during which learners need to acquire interpersonal skills and dispositions, such as cooperation and empathy, and the willingness to be open-minded to the ideas of others.
- In solving problems, learners need to learn how to do so by complying with the universal intellectual standards of reasoning, such as clarity, accuracy, precision, relevancy, significance, breadth and depth.
- In communicating the solution to a problem and justifying its solution, learners need to learn how to express themselves clearly, in writing and verbally (Hmelo-Silver *et al.,* 2007:100).

Inquiry-based learning

According to Arsal (2015:141), the critical thinking skills of pre-service teachers can improve if they are exposed to student-centered learning experiences, such as inquiry-based teaching. The teacher's role in inquiry-based teaching is to facilitate the learning process. Hmelo-Silver *et al*. (2007:100) assert that in inquiry-based learning students learn content as well as discipline-specific reasoning skills and practices by collaboratively engaging in investigations. Laboratory activities have long had a distinctive and central role in the science curriculum and science teachers have suggested that many benefits accrue from engaging students in science laboratory activities. More specifically, according to Qing *et al.* (2010:4598), when properly developed, inquiry-centered laboratories have the potential to "enhance students' constructive learning, conceptual understanding, and understanding" of the nature of science. Learning by using the inquiry approach involves students in formulating their own questions about a theme and having time to explore the answers using the **scientific method** (Figure 2.5) during their investigations. The students are both problem posers and problem solvers within inquiry learning. This is supported by Hofstein *et al.* (2001:193) who assert that the scientific method promotes inquiry, formulating questions, designing and conducting scientific investigations, formulating and revising scientific explanations, recognising and analysing alternative explanations which are abilities integral to critical thinking.

Figure 2.5 illustrates a possible **strategy** to facilitate inquiry-based learning by using the **scientific method**.

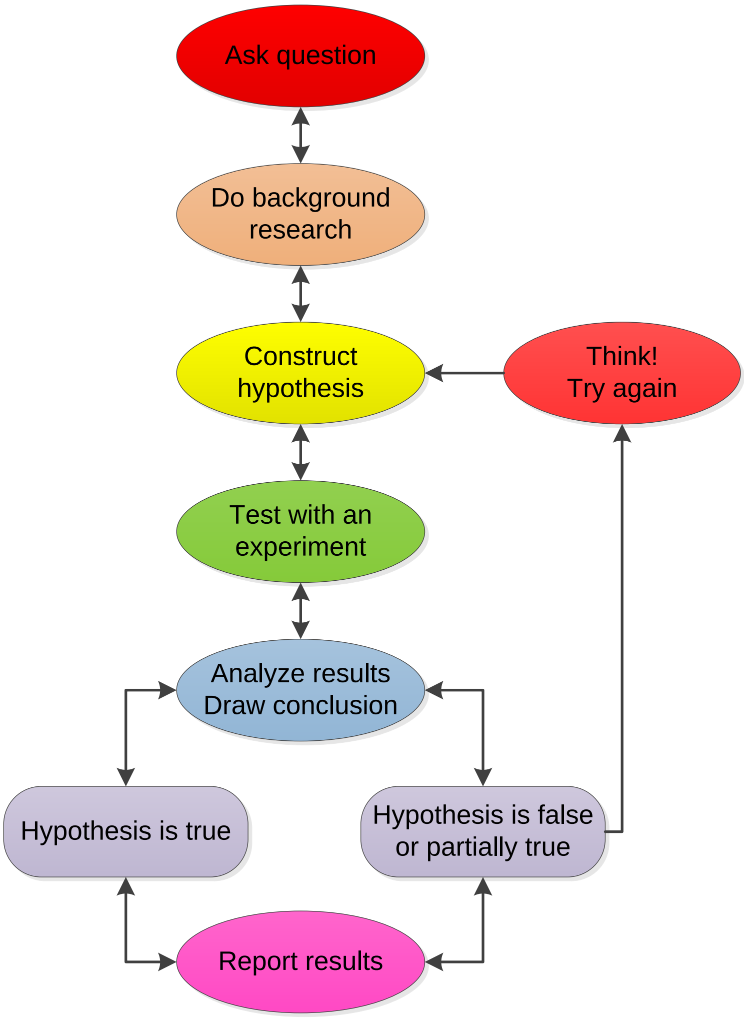


Figure 2.5: The scientific method (Gebhart *et al.,* 2012:4)

In summary, the scientific method depicted in Figure 2.5 comprises the following steps:

- Defining/Identifying the problem.
- Stating a possible hypothesis.
- Making observations or testing hypothesis and performing experiments
- Organising and analysing data.
- Establishing if experiments and observations support hypotheses.
- If not, performing new experiments and repeating step 4.
- Drawing conclusions.

The importance of appropriate questioning in inquiry-based learning is highlighted by Green and Murris (2014:127), who state that open procedural questioning extends students' thinking, enhances specific thinking skills and addresses inquiry. This is supported by McCollister and Sayler (2010:43), who argue that critical questioning is important to infuse critical thinking in teaching and learning, and "raises the intellectual level of thinking" in classrooms. Green and Murris (2014:127) propose the following non-content-specific questions summarised in Table 2.10, to engage students in further inquiry and critical thinking:

Table 2.10: Different kinds of open procedural questions used during teaching

Clarifying questions (listening and checking understanding).	Could you explain what you mean? Can you tell us a little bit more about your thinking?
Reasoning questions (expanding, probing, seeking justification).	What are your reasons for saying this? Why do you think that? If it is true, what will follow?
Inquiry questions (connecting, generalising, making distinctions).	Are you saying you agree ... disagree? Why? Is that always the case? Is that the same as ... ?
Creative questions (speculating, exploring implications and contexts).	What if ...? Is it possible that ...? How is that relevant ... ?
Evaluative questions (summarising, concluding).	What difference of opinion ... ? Have we learned anything new? How should we take this forward?

(Green & Murris, 2014:127)

Independent teaching and learning is an act of constructing knowledge in collaboration with others, or independently. The learning process involves the students' metacognitive skills of planning, monitoring and reflection in order to apply the new knowledge or information. The independent teaching method is in line with the requirements set out in the CAPS document (*cf.* Tables 2.1 and 2.2), which specify the use of the scientific and inquiry methods to enrich and enhance students' scientific language. An inquiry-based project allows students to use a question as a starting point and from there experimenting will be used to accept or reject hypotheses. Many of these abilities, namely questioning and hypotheses testing, require the application of critical thinking skills.

2.7.2.4 Interactive/participative teaching methods and related strategies

Interactive (participative) teaching involves two-way communication (cooperation) between the teacher and the students and between students. The teacher continuously monitors and responds to students' thinking. The teacher continues teaching by adjusting the flow and focus of a theme in response to how the students are thinking with the aim of allowing them to explore by asking questions, solving problems, processing, logical reasoning and communicating in the process of acquiring knowledge (Gawe, 2008:209; Grosser, 2014:241; Sessoms, 2008:88).

One of the methods through which interactive/participative teaching can be introduced into classrooms is using cooperative learning which promotes participation (Burden & Byrd, 2010:151; Gawe, 2008:209). According to Burden and Byrd (2010:152), Gawe (2008:209), Gunter *et al.* (2003:257) and Slavin (2003:270) cooperative learning is a structured and systematic way of teaching in which learners work together to ensure that all members in their groups have learnt and understood the same content, thus achieving a common goal.

Many different cooperative learning methods have been described and researched in the literature, but the most commonly found are described in Table 2.11 (Burden & Byrd, 2010:151; Gawe, 2008:221; Gunter *et al*., 2003:259; Slavin, 2003:270).

Table 2.11: Cooperative learning methods

Method	Application
1. Student teams achievement division (STAD)	• Students are assigned to four-member heterogeneous groups. • Teacher presents a lesson. • Students study worksheets and work within their groups to make sure all team members have mastered the lesson. • Individual tests or quizzes on material are given. • Students' scores are compared to their own past averages. • Points are summed to form team scores. • Team with highest score is recognised.
2. Teams-games-tournaments (TGT)	• Students are assigned to four-member heterogeneous groups. • Teacher presents a lesson. • Students study worksheet and work within their groups to make sure all team members have mastered the lesson. • Students play academic games. • Games are played weekly in a tournament with members of other teams. • Team with highest score is recognised.

Method	Application
3. Cooperative integrated reading and composition (CIRC)	• Comprehensive programme for teaching reading and writing. • Students work in four-member groups. • Students engage in activities with one another, including reading, make predictions, summarising stories, writing responses, mastering spelling and vocabulary.
4. Jigsaw	• Students are assigned to expert groups and each group is given academic material. • Students read and discuss material in expert groups. • The experts return to their home groups to teach the information to their group mates. • Quizzes / tests are given to each learner.
5. Learning together	• Students work in heterogeneous groups on assignments. • Groups hand in a single completed assignment. • Students receive praise and rewards based on group product.
6. Group investigation	Students work in small groups using cooperative inquiry, group discussion, cooperative planning and projects.

(Burden & Byrd, 2010:151; Gawe, 2008:221-222; Gunter *et al*., 2003:259-271; Slavin, 2003:273-276).

Table 2.12 illustrates additional cooperative learning strategies.

Table 2.12 Additional cooperative learning strategies.

Strategies	Method
Think-pair-share	• Students initially work independently. • Move to pairs to discuss their findings/answers. • Students must report.
Round-robin	• Place students in groups and they share their answers with others verbally.
Panel	• 4 – 6 participants with a chairperson discuss a topic among themselves and rest of class listens and asks questions.
Symposium	• Formal presentation of information by each member.
Debate: polar opposites	• Ask the class to examine two written-out versions of for example, a theory/law of nature, one is incorrect/the opposite of the other. • In deciding which is correct, students will have to examine a topic from all angles.

Strategies	Method
Role-playing	• Student-directed activity in which students act a particular situation. • Rest of class observes and analyses the situation.
Simulations	• Place students in real-life situations. • Students are required to assume roles, make decisions and face consequences.
Games	• Involve students in competition. • Teach variety of skills, including problem-solving and decision-making.
Picture prompt	• Show students an image with no explanation. • Ask them to identify/explain it. • Students justify their answers.
Think break	• Teacher asks a rhetorical question. • Allow 20 seconds for students to think about the problem. • Teacher goes on to explain.
Pass the pointer	• Place a complex/intricate/detailed image on screen. • Ask students to identify key features with aid of pointer. • Ask questions about items students do not understand.
Empty outlines	• Distribute partially completed outline of lecture. • Ask students to complete the outline.
Ask the winner	• Students silently solve a problem. • Teacher reveals the answer. • Ask students who got it right to raise their hands. • All students who answered incorrect, need to talk with someone with a raised hand.
Interactive video quizzes	• Using annotations and making them hyperlinks to other uploaded videos. • Teachers can construct an on-screen multiple choice test leading to differentiated video reactions, depending on how student answers.

(Burden & Byrd, 2010:152-157; Grosser, 2014:236; Kramer, 2006:104; VanGundy, 2005:169-340)

Opportunities for acquiring critical thinking skills and traits such as problem-solving, communication, questioning, processing, humility, empathy, open-mindedness and understanding are addressed with cooperative learning activities.

When students are accustomed to being passive learners by merely memorising and recalling information (teacher-centred), it may be difficult at first to engage them in active learning (student-centred), that requires the application of critical thinking skills (Snyder & Snyder, 2008:96).

2.8 CHAPTER SUMMARY

This chapter focused on a conceptualisation of critical thinking. Critical thinking involves the interrelated application of different elements, such as the core critical thinking skills, metacognitive strategies, critical thinking dispositions/behavioural traits, intellectual traits and the universal intellectual standards of reasoning (*cf.* 2.2).

The importance of enhancing the development of critical thinking was linked to the CAPS curriculum, teaching and learning in 21st century, the acquisition of life skills and the role of critical thinking in Life Sciences (*cf.* 2.3). Teachers themselves need to be good critical thinkers before they can teach learners to think critically.

The critical thinking abilities of pre-service teachers within an international and national context revealed that school learning apparently does not prepare pre-service teachers to apply critical thinking skills, and that the development of the critical thinking skills of pre-service teachers are fragile and in need of development (*cf.* 2.4).

Different measuring instruments, multiple-choice, open-ended and commercially available tests to assess the development of critical thinking skills were explored in section 2.5. In the absence of subject-related tests to establish the application of critical thinking in Life Sciences, the researcher decided to set his own subject-related test, comprising closed multiple-choice test items as well open test items to establish the extent to which the students possessed the critical thinking skills on which the research focused prior to, and after the Thinkig Maps intervention.

Factors that could inhibit the development of students' critical thinking such as political, educational, personal, behavioural, cultural and language factors were discussed, and the importance of, in particular, teaching practices to enhance the development of critical thinking skills were highlighted (*cf*. 2.6).

Finally, different learning theories, teaching styles, teaching methods and teaching strategies and their relation to the development of critical thinking were described with the aim to identify a suitable teaching-learning framework that would guide the design and implementation of the Thinking Maps intervention (*cf*. 2.7). Flowing from the discussions in section 2.7 the researcher argued that a cognitivist and cognitive constructivist teaching and learning framework and the facilitation of teaching and learning by means of independent teaching methods and strategies would provide the necessary opportunities to enhance the development of critical thinking. Independent teaching encourages learner activity and independent involvement in selecting, analysing and evaluating information.

The next chapter, Chapter 3, clarifies the merits of visual learning, with specific reference to the use of Thinking Maps, for enhancing the development of critical thinking.

CHAPTER 3

DEVELOPING CRITICAL THINKING THROUGH VISUAL LEARNING: THE ROLE OF THINKING MAPS

3.1 INTRODUCTION

In Chapter 2 the researcher identified cognitivism and cognitive constructivism as suitable theories to underpin teaching and learning that would enhance the development of critical thinking. In addition, applying independent teaching methods would also possibly contribute to creating opportunities for enhancing the development of critical thinking in Life Sciences. In Chapter 3 the role of visual learning by using Thinking Maps as a teaching strategy that would support independent teaching and learning for enhancing the development of critical thinking in Life Sciences, is explored. The chapter addresses the following issues:

3.2 Characteristics of effective learning

3.3 Learning styles

- Introduction
- Visual learning
- Auditory learning
- Kinaesthetic learning
- Learning through reflection

3.4 Types of visual learning strategies

- Mind Maps
- Concept Maps
- Graphic organisers
- Charts and diagrams

3.5 Thinking Maps as visual learning strategy to enhance the development of critical thinking

- The difference between Thinking Maps and other visual strategies
- Thinking Maps: A concept clarification
- Types of Thinking Maps and their related functions
- The role and place of Thinking Maps in Life Sciences to enhance the development of critical thinking
- The importance of Thinking Maps for enhancing effective learning and critical thinking skills

3.6 Chapter summary

Although it was important for the researcher to determine whether the use of Thinking Maps would not only provide opportunities to enhance the development of critical thinking, the use of Thinking Maps also had to contribute to effective learning of subject content. The following section therefore explores the characteristics of effective learning and aligns the criteria for effective learning with the use of Thinking Maps.

3.2 CHARACTERISTICS OF EFFECTIVE LEARNING

Watkins (2002:1) defines effective learning as a reflective activity where students draw upon prior learning experiences to understand and evaluate present learning experiences with the aim to gain new knowledge independently and in collaboration with others. Emanating from this definition of effective learning one can conclude that the effective learner:

- is an active and strategic learner;
- is skilled to work in groups;
- is able to develop goals and plans; and
- monitors his/her own learning towards achieving goals.

Grosser (2007:38), Monteith (2002:93) and Pritchard (2014:119-120), add to the characteristics of effective learning by adding the following elements:

- new information is linked to previous knowledge;
- information is organised;
- cognitive and metacognitive skills and strategies are acquired to aid meaning-making of information;
- effective learning is cumulative and occurs in phases, although a linear connection is not assumed; and
- is influenced by social interaction.

The aforementioned elements align well with the perspective of De Corte (2011:33-47) who regards effective learning as the contextual and collaborative construction of knowledge as well as the importance of well-developed self-regulation skills applied during the process of learning.

Considering the above characteristics of effective learning, Watkins (2002:2) emphasises and concurs with De Corte (2011:35) that learning is not only the acquisition of particular skills and strategies, but also involves the student in core critical thinking and metacognitive processes of self-regulation, namely planning, monitoring and evaluation.

Many of the aforementioned elements cited for effective learning are contained in the perspective of Frenton (2015) who identied 20 principles of learning for the 21st century.

- Students' beliefs about their own ability affect their cognitive functioning and learning.
- Pre-knowledge affects new learning.
- Cognitive development and learning are not limited by general stages of development.
- Learning is based on context.
- Acquiring long-term knowledge and skills depends on extensive practice.
- Clear and timeous feedback to students is important for learning.
- Self-regulatory skills are important and can be taught.
- Creativity can be fostered and is required for effective problem-solving.
- Learning needs to be enjoyable to motivate students intrinsically.
- Mastery goals enable students to face challenging tasks better.
- Teachers' expectations affect students' motivation to learn.
- Setting short term goals with moderate challenges enhance motivation.
- Learning is situated within various social contexts.
- Interpersonal relationships and communication are critical for learning and social development.
- Emotional well-being plays a role in academic performance.
- Clear expectations guide and direct learning.
- Effective classroom management is based on high expectations, nurturing positive relationships, providing a high level of student support.
- Formative and summative assessments are both important and useful.
- Assessment tasks shoud be fair.
- Fair interpretation should accompany student assessment.

The use of Thinking Maps supports a number of the characteristics of effective learning, namely: it involves active learning, information is organised, it involves the acquisition of thinking processes and learners can monitor their own learning (Hyerle & Yaeger, 2007:8-16).

Thinking Maps furthermore support the use of visual learning. The next section will elucidate the use of visual learning as a learning style.

3.3 LEARNING STYLES

3.3.1 Introduction

Types of learning, or learning styles, can be defined in multiple ways. According to Grosser (2009:12), Gilakjani (2012:105), and Gilakjani and Ahmadi (2011:469) and Pritchard (2014:69), learning styles involve orientations to process information in certain ways. Pritchard (2014:46) defines a learning style as a preferred way of learning and studying. He argues that individuals have preferences, which refer to specific intellectual approaches to learning, for example using pictures instead of text; working in collaboration with others instead of working alone In essence, learning styles refer to the primary and preferred way in which humans acquire information, which can be visual, auditory, kinaesthetic or reflective (Gilakjani, 2012:105). Each of the styles will be summarised briefly.

3.3.2 Visual learning

Visual students prefer sight-based learning, writing, drawing, neatness, demonstrations, pictures, videos, graphics, diagrams, charts and models. Visual students think in pictures and learn best in visual images; they depend on the teacher's body language to help with understanding and take descriptive notes on presented material (Gilakjani, 2012:105; Gilakjani & Ahmadi, 2011:469).

3.3.3 Auditory learning

Auditory learning is voiced-based learning and auditory students prefer talking, reading aloud, singing, and listening to lectures, recordings, storytelling and music. According to Gilakjani (2012:106), and Gilakjani and Ahmadi (2011:470), auditory students discover information through listening to lectures, recordings, storytelling and music. These students gain knowledge from reading out loud and may not fully understand written information.

3.3.4 Kinaesthetic learning

Kinaesthetic students prefer movement-based activities (Gilakjani, 2012:106; Gilakjani & Ahmadi, 2011:470). Gilakjani (2012:106) and Gilakjani and Ahmadi (2011:470) concur that kinaesthetic individuals learn best with an active "*hands-on*" approach and favour interaction with the physical environment.

3.3.5 Learning through reflection

According to Pritchard (2014:48), reflectors collect as much information as possible and make careful observations before they make decisions. They collect data and analyse the data before any conclusion is made. Reflectors are slow to make up their minds but when they do, it is based on sound knowledge, opinions, and their own experiences and what they have taken in when watching and listening to others.

Pritchard (2014:51) argues that students use all the different types of learning to some extent, but some students rely heavily on one of them and different students may need different types of learning. From this discussion one may conclude that teachers must cater for a variety of students to accommodate their learning types.

As this research explored the effect of Thinking Maps as a visual learning strategy for enhancing critical thinking, the next section will be devoted to identify the role of Thinking Maps among the other different types of visual learning strategies, and motivate why Thinking Maps were regarded as the more suitable visual strategy to enhance the development of critical thinking skills in the context of this research.

3.4 TYPES OF VISUAL LEARNING STRATEGIES

Our ability to learn visually is greater than by any of our other senses (Hyerle & Yeager, 2007:3), and 80% of information that comes into our brain is visual (Jensen in Hyerle & Yeager, 2007:3).

Visual strategies involve, among others, the use of Mind Maps, Concept Maps, Graphic Organizers and tables, charts and diagrams. Each of the strategies will be briefly discussed below.

3.4.1 Mind Maps

Mind Maps (*cf.* Figure 3.1), are visual tools making meaning of or explaining one central concept or idea (Buzan, 2014:14). According to Hyerle (2009:155), Mind Maps:

- promote creative thinking;
- enable students to be creative and personalise their learning strategy;
- are flexible with different ways of representation;
- promote students' disposition for ingenuity, originality and insightfulness to express their thinking process;
- explore all the creative possibilities of a given subject; and
- create new conceptual frameworks within which previous ideas can be reorganised.

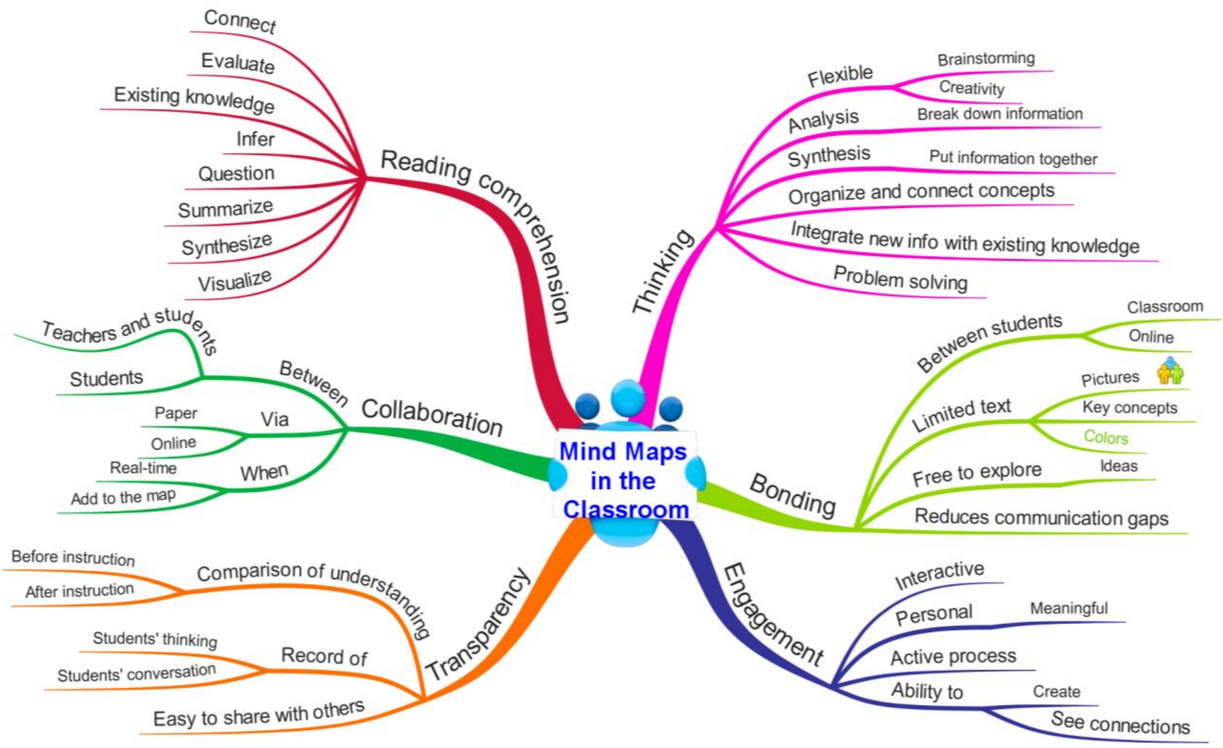


Figure 3.1: Mind Map

Figure 3.1 illustrates the construction of the Mind Map that focuses on understanding a particular concept or idea. Students start in the centre of a page and branch out as a concept or idea expands. Students are able to personalise their thinking process with images, colour, codes and emphasis (Hyerle, 2009:154).

3.4.2 Concept Maps

Concept Maps (*cf*. Figure 3.2) are visual tools for organising and representing knowledge as relationships between ideas with topics and sub-topics (Novak, 2006:1). Novak (2006:1-2) states that Concept Maps:

- can help students to identify general concepts prior to learning and assist in mastering learning tasks through progressively more explicit knowledge;
- are evaluation tools and encourage students to acquire meaningful learning patterns; and
- are effective in identifying valid and invalid ideas held by students.

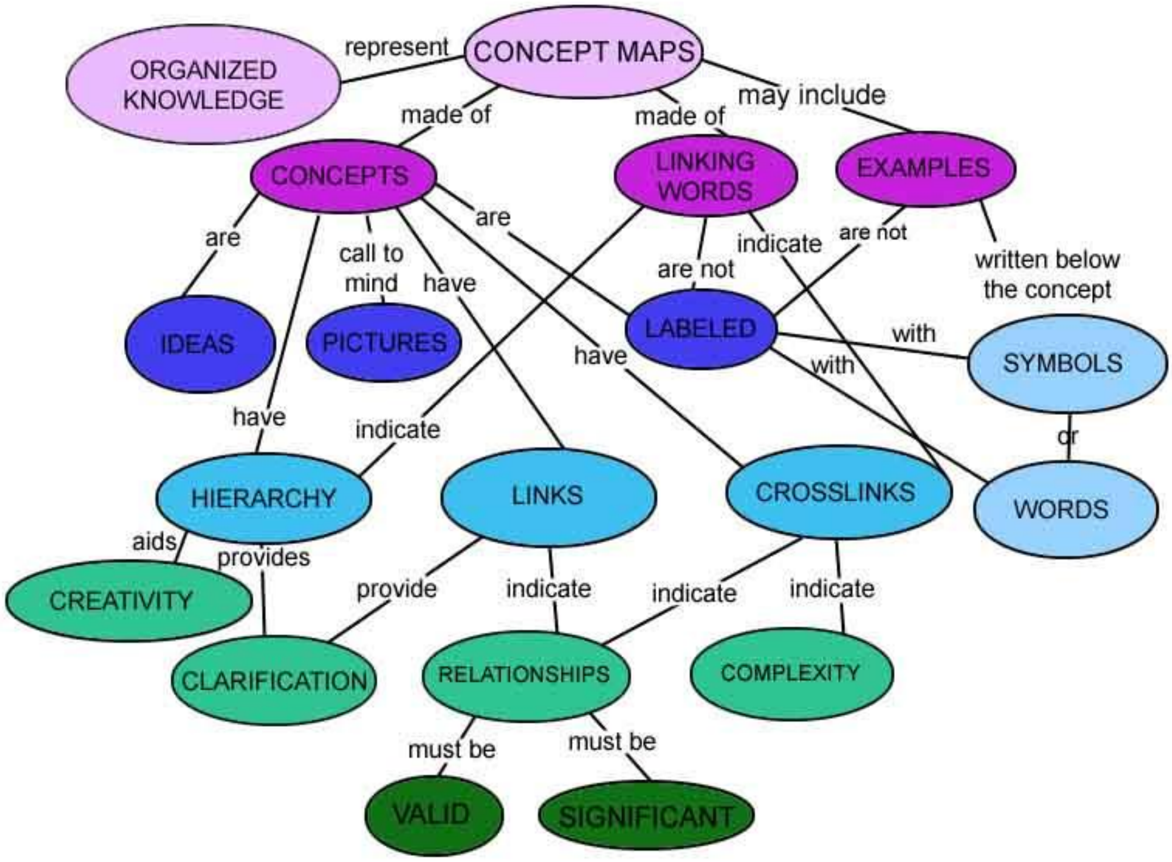


Figure 3.2: Concept Map (Novak, 2006:1)

Figure 3.2 illustrates the general structure of a Concept Map. Concept Maps include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts or propositions, indicated by a connecting line between two concepts. Words on the line specify the relationship between the two concepts (Novak, 2006:1).

3.4.3 Graphic Organisers

Graphic Organisers (*cf*. Figure 3.3) are visual tools that resemble networks of information and allow students to organise information around one thought or idea (Ausubel, 1978:251). Teachers often match the Graphic Organisers with content specific strategies (life cycles in Life Sciences, time lines in History, Venn-diagrams in Mathematics) and Graphic Organisers are therefore task and subject specific. Graphic Organisers, as illustrated by Ausubel (1978:151-155), can be used to enhance students' thinking skills by encouraging brainstorming, generating new ideas, connecting parts to the whole, drawing sequence and analysing causes and effects. Graphic Organisers have a number of attributes that enhance students' thinking skills.

- They allow students to make connections among pieces of information and make information easier to recall.

- They also allow students to break information into manageable parts, so that they can easily see the relationships among the separate ideas.
- They provide a means to observe and assess the students' thought processes (Hyerle, 2009:155-156).

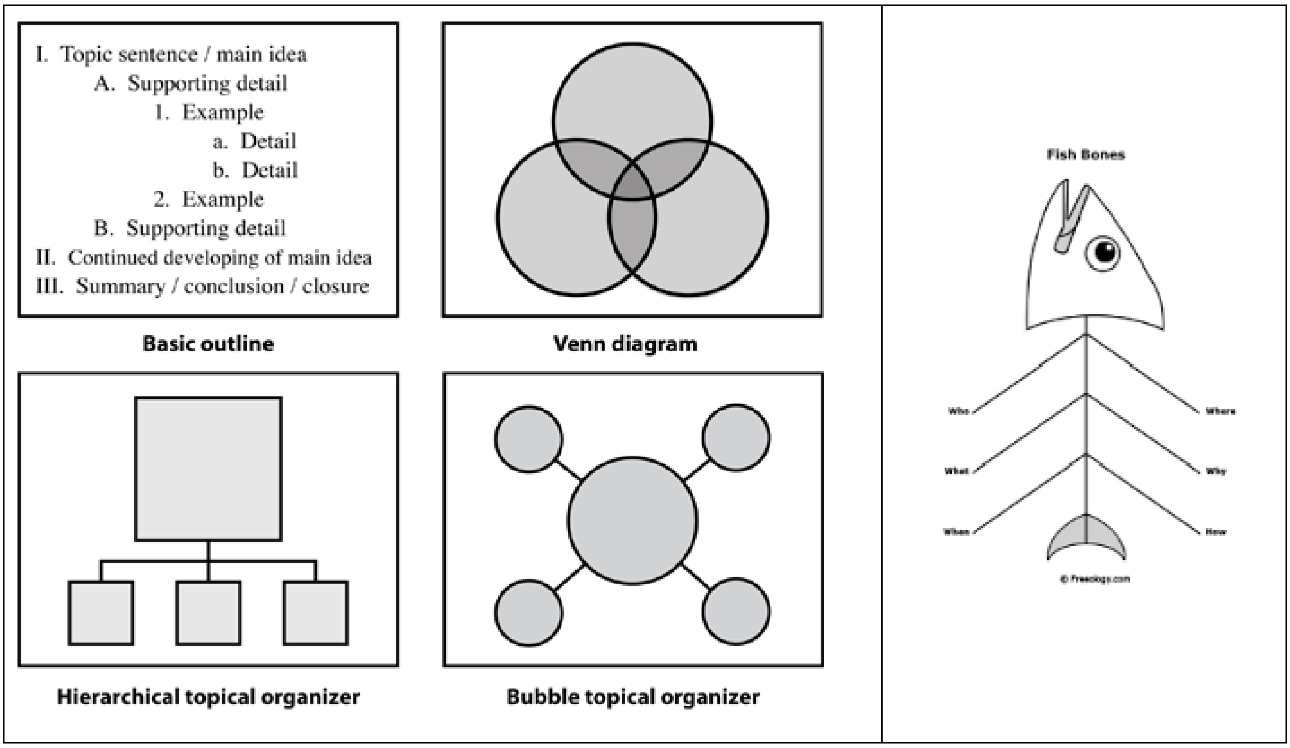


Figure 3.3: Graphic Organisers (Figueras, 2013)

Figure 3.3 illustrates possible, flexible structures of Graphic Organisers. Teachers create a specific visual structure that students follow and complete as lessons progress (Hyerle, 2009:155). Hyerle (2009:155) argues that Graphic Organisers are highly structured and of good use for students as they systematically organise ideas.

3.4.4 Charts and diagrams

Pie charts, bar charts, histograms, line graphs and diagrams (*cf.* Figure 3.4) are all different ways of representing information visually. They usually provide a quick summary that gives a visual image of the data/information being presented (Gilmartin & Rex, 1999:14).

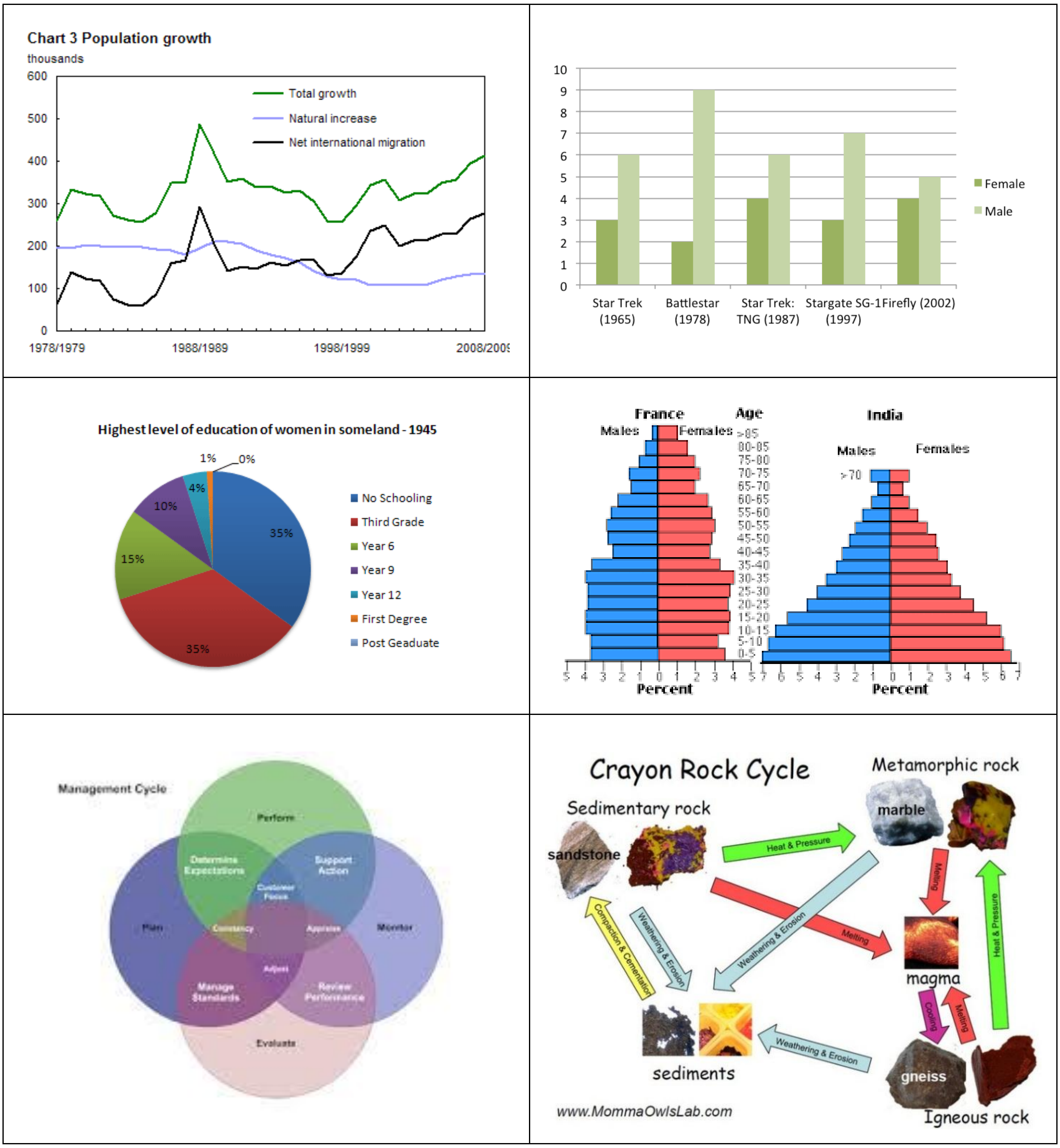


Figure 3.4: Chart and diagrams (Google images)

Figure 3.4 demonstrates some charts and diagrams which are used to illustrate information discussed in subject-content, case studies or experimental procedures. It is important to be able to interpret them correctly as they present the facts and figures in such a way so as to confirm an argument (Gilmartin & Rex, 1999:21).

None of the aforementioned visual strategies (Mind Maps, Concept Maps, Graphic Organisers, charts and diagrams) scaffold the development of thinking processes (Hyerle, 2009:157). However, according to Hyerle (2009:157), Thinking Maps provide a strong connection between brain research and exactly mirror and support the development of students' thinking processes (*cf*. 3.5.5).

As the focus of the study was on Thinking Maps to enhance the critical thinking skills of pre-service Life Science teachers, the next section will elucidate the importance of Thinking Maps as a visual learning strategy to enhance the development of critical thinking.

3.5 THINKING MAPS AS VISUAL TEACHING AND LEARNING STRATEGY TO ENHANCE THE DEVELOPMENT OF CRITICAL THINKING

Thinking Maps is a teaching strategy used in successful classrooms to promote cognition and metacognition amongst students. Costa (2009:16) stated that "Although thinking is innate and spontaneous, skilful thinking must be cultivated." This is the crux of all of education – teaching students how to think and reason critically, and in this regard Thinking Maps appear to be a valuable strategy.

The following section compares Thinking Maps to the other visual strateiges.

3.5.1 The difference between Thinking Maps and other visual strategies

According to Hyerle (2009:151), similarities between Thinking Maps and other visual learning strategies include that they are all visual tools that could be used during teaching and assessment, and all can be highly successful. However, he states that Thinking Maps are *cognitive tools* to facilitate specific thinking skills (Hyerle, 2009:151). There are several differences between Thinking Maps and the other visual strategies, as illustrated in Table 3.1.

Table 3.1: Differences between Thinking Maps and other visual strategies

Thinking Maps	Other visual strategies
Fixed visual designs for eight thinking processes. Common set of fixed visual patterns across subject disciplines, grades and schools, reinforced in similar ways. Not ready-made by the teacher.	Focus on isolated tasks and defined structures. Can be ready-made and given to students by the teachers. Flexible and can take on different ways of representation. Learners can construct individualised maps, that differ across subjects.
Open-ended to complete thoughts and ideas.	Restrict the thought process to fill the defined space with concept information.
Easily transferable across subjects, due to fixed designs.	Difficult to transfer from one subject to the next due to flexible structures.
Student-oriented, individual meaning-making.	Mostly teacher-oriented and often ready made.

Thinking Maps	Other visual strategies
Visual strategy for making meaning, organising information and acquiring a thought process.	Visual strategy for organising information and making meaning of a topic.
Focus on eight fundamental integrated thinking processes.	Focus on explaining a central concept in detail.
Cross-discipline strategy to reflect depth and complexity of thinking.	Personalised, content specific strategy.
Main functions are making meaning, organising information and acquiring a thought process.	Main function is to summarise and organise information.

(Hyerle, 2009:151-157; Hyerle, 2014:162-163)

From Table 3.1 it is clear that Thinking Maps could be regarded as effective for enhancing the development of critical thinking because they address eight fundamental thinking processes that are involved in critical thinking and describe how these thinking processes work in unison. Additionally, Thinking Maps are not subject-bound, are student-oriented and clearly define cognitive skills, drive learning, incorporate metacognitive strategies and eliminate confusion that can come from other maps and graphic organisers that have flexible structures (Hyerle, 2014:162-163). According to Hyerle and Yeager (2007:8), students who consistently use the same visual pattern for a specific thought process soon have a visual pattern for thinking and become independent learners.

The subsequent sections explore the use of Thinking Maps during teaching and learning.

3.5.2 Thinking Maps: A concept clarification

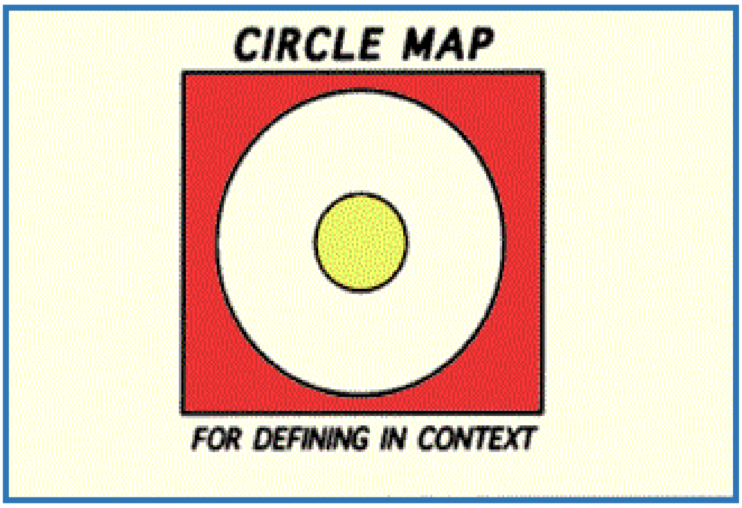
Thinking Maps is a teaching strategy that consists of a set of eight visual tools designed to help students develop critical thinking processes and habits for problem-soving, as well as reading (Hyerle & Yeager, 2007:2). Thinking Maps are designed to represent a specific cognitive process that can be used in a multidisciplinary and integrated fashion across age groups in any subject field (Hudson, 2013:9).

3.5.3 Types of Thinking Maps and their related functions

Thinking Maps is a set of eight maps based on cognitive skills that support the brain’s natural tendency to detect patterns. For this reason the maps are used across the curriculum, in any subject (Hudson, 2013:9). More than one map may be used for a particular topic highlighting the interrelated application of different cognitive skills visually. Thinking Maps are visual representations of the following skills namely, defining, describing, comparing, categorising, seeing cause-and-effect relationships; analysing part-whole relationships and helping students see their own learning pathway or the thought processes and finding analogies utilised to solve a problem. According to Hyerle (2009:153), students who present their thinking with visual tools practise metacognition because they describe the thinking processes they use to organise content and knowledge. The Thinking Maps can be used on their own or in tandem with other Thinking Maps to create a common visual language for students and teachers at all grade levels and in all subject areas (Hudson, 2013:3; Hyerle, 2009:164-165). Examples of how the eight different Thinking Maps could be applied to Life Sciences are explained in the following sections.

3.5.3.1 Circle Maps

Figure 3.5 highlights the thinking process related to defining in context, which focuses on defining a concept, thing, or idea in specific contexts (Hyerle & Yeager, 2007:24). Construction of a Circle Map begins with a small inner circle and a larger outside circle. Words, symbols or pictures are placed in the innermost circle. This would be the concept, word, or symbol that needs to be understood and defined. Context information that gives definition to the topic makes up what is written or drawn in the outer circle. The information in these two circles together define a topic and shows the thinking process. Circle Maps should be filled with key words, phrases, descriptors, and/or illustrations (Hyerle & Yeager, 2007:26).



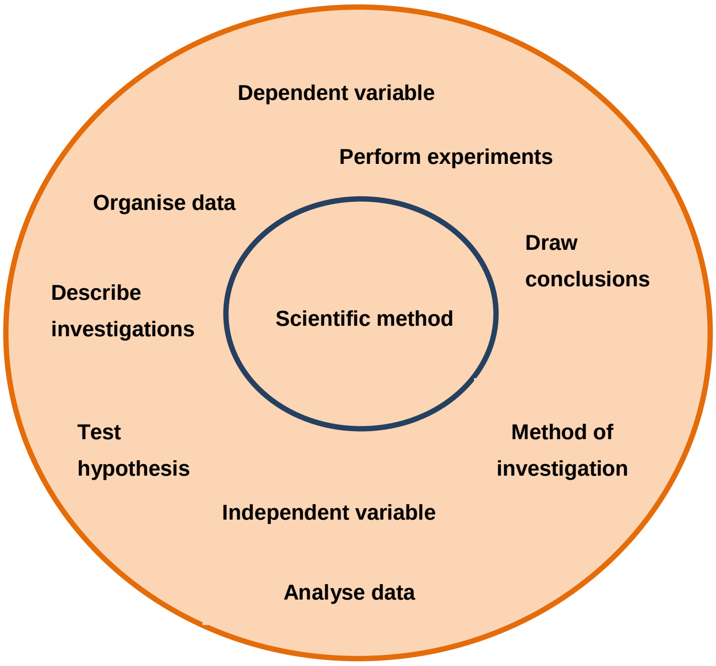
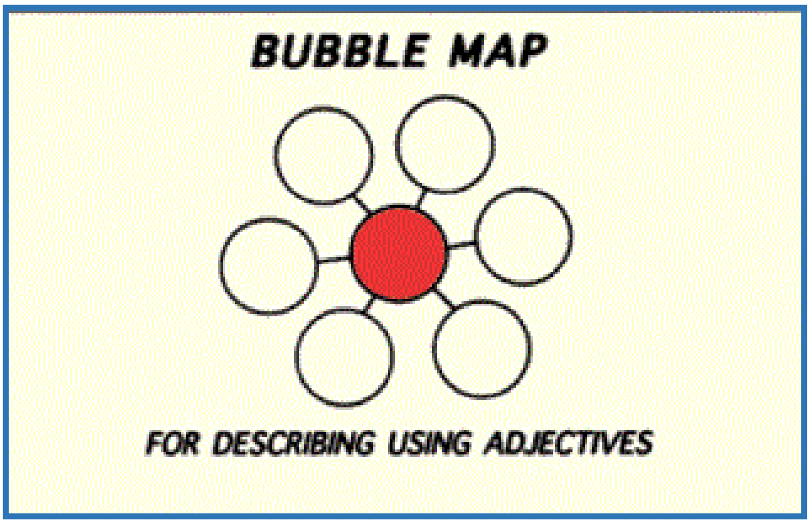


Figure 3.5: Circle Map:Describing the scientific method (Adapted from Hyerle & Yeager, 2007:24)

Circle Maps are used mainly for brainstorming ideas and thoughts about a topic (Hyerle, 2014:165). They can be used on their own or as a starter map. Circle Maps provide a formative assessment of what the student knows at a specific moment in time. Circle Maps have many applications, such as vocabulary development, accessing prior knowledge, identifying misconceptions or reviewing information after lessons (Hyerle & Yeager, 2007:26).

3.5.3.2 Bubble Maps

The thinking process involved in describing properties or providing attributes or characteristics is captured with a Bubble Map (Figure 3.6). The Bubble Map is used to describe attributes or characteristics by using adjectives with the aim of identifying sensory and emotional qualities of a concept (Hyerle & Yeager, 2007:30). The Bubble Map is constructed with a word or symbol being placed in a larger inside circle. This would be the concept, noun or symbol to be described. Adjectives describing the noun, concept or symbol in the inner circle are written in bubbles connecting to the inner circle. Key words used to guide the construction of the Bubble Map include: describe, use vivid language, identify comparisons, qualities, characteristics and properties (Hyerle & Yeager, 2007:32).



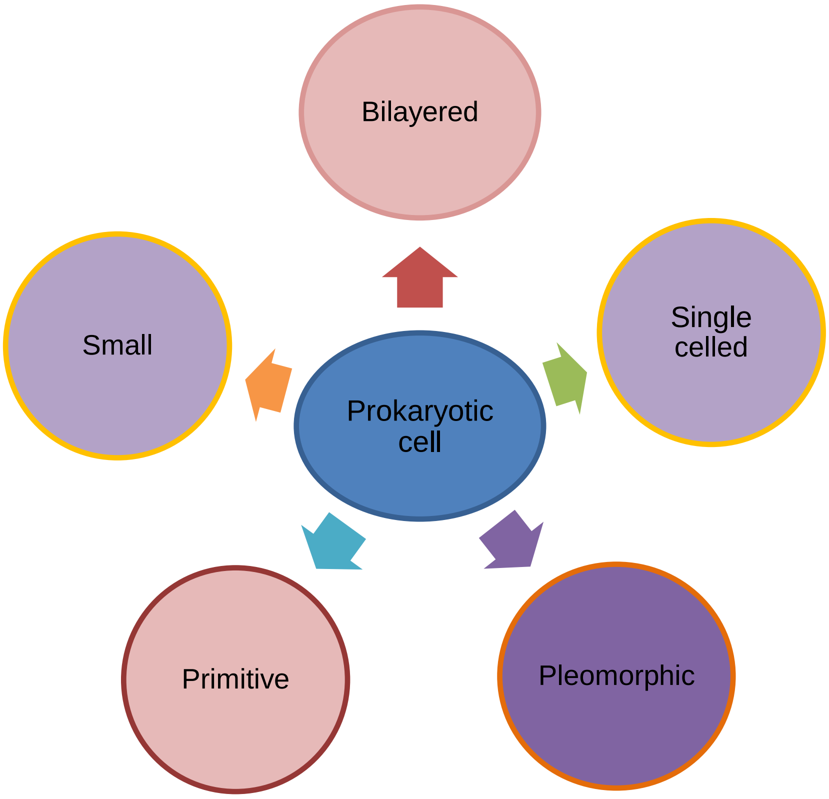
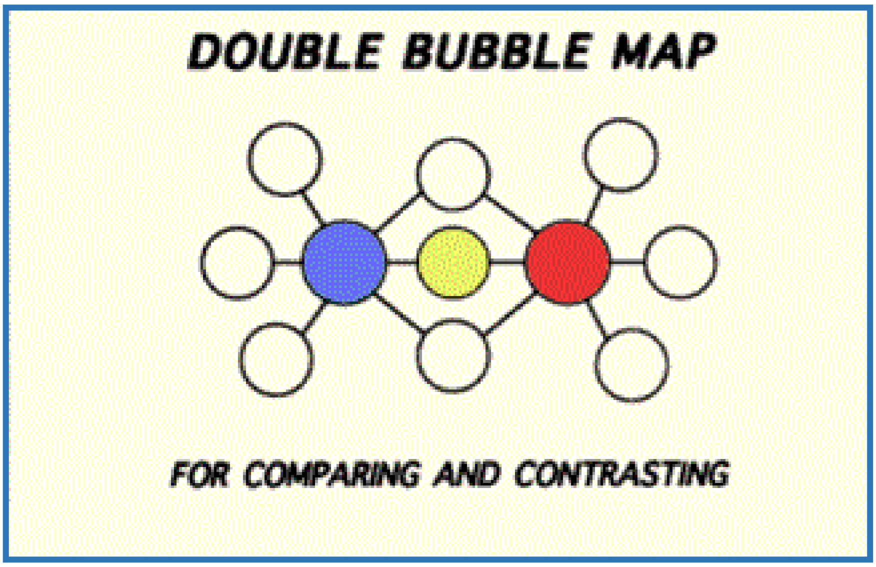


Figure 3.6: Bubble Map: Characteristics of the prokaryotic cell (Adapted from Hyerle & Yeager, 2007:30)

3.5.3.3 Double Bubble Map

Figure 3.7 highlights the thinking process that involves comparing and contrasting any two things (Hyerle & Yeager, 2007:36) with a Double Bubble Map. To construct a Double Bubble Map begins with drawing two large circles and writing the items being compared in their centres. then adding middle bubbles for words, phrases, or symbols that show similarities between the two items. Outside bubbles can be added connected to the two things being compared, listing words or phrases that identify differences. Key words used to guide the construction of the Double Bubble Map include: compare, contrast, similarities, differences, distinguish between, and differentiate (Hyerle & Yeager, 2007:38).



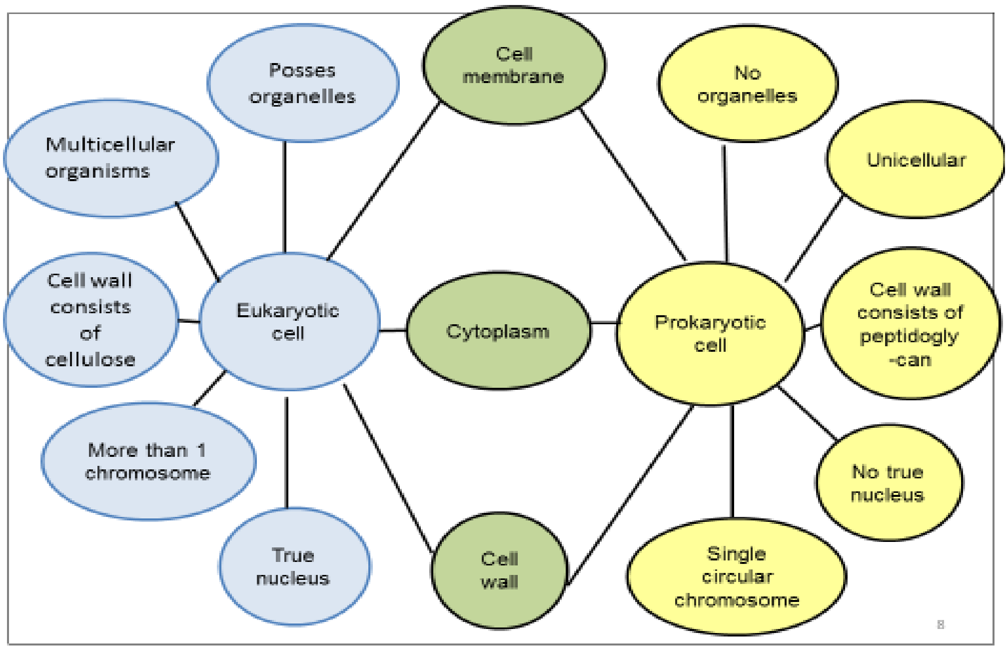
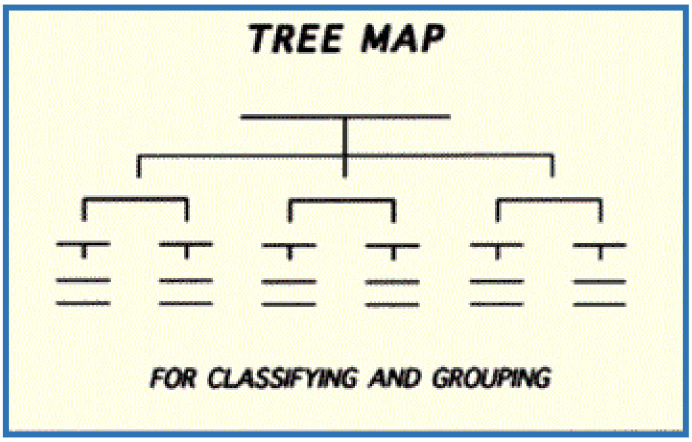


Figure 3.7: Double Bubble Map: Comparing the eukaryotic cell and the prokarytotic cell (Adapted from Hyerle & Yeager, 2007:36)

Double Bubble Maps can be used to compare anything that students are studying, requiring students to think about the idea or concept as points with counterpoints. Double Bubble Maps are also used for prioritising which information is most important within a comparison (Hyerle, 2014:165).

3.5.3.4 Tree Maps

The thinking process involved in classifying and identifying is depicted with a Tree Map (Figure 3.8). The Tree Map classifies or sorts things and ideas into categories or groups by reflecting main ideas and details (Hyerle & Yeager, 2007:42). The construction of a Tree Map begins with writing the category name or main idea of the topic on the top line, drawing connection lines going down to sub-categories or supporting ideas. Below each sub-category or supporting idea lines list specific members or details of that sub-category or supporting ideas. Key words used to guide the construction of a Tree Map include among others the following, classify, sort, categorise, identify the main idea and supporting idea and give sufficient and related details (Hyerle & Yeager, 2007:44).



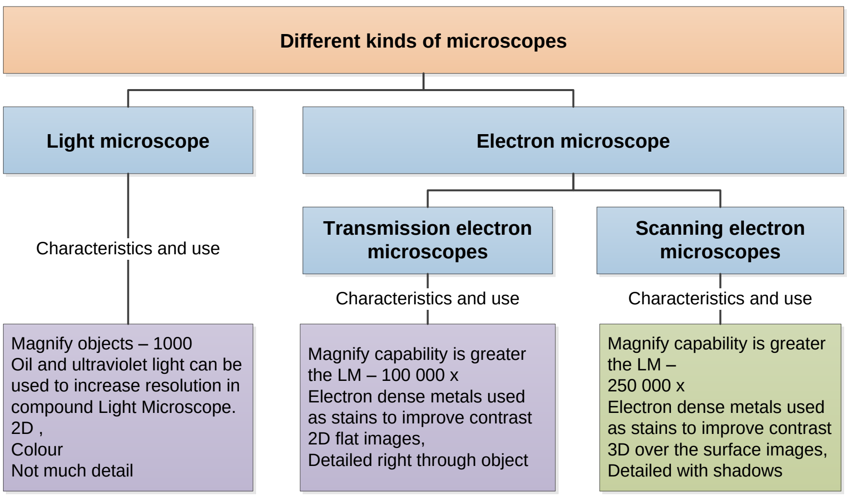


Figure 3.8: Tree Map: Classifying microscopes (Adapted from Hyerle & Yeager, 2007:42)

Tree Maps can be used to classify information based on their attributes or details. For a slight variation, Tree Maps can be developed inductively through reverse construction (starting with the individual members and working backwards to the main topic). It also enables students to work deductively; they learn to create concepts and ideas as category headings and add supporting ideas and detail in the branches (Hyerle, 2014:165).

3.5.3.5 Brace Map

The “Whole to Part” thinking process can be visualised with a Brace Map (Figure 3.9). Brace Maps are used to identify the whole to part relationship while analysing the component parts of physical objects, and identifying the spatial relationship of parts to the whole or structural analysis (Hyerle & Yeager, 2007:48). Construction of a Brace Map begins with a name of the whole object being placed on a line to the extreme left. The lines in the middle of the sets of braces should be filled with words describing major parts of the whole to the left by using nouns. The lines to the extreme right are for component parts of the parts of the whole. Key words used to guide the construction of a Brace Map include: parts of, show the structure, take apart, identify the structure, physical components, and anatomy (Hyerle & Yeager, 2007:50).

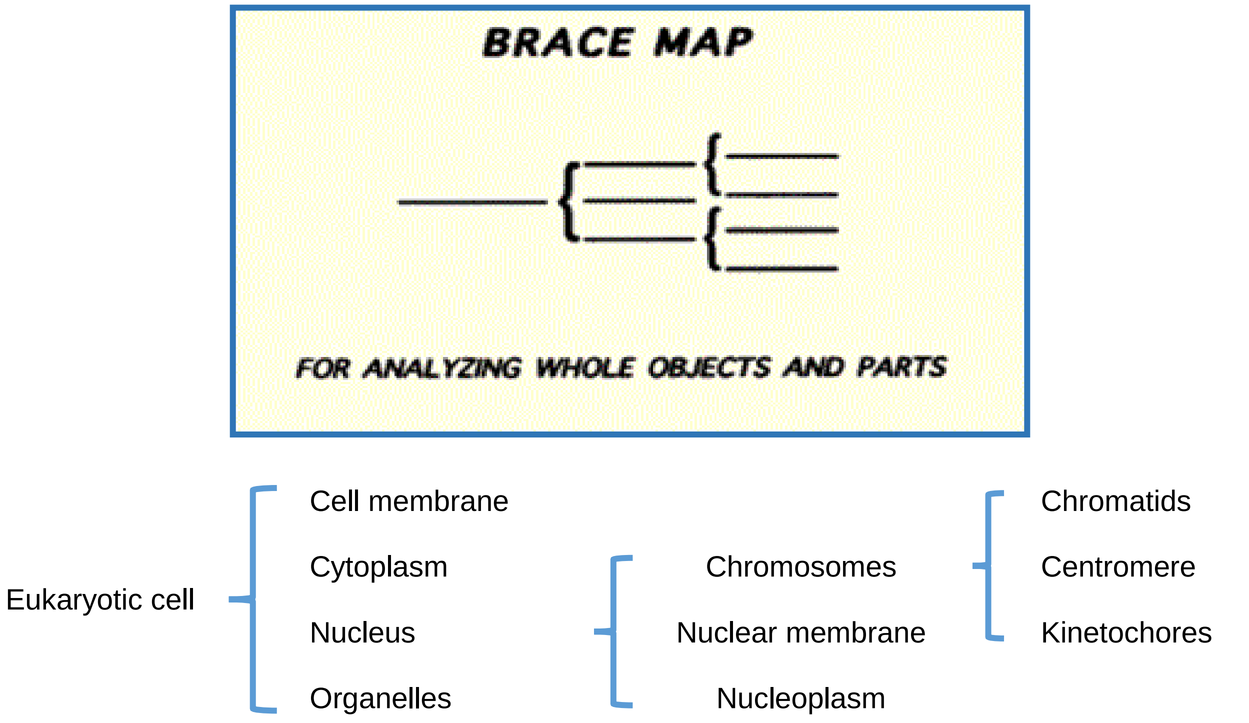
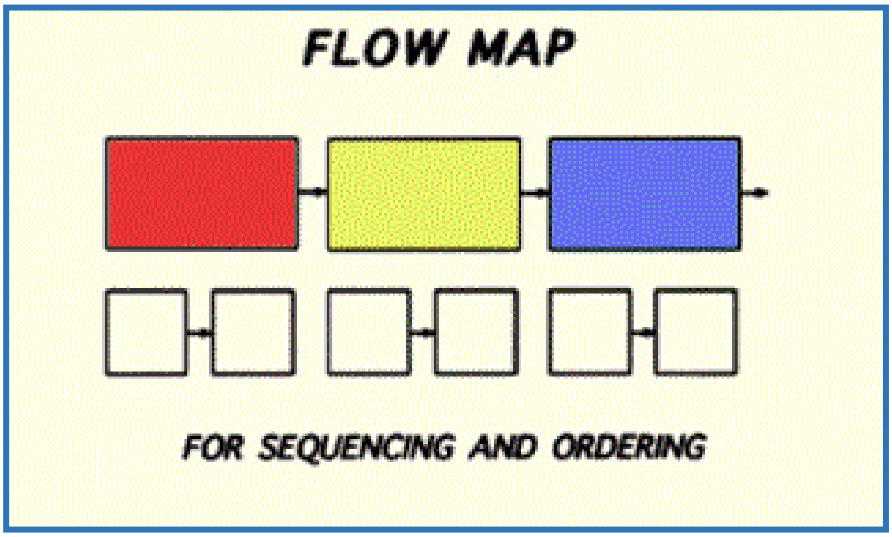


Figure 3.9: Brace Map : Analysing the eukaryotic cell (Adapted from Hyerle & Yeager, 2007:48)

Brace Maps can be used to analyse any concrete physical object such as structures in science, parts of a number in mathematics (Hyerle & Yeager, 2007:51). According to Hyerle (2014:165), Brace Maps support the development of spatial reasoning and understanding physical boundaries.

3.5.3.6 Flow Map

Sequencing as a thinking process, which is related to ordering of information, is presented in Figure 3.10. The Flow Map sequences the stages and sub-stages of an event, identifies the steps in a process, and orders information (Hyerle & Yeager, 2007:54). To construct a Flow Map the name of the event or sequence is written above the first stage. Then the major stages of the events are written in the large rectangular boxes flowing from left to right, and finally the sub-stages of each major stage in the smaller rectangular boxes below. Key words used to guide the construction of a Flow Map include: sequence, put in order, retell/recount, cycles, patterns, show the process, and solve multi-step problems. Flow Maps can be written horizontally, vertically, or in any direction as long as all the stages are connected. Students may draw their stages cyclically, as rises and falls, or to show comparisons or degrees (Hyerle & Yeager, 2007:54).



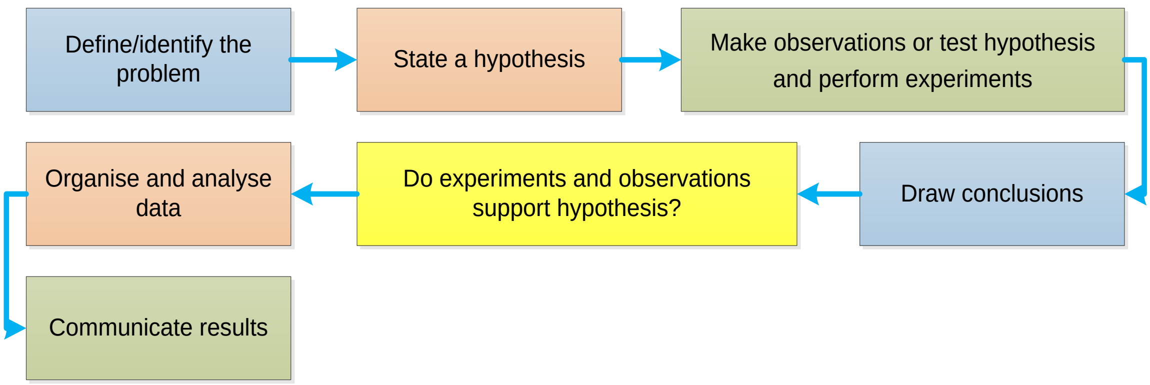
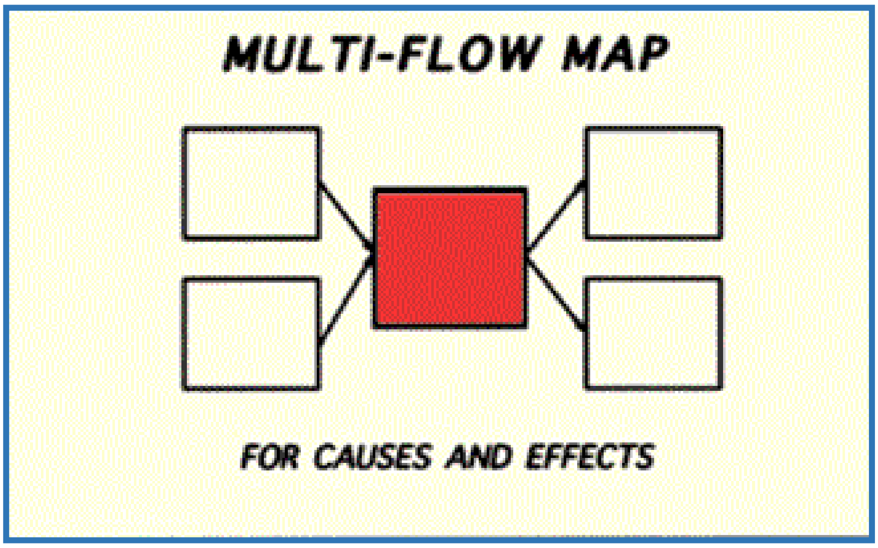


Figure 3.10: Flow Map: Steps in the scientific method (Adapted from Hyerle & Yeager, 2007:54)

Flow Maps can also show the order of objects arranged from smallest to largest. Common uses of Flow Maps include life cycles, problem-solving steps, historic events, and time lines (Hyerle & Yeager, 2007:56).

3.5.3.7 Multi-Flow Map

Figure 3.11 highlights the thinking process related to analysing cause and effect with the use of a Multi-Flow Map (Hyerle & Yeager, 2007:60). To construct a Multi-Flow Map an important event that occurred is written in the large centre box. On the right side of the large centre box, the effects of that event are connected with arrows. On the left of the large centre box, the causes of that event are connected to the centre with arrows. This illustrates how the causes lead into the event and how the effects come out of the event. Key words used to guide the construction of a Multi-Flow Map include: causes and effects, discuss the consequences, “what would happen if?” “if . . . then,” predict, describe the change, identify the motivation behind, “identify the results of,” and “what happened because of ?” In Multi-Flow Maps, the number of causes do not have to match or balance the number of effects. Multi-Flow Maps can be constructed as one-sided to focus on just causes or just effects of an event (Hyerle & Yeager, 2007:62).



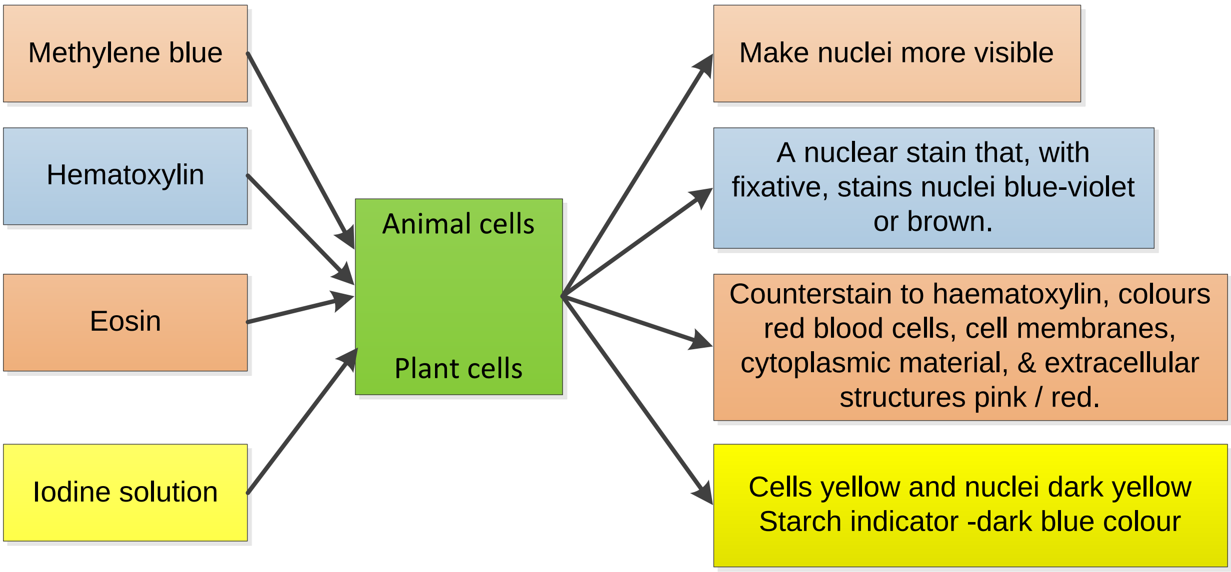


Figure 3.11: Multi-Flow Map: The effect of stains (Adapted from Hyerle & Yeager, 2007:60)

Applications of Multi-Flow Maps include historic analysis, reading and predicting events, and behaviour management (Hyerle & Yeager, 2007:63).

3.5.3.8 Bridge Map

Figure 3.12 illustrates the thinking process that involves the identification of analogies by means of a Bridge Map. The Bridge Map identifies similarities between relationships and creates analogies (Hyerle & Yeager, 2007:66). Construction of a Bridge Map begins with the relating factor or the relationship being written on the line of the bridge to the far left, between the top and bottom phrases, symbols, or words (see Figure 3.12 below). The first pair of terms that share this relationship is written on the left side of the bridge and a second pair of terms that share this relationship on the right side of the bridge. Key words used to guide the construction of a Bridge Map include: identify the relationship, guess the rule, symbolism, metaphor, allegory, analogy and simile (Hyerle & Yeager, 2007:66).

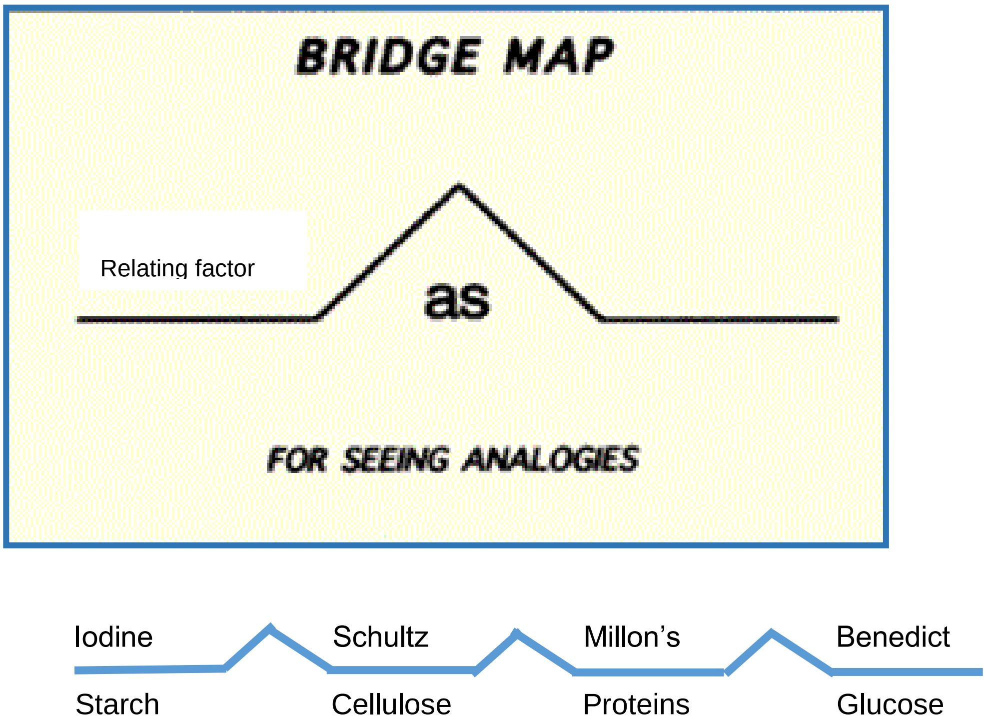


Figure 3.12: Bridge Map: Reagents and food tests(Adapted from Hyerle & Yeager, 2007:66)

Bridge Maps help students identify similarities between relationships and as long as the relationship holds true, the bridge can be extended to more than two pairs of words. Possible applications for Bridge Maps include: scientific concepts, historic events, and mathematical relationships (Hyerle & Yeager, 2007:66).

3.5.3.9 The Frame of Reference

A Frame of Reference should be added to all the maps. Frames of Reference allow students to frame their maps within three metacognitive ideas , namely "How do you know what you know?" "What is influencing the information in your map?" or "Why is this information important?" (Hyerle & Yeager, 2007:20). A Frame of Reference is a box drawn around any map that gives students a way to reference their maps within specific contexts and allows students to connect their prior knowledge to a specific curriculum topic. Each Frame of Reference can be individually tailored to meet the specific need/curriculum/context of the purpose of the map. Frames of Reference encourage reflective thinking and the development of metacognition. (Hyerle, 2014:166; Hyerle & Yeager, 2007:20).

In this research, the researcher concentrated on the following maps during intervention: the **Circle Map**, the **Tree Map** and the **Multi-Flow Map**, as these maps provide opportunities for acquiring the skills to analyse, synthesise and evaluate. These are important skills that Life

Science students need to apply to make sense out of Life Science phenomena and to make effective decisions/conclusions about scientific issues.

The contributions of Thinking Maps towards the development of critical thinking skills in Life Sciences, are explained in the section below.

3.5.4 The role and place of Thinking Maps in Life Sciences to enhance the development of critical thinking

To the best knowledge of the researcher, no research studies have established the effects of Thinking Maps for enhancing the development of critical thinking skills in Life Sciences. It is reasonable to assume that Thinking Maps will enhance the development of critical thinking because they:

- define cognitive skills and enable students to think with depth and apply new knowledge to complex tasks;
- give pathways for thinking about thinking resulting in improved metacognitive skills;
- make learning meaningful because they support the brain in turning subject-content into visual-spatial-verbal format;
- require students to move and interact, collaboratively accessing their knowledge to strengthen connections and support;
- allow for the accurate evidence of student performance over time and provide students with life-long thinking tools (Hyerle, 2014:173-174; Hyerle & Yeager, 2007:8-16).

Considering the skills (*cf.* Table 2.2) and specific outcomes to be acquired in Life Sciences (*cf.* Table 2.1), it is clear that the application of Thinking Maps could probably play a major role in enhancing critical thinking skills that underpin the achievement of specific outcomes in Life Sciences.

Hyerle (2014:163) asserts that thoughts through words, orally or through writing, are "dramatically under-presented" by words and numbers, only because they reflect linear representations of information. He argues that the networks of ideas in our brain are non-linear and "highly associative." Thinking Maps support the brain in creating patterns from content specific information. This makes learning meaningful for students because Thinking Maps link the information students are learning to their own emotional frames of reference and give them ownership of their thinking processes and their learning. Thinking Maps give explicit pathways for thinking about thinking resulting in improved student performance (Hyerle, 2014:169). Processing information that is placed on a Thinking Map, moves the information to the long-term memory. Moreover, the use of Thinking Maps supports cognitive (*cf*. 2.7.1.2) and cognitive constructivist (*cf.* 2.7.1.3) teaching and learning theory that could be regarded as suitable to promote the development of critical thinking, as their approaches to teaching involve students in active, independent and/or social meaning-making and problem-solving processes that provide opportunities to acquire and develop critical thinking.

In addition, the use of Thinking Maps comply with the criteria for effective learning (*cf*. 3.2), because students not only acquire particular skills and strategies, but are also involved in the metacognitive processes of planning, monitoring and self-reflection (self-regulation).

In order to assess the development of critical thinking skills through the use of Thinking Maps, the researcher had to give some consideration to how Thinking Maps should be assessed.

3.5.5 Assessing students' Thinking Maps

According to Hyerle and Yeager (2007:283), Thinking Maps are designed to be used in the process of instruction and are not seen as final products to be assessed. In this research, the students worked independently, and decided which of the three Thinking Maps that this research focused on could be the most appropriate to use as a learning strategy to analyse, synthesise and evaluate subject content presented during the intervention effectively.

The researcher provided the students with the following checklists with criteria (Table 3.2, Table 3.3) as a guide that they had to adhere to when constructing the Thinking Maps. The researcher also used the checklists with criteria for assessing the quality of the students' Thinking Maps and to monitor and gauge their progress regarding the development and application of the critical thinking skills on which the research focused, namely analysis, synthesis and evaluation to subject content.

Table 3.2 provides a more detailed and specific checklist with criteria that pay attention to a number of important critical thinking skills, dispositions and universal intellectual standards of reasoning involved in critical thinking.

Table 3.2: Thinking Maps Checklist

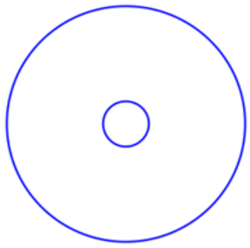
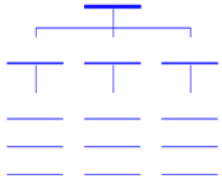
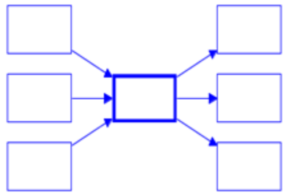
Criteria	Complete		Incomplete	
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts.		The Thinking Map displays evidence of minimal or no concepts.	
Thought process **(Verb or keyword linked to Thinking Map)**	The thought processes utilised are correctly linked to the Thinking Map.		The thought processes utilised are incorrectly linked to the Thinking Map.	
Collaboration	The Thinking Map displays collaborative evidence (different colours used to add ideas and information).		The Thinking Map idsplays no or minimal evidence of collaboration (no additional ideas or information added).	
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly and reflect deeper thought about the concept/idea.		The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	
Originality	The Thinking Map displays new and creative facts about the concept/idea (breadth and depth)		The Thinking Map only reflects a basic and simplistic understanding of the concept/idea.	
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.		The Thinking Map displays no finer and rich detail about the concept /idea.	
Layout	The technical structure of the Thinking Map is laid out correctly.		The technical structure of the Thinking Map is laid out incorrectly.	

The criteria indicated in Table 3.2 and how they were applied to the research, are briefly explained below:

Fluency: Fluency refers to generating many different ideas. It is an important skill to practise because a variety of ideas would enable one to consider appropriate solutions to one's problem (Pikulsky & Chard, 2005:512).

Thought process: The student participants had to select the approppropriate Thinking Maps to align with the thought processes linked to the Life Science subject content. The following thought processes and Thinking Maps were applicable in the context of this research.

Table 3.3: Thought processes and Thinking Maps applicable in the research

		
Circle Map	**Tree Map**	**Multi-Flow Map**
Define	Classify	Cause and effect
Brainstorm	Categorize	Decision and consequence
Generate	Organize	Reason and influence/result
Name	Group	Input and output
Identify	Cluster	

Collaboration: Although the researcher focused on independent learning in the context of the research, and students did not construct Thinking Maps collaboratively, student participants were given the opportunity to give feedback on their Thinking Maps during lectures. This provided the student participants with the opportunity to check the information in their Thinking Maps and to add or rectify information.

Flexibility: Fluency is about generating as many ideas that are different from each other (Costa, 2009:21-23). Flexible thinkers think out of the box and in alternative ways and are creative problem-solvers (Costa, 2009:21-23).

Originality: Originality refers to ideas that are unusual, unconventional and different (MacFarlane, 2007:18). In the context of the research, student participants had to use the Thinking Maps to analyse, synthesise and evaluate subject content information in a novel way, that would differ from the work of others.

Elaboration: Elaboration refers to providing evidence of interesting and elaborate detail to information that would improve understanding and clarity (Niehuis *et al.*, 2001:120).

Layout: The structures of the Thinking Maps had to correspond with the original structures designed by Hyerle and Yeager (2007:24-66) for the various thinking processe.

Table 3.4 below, provides a more holistic assessment of the quality of the Thinking Maps in general that could be used to assess relevancy and elaboration (detail).

Table 3.4: Checklist for assessing the Thinking Maps in terms of relevancy and elaboration (detail)

1 **0-29%**	**Not achieved**	The Thinking Map displays misconceptions regarding the subject content.
2 **30-39%**	**Elementary achievement**	The Thinking Map displays a limited understanding of the subject content.
3 **40-49%**	**Moderate achievement**	The Thinking Map displays a simplistic understanding of the subject content.
4 **50-59%**	**Adequate achievement**	The Thinking Map displays a basic understanding of the subject content.
5 **60-69%**	**Substantial achievement**	The Thinking Map displays a basic understanding as well as new ideas about the subject content.
6 **70-79%**	**Meritorious achievement**	The Thinking Map displays basic and new ideas as well as finer detail about the subject content.
7 **80-100%**	**Outstanding achievement**	The Thinking Map displays a deeper understanding of the subject content and supplies rich, diverse and creative ideas about the subject content.

3.6 CHAPTER SUMMARY

Chapter 3 focused primarily on clarifying the role of visual learning, what Thinking Maps are and their importance for developing critical thinking. The use of Thinking Maps supports the criteria for effective learning (*cf.* 3.2) as the construction of Thinking Maps involves students in active meaning-making, often in collaboration with others, and promotes the application of cognitive skills, metacognitive strategies, dispositions as well as the universal intellectual standards of reasoning.

Different types of visual learning strategies, namely Mind Maps, Concept Maps, Graphic Organizers, charts, diagrams and Thinking Maps were explored (*cf.* 3.4, 3.5). Thinking Maps could be regarded as more suitable to enhance the development of critical thinking, as they facilitate more explicitly the cognitive skills (defining, describing characteristics, contrasting, classifying, whole-part thinking, sequencing, cause-and-effect reasoning and analogical reasoning) and metacognitive strategies (self-regulation) involved in critical thinking (*cf*. Figure 2.1). Moreover, Thinking Maps enable students to think with clarity, relevance, depth, breadth and logic when constructing the maps, thus promoting the development of the universal intellectual standards of reasoning (*cf*. 2.2.4). In addition, a number of critical thinking dispositions/behavioiural traits such as accuracy, open-mindedness, systematicity and persistence are required to construct good quality Thinking Maps (*cf.* 2.2.3).

The researcher identified the Circle Map (*cf*. 3.5.3.1), Tree Map (*cf*. 3.5.3.4) and the Multi-Flow Map (*cf*. 3.5.3.7) to be utilised in the context of the research as these maps provide opportunities for acquiring the critical thinking skills to analyse, synthesise and evaluate.

The following chapter, Chapter 4, provides a detailed discussion of the research methodology that was employed in the context of the study.

CHAPTER 4
EMPIRICAL RESEARCH DESIGN

4.1 INTRODUCTION

In this chapter, the researcher explains the research design that was employed in the context of determining the role of Thinking Maps to enhance the critical thinking skills of pre-service Life Science teachers. This chapter addresses the following issues:

4.2 Research paradigm

- What is a research paradigm?
- Types of research paradigms

4.3 Research aim, objectives, hypotheses and variables

4.4 Research methodology

- Research design
- Research strategy
- Data collection methods
- Sampling
- Data analysis and interpretation
- Quality criteria
- Ethical considerations

4.5 Chapter summary

The first section in this chapter addresses the research paradigm that framed the research.

4.2 RESEARCH PARADIGM

4.2.1 What is a research paradigm?

According to Creswell (2009:6-6) and Nieuwenhuis (2010:47), a paradigm is a set of basic beliefs that influence one's worldview and guides a researcher's actions during research. These beliefs refer to beliefs about the role of the researcher, the role of the research participant, the best way to collect data to answer the research question, and the purpose of the research.

The following section briefly explains the main paradigms in educational research and motivates the choice of a particular paradigm for the present research.

4.2.2 Types of research paradigms

4.2.2.1 Positivism

According to Jansen (2010:21), a positivistic research paradigm is concerned with the gathering of objective data regarding a research phenomenon. He states that facts (knowledge) are objective, observable and can be explained in terms of scientific laws. Terms like investigate, experiments, surveys, comparison, quantitative data and correlation are used in a positivistic paradigm. Cohen *et al*. (2007:9) agree and furthermore concur that positivistic paradigms are concerned with measurement, numerical data and statistical analysis.

4.2.2.2 Interpretivism/Socio-constructivism

Jansen (2010:21) indicates that interpretivism/socio-constructivism focuses on an interaction between the researcher and the participants to gain insight into the participants' life-worlds by interacting with them, and appreciating and clarifying meanings they attribute to understanding research phenomena. According to Creswell (2009:8), socio-constructivism is the development of subjective meanings of experiences where individuals try to understand the world in which they live and work.

4.2.2.3 Pragmatism

Pragmatism originates from actions, situations and consequences and is concerned with applications and solutions to problems (Creswell, 2009:10). Focus is not on the method but on the research problem and combining quantitative and qualitative approaches to gain a deeper understanding (knowledge) of a research problem (Creswell, 2009:11).

4.2.2.4 Critical theory

Critical theory is concerned with experiences related to discrimination pertaining to gender, race, class or other types of oppression (Jansen, 2010:21). Jansen (2010:21) argues that inequality, racial conflict and class conflict lead to resistance in the following generations, which could result in responses to injustices. Differences in background (culture, religion, socio-economic environment, gender) have an effect on people, the society and their understanding of human relationships.

According to Jensen (1997:1), the purposes of critical theory are:

- to promote a diverse educational system for all individuals, which steer them away from over-specialisation;
- to create a social balance between "personal autonomy of the individual and universal solidarity of the collective";
- to promote revolution against all forms of discrimination, including those based on gender, sexual orientation, race and religion;
- to promote revolution against all forms of fascism and nationalism; and
- to preserve good moral values that promote universal solidarity.

4.2.2.5 Advocacy participatory view

Creswell (2009:9) asserts that the advocacy participatory view involves politics and a political agenda. Typically, this type of research has an action agenda to reform and change participants' lives. Creswell (2009:9) maintains that social issues like empowerment, suppression, domination, inequality and alienation need to be addressed. The researcher and participants must work collaboratively to voice their concerns and try to improve their lives (Creswell, 2009:9).

In the present study, the researcher worked within a **positivistic paradigm** as he aimed to gather numerical data objectively from the research participants (Jansen, 2010:21). The researcher's beliefs regarding the role of the researcher centred on an external, objective role to establish the impact of a Thinking Maps intervention on the development of critical thinking skills. The data collected by means of testing were statistically analysed, supported by a positivistic paradigm that is concerned with measurement, numerical data and statistical analysis (McMillan & Schumacher, 2008:254).

In order to answer the research questions, the research formulated a number of objectives and hypotheses, and identified the variables in the research that would be manipulated, which are presented below.

4.3 RESEARCH AIM, OBJECTIVES, HYPOTHESES AND VARIABLES

The main aim of the study was to determine to what extent first year pre-service Life Science teachers are effective at applying the critical thinking skills to analyse, synthesise and evaluate information, and if not, to establish how a Thinking Maps intervention can enhance the development of the critical thinking skills analysis, synthesis and evaluation among the first year pre-service Life Science teachers.

The main aim was operationalised in the following objectives:

- To determine what the development of critical thinking skills entail by means of a literature review.
- To determine which critical thinking skills are important for Life Sciences by means of a literature review.
- To explain what Thinking Maps are by means of a literature review.
- To investigate how Thinking Maps can enhance the development of critical thinking skills in Life Sciences by means of a literature review.
- To determine how effective first year pre-service Life Science teachers are in applying the critical thinking skills of analysing, synthesising and evaluating by means of a pre-test.
- To examine to what extent a Thinking Maps intervention can develop the critical thinking thinking skills of analysing, synthesising and evaluating among first year pre-service Life Science teachers by means of a post-test and the Thinking Maps constructed by the pre-service teachers during the intervention.
- To examine to what extent there will be a difference in the pre- and post-test results of an experimental and control group regarding the application of critical thinking skills, after a Thinking Maps intervention, and in the absence of a Thinking Maps intervention, by comparing the pre-and post-test results of the different groups.
- To establish to what extent a Thinking Maps intervention would contribute to the development of the universal intellectual standards of reasoning involved in critical thinking by means of open questions in the pre-tests and post-tests.

The last objective was not a main focus of the study, but the researcher wanted to obtain initial data for a future study in relation to whether students could apply the intellectual standards of reasoning to the motivations they provide for test answers.

As the study determined cause and effect relationships, the following tentative hypotheses guided the execution of the study:

Research hypotheses

The following research hypotheses regarding the impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers were proposed:

$H^0{}_1$: There will be no statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after completion of the Thinking Maps intervention.

$H^a{}_1$: There will be a statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after completion of the Thinking Maps intervention.

$H^0{}_2$: There will be no statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after normal classroom lecturing (in the absence of teaching with Thinking Maps).

$H^a{}_2$: There will be a statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants in Experimental groups 1 and 2 after normal classroom lecturing (in the absence of teaching with Thinking Maps).

In the context of the study, critical thinking skills (analysis, synthesis, evaluation) were regarded as the dependent variables (Creswell, 2012:115) and the Thinking Maps intervention as the treatment or independent variable (Creswell, 2012:116, 117). Moreover, biographic variables such as gender, home language, culture and type of school attended could be regarded as control variables (Creswell, 2012:117) that could have influenced the research results. The various subgroups of the biographical variables however did not contain sufficient participants for statistical analyses (*cf*. 6.3.1). It was therefore not possible for the researcher to control for the influence of these variables (McMillan & Schumacher, 2006:129).

The next section explains and motivates the research methodology that was employed in the study.

4.4 RESEARCH METHODOLOGY

The research methodoly employed in the context of the research involved the selection of a research design, research strategy, research participants, data collection methods and statistical procedures to analyse the data. Details about each of the mentioned aspects are provided in the subsequent sections.

4.4.1 Research design

Creswell (2009:3) and Leedy and Ormrod (2013:97) state that a research design entails a carefully planned route or decisions that a researcher takes about how to achieve the aims and objectives of a research study. In support of a positivist paradigm, the researcher used a

quantitative, quasi-experimental research design, as the aim was to establish the effect of an intervention in an experimental and control group situation.

4.4.1.1 Quantitative research design

Creswell (2009:145-169) and Leedy and Ormrod (2013:97) indicate that quantitative research is structured and planned, the researcher is not subjectively involved in data collection, but takes on an external role in data collection and objectively gathers numerical data. In this research, the researcher systematically and objectively collected numerical data from a selected group of participants, in this case the first year Life Science pre-service teachers (Leedy & Ormrod, 2013:94).

The researcher acknowledges the following advantages and disadvantages of quantitative research, as identified by Fouché *et al*. (2011:143-158), Kruger (2003:18-19) and O'Neill (2006).

Advantages

Quantitative research:

- allows for a broader study, involving a greater number of subjects, and enhancing the generalisation of the results;
- could allow for greater objectivity and accuracy of results. Generally, quantitative methods are designed to provide summaries of data that support generalisations about the phenomenon under study. In order to accomplish this, quantitative research usually involves few variables and many cases, and employs prescribed procedures to ensure validity and reliability; and
- avoids personal bias by researchers keeping a 'distance' from participating subjects and employing subjects unknown to them.

Limitations (Disadvantages)

Quantitative research:

- collects a much narrower and sometimes superficial dataset;
- provides limited results as it provides numerical descriptions rather than detailed narrative and generally provides less elaborate accounts of human perception;
- is often carried out in an unnatural, artificial environment so that a level of control can be applied to the exercise. This level of control might not normally be in place in the real world, yielding laboratory results as opposed to real-world results;

- will in addition to pre-set answers not necessarily reflect how people really feel about a subject and in some cases might just be the closest match; and
- can lead to the development of standard questions by researchers based on 'structural' bias and false representation, where the data actually reflect the view of the researchers instead of the view of the participant.

As this research involved the manipulation of a dependent variable (critical thinking skills), the researcher used a **quantitative, experimental research design** (Creswell, 2012:307). The research was structured and planned, and numerical data were collected objectively and statistically analysed (Creswell, 2009:145; Maree & Pietersen, 2010a:145).

4.4.2 Research strategy

According to Creswell (2009:11), a research strategy, or strategy of inquiry, refers to designs or models that provide direction for the research procedures. Maree and Pietersen (2010a:149) classify quantitative research strategies as experimental and non-experimental. The researcher used an experimental research strategy. Three main categories of experimental research strategies can be distinguished, namely pre-experimental, quasi-experimental and true experimental (Fouché *et al*., 2011:144).

The experimental design adheres to the cause-and-effect question and the following characteristics distinguish the experimental design from others.

- Manipulation takes place.
- Experimental and control groups are present.
- Random selection of participants to experimental and control groups takes place (Fouché et al., 2011:144; Maree & Pietersen, 2010a:149).

The non-experimental design is used in descriptive studies, mainly surveys, in which the participants who have been selected to take part in the research are measured on all the variables applicable without any manipulation (Fouché *et al*., 2011:144; Maree & Pietersen, 2010a:152).

The following section discusses the quasi-experimental research strategy that was employed in this research.

4.4.2.1 Quasi-experimental research

Quasi-experimental research strategies aim to evaluate interventions but do not use randomisation. Quasi-experiments aim to demonstrate causality between an intervention and an outcome in non-randomly selected experimental and control groups (Creswell, 2009:160; Creswell, 2012:307; Leedy & Ormrod, 2013:245).

Using this basic definition, it is evident that although the randomised controlled trial is generally considered to have the highest level of credibility with regard to assessing causality, researchers often choose not to randomise the intervention for one or more reasons:

- difficulty of randomising subjects;
- difficulty to randomise by locations (e.g. fixed classes); or
- small available sample size (Leedy & Ormrod, 2013:245; Thyer, 2012:93).

In this research, the researcher used non-randomised intervention because the participants were in fixed classes, and the research focused on a small group of participants, namely a group of first year pre-service Life Science teachers at a South African university. The researcher employed quasi-experimental research with a nonrandomised control group pre-test and post-test design, or as referred to by Creswell (2009:160), as a non-equivalent control group pre-test and post-test design, to determine the effects of a Thinking Maps intervention on enhancing the development of critical thinking skills (Leedy & Ormrod, 2013:245).

The researcher acknowledges the following advantages and limitations of quasi-experimental research as identified by Fouché *et al*. (2011:143-158), Kruger (2003:18-19) and McMillan and Schumacher (2008:273):

Advantages

- Quasi-experimental research is used when randomisation is impractical and/or unethical.
- Quasi-experimental research is typically easier to set up than true experimental designs.
- Quasi-experimental research minimises threats to external validity as natural environments do not suffer the same problems of artificiality as compared to a well-controlled laboratory setting.
- Quasi-experiments are natural experiments, allowing for some generalisations to be made about the population.
- Quasi-experimental designs are efficient in longitudinal research that involves longer time periods which can be followed up in different environments.

Limitations (Disadvantages)

- Quasi-experimental estimates of impact are subject to contamination by confounding variables.

- Difficulty to generalise results due to a lack of randomisation.
- The lack of random assignment in the quasi-experimental design method may allow studies to be more feasible.
- Non-randomisation makes it harder to rule out confounding variables and introduces new threats to internal validity.
- Because randomisation is absent, some knowledge about the data can be approximated, but conclusions of causal relationships are difficult to determine due to a variety of extraneous and confounding variables that exist in a social environment.
- Causation cannot be fully established because the experimenter does not have total control over extraneous variables.
- Using unequal groups can also be a threat to internal validity. If groups are not equal, which is sometimes the case in quasi-experiments; the experimenter might not be able to conclusively indicate what the causes are for the results (Fouché *et al.,* 2011:143-158; Kruger, 2003:18-19).

As it was not possible for the researcher to sample research participants randomly, a quasi-experimental research strategy was regarded as apposite for the study. The researcher used intact, preselected groups of participants, gave a pre-test, administered the treatment condition to one group, and gave the post-test, after which a second experiment was conducted in a similar way with a new experimental and control group (the experimental group in the first experiment became the control group, and the control group became the experimental group).

4.4.3 Data collection methods

4.4.3.1 Pre- and Post-testing

To generate data, the researcher made use of pre- and post-testing. According to Cohen *et al.* (2007:414), in tests researchers have a powerful method of data collection.

As the first year Life Science content links with the content dealt with at Grade 12 level, pre-test 1 measured the extent to which the participants acquired the skills to execute critical thinking (analysis, synthesis, evaluation) in Life Science content dealt with at school level. Pre-test 1, was written at the onset of Experiment 1 that took place during weeks 1 – 6 of the first semester during 2016. Similarly, pre-test 2 was written at the onset of Experiment 2, that took place during weeks 7-12 of the first semester during 2016, based on the learning content that was dealt with in weeks 7-12 of semester 1.

Based on the pre-test results, Thinking Maps interventions (an intervention was developed for the first six weeks of semester 1 and for the last six weeks of semester 1, respectively) were developed to address the deficiencies noted in the pre-test results at the onset of the first six weeks and second six weeks of the first semester during 2016. The intervention was implemented for a period of twelve weeks with Experimental groups 1 and 2 on a rotational basis (six weeks per group). On conclusion of the intervention with each group, a post-test, post-test 1 (written at the end of week 6) and post-test 2 (written at the end of week 12) were written to establish the effect of the Thinking Maps intervention on enhancing the development of the critical thinking skills (analysis, synthesis, evaluation) in the context of the subject content dealt with in each semester, respectively.

In addition, pre-test 1 was administered again as a second post-test, post-test 1B, and pre-test 2 was administered as a second post-test, post-test 2B, to test for the transfer of critical thinking skills to different subject content.

The tests were norm-referenced, as comparisons were drawn between the achievements of the control groups relative to the achievements of the experimental groups.

According to the best knowledge of the researcher, there is no test commercially available for researchers to determine the impact of Thinking Maps to enhance critical thinking skills in Life Sciences in the South African context. Therefore, the researcher developed tests for pre- and post-test purposes.

The various pre-tests and post-tests used in the context of the research focused on the following subject content. Table 4.1 provides a break down of the topics in Life Sciences that were addressed during the research.

Pre-test 1: Grade 12 Life Sciences

Post-test 1: Content dealt with during weeks 1 - 6 of the intervention - problem-based learning and the scientific method.

Post-test 1 B: A repetition of pre-test 1 (Grade 12 Life Sciences)

Pre-test 2: Content dealt with during weeks 1 – 6 of the intervention – content that focused on problem-based learning and the scientific method.

Post-test 2: Content dealt with during weeks 7 – 12 of the intervention – content that mainly focused on problem-based learning.

Post-test 2 B: A repetition of pre-test 2 – content that focused on problem-based learning and the scientific method.

The tests focused on the application of analysis, synthesis and evaluation to different subject-content as the researcher tested for the transfer of critical thinking skills (Norris & Ennis 1989:101) (*cf.* 2.5.2, 2.5.5) in a balanced way (*cf.* Appendix C; Table 6.11).

In the context of assessing critical thinking skills, a pioneer in the field of critical thinking assessment, Robert Ennis (1993:184), argues for the use of open questions in conjunction with multiple-choice questions, where students have to justify/defend their answers.

The pre- and post-tests comprised multiple-choice items with one correct answer, and a follow-up open question for each multiple-choice answer where the student needed to motivate an answer. Motivating an answer served as a measure to control for guessing answers in the multiple-choice test, and to reflect the universal intellectual standards of reasoning, such as the depth, breadth, relevance, significance and logic of the participants' reasoning. As the focus of these tests was to determine the effectiveness with which the pre-service teachers applied skills to analyse, synthesise and evaluate information, the multiple-choice questions in equal proportions addressed the skills to analyse, synthesise and evaluate. Although the questions in the pre- and post-tests were not exactly the same, the skills tested (analysis, synthesis and evaluation) remained the same. Both tests reflected the progressive nature of the content that was covered during the first and second semesters of 2016. Moreover, the content of the pre- and post-tests also differed, as the researcher wished to establish to what extent transfer of the skills acquired during the intervention was effective in a different context.

Due to ethical considerations, it was not possible for the researcher to recruit the participants, or administer the informed consent and tests to his own students. He requested an independent person, whom he trained, to assist him with the aforementioned tasks. The independent person was observed by an independent statistician who is knowledgeable on ethical research conduct.

The data derived from the pre-tests and post-tests were captured, analysed and interpreted with the assistance of an independent statistician from NWU, Vaal Triangle Campus.

The programme depicted in Table 4.1 was followed during the first semester of 2016, for Experiment 1 (weeks 1-6) and Experiment 2 (weeks 7-12).

Table 4.1: Procedural program for the first semester

Data collection Experiment 1	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
	Pre-test 1					Post-test 1 Post-test 1B
Experimental group						
Intervention Thinking Maps	1 Period Scientific method & Data analysis	1 Period Microscopy	1 Period Mosaic model Diffusion & Osmosis	1 Period Chemistry concepts	1 Period Organic Carbohydrates	1 Period Energy & ATP Metabolism -Cata- & Anabolism
Control group						
No intervention	1 Period Scientific method & Data analysis	1 Period Microscopy	1 Period Mosaic model Diffusion & Osmosis	1 Period Chemistry concepts	1 Period Organic Carbohydrates	1 Period Energy & ATP Metabolism -Cata- & Anabolism
All groups						
Normal teaching and practical	1 Period Indigenous knowledge Study hints	2 Periods -Different cells -Cell membranes	2 Periods Cell division	1 Period Inorganic	2 Periods Lipids Proteins Nucleic acids	1 Periods Enzymes

Data collection Experiment 2	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
	Pre-test 2						Post-test 2 Post-test 2B
Experimental group							
Intervention Thinking Maps	1 Period Photosynthesis	1 Period Starch tests: Water bath, boiling water, alcohol, iodine solution	1 Period Cell respiration Anaerobic fermentation	1 Period DNA	1 Period RNA	1 Period Cell division	
Control group							
No intervention	1 Period Photosynthesis	1 Period Starch tests: Water bath, boiling water, alcohol, iodine solution	1 Period Cell respiration Anaerobic fermentation	1 Period DNA	1 Period RNA	1 Period Cell division	
All groups							
Normal teaching and practical	1 Period Experiments	2 Periods Light, chlorophyll, carbon dioxide needed for photosynthesis	2 Periods Experiments: Sugar, yeast, thermometer, rubber stopper	1 Period DNA continued	2 Periods RNA continued	1 Period Conclude semester	

4.4.3.2 Student Thinking Maps

The researcher also used the Thinking Maps generated by the student participants during the intervention to collect data in relation to the application of the critical thinking skills analysis, synthesis and evaluation. The Thinking Maps were not regarded as primary data collection instruments, but were used to provide the researcher with information regarding how well the students could apply critical thinking processes to the Life Science subject content. The students worked independently, and decided which of the three Thinking Maps the research focused on (Circle Map, Tree Map, Multi-Flow Map) would be the most appropriate to use to analys, synthesise and evaluate the information provided during the Life Science lectures. Students generated Thinking Maps in class and for homework. The researcher provided the students with checklist(s) (*cf*. Table 3.2; Table 3.3) to guide the construction of their Thinking Maps. The checklists with criteria also allowed the researcher to monitor and gauge the effectiveness of the students to apply critical thinking skills in the subject content presented to them.

Marks were allocated to students for their Thinking Maps, which were captured, analysed and interpreted with the assistance of an independent statistician from NWU, Vaal Triangle Campus. Examples of the students' Thinking Maps can be found in Appendix D.

4.4.4 Sampling

Creswell (2012:141), and Maree and Pietersen (2010b:538) maintain that it is important for a research study to be representative of the population, but usually it is impossible to include the entire population in a study, as time and costs are the main restrictions. According to Creswell (2012:142), and McMillan and Schumacher (2008:119), a population is a group of individuals with the same characteristics. When a researcher selects a sample, the characteristics of the population always have to be kept in mind. In this study, the population comprised all first year pre-service teachers at universities in South Africa. It was not possible to do research with the entire population, due to time, costs and logistical constraints, therefore a study population was identified. A study population is a heterogeneous, smaller group from the population from which the sample is selected (Maree & Pietersen, 2010b:538). In the context of this study, the study population comprised all first year pre-service teachers at a university in Gauteng, South Africa. The sample was selected from this study population. According to Maree and Pietersen (2010b:540), a sample is a heterogeneous group of participants from whom data were collected relevant to the research question.

According to Creswell (2012:142), researchers employ either probability or non-probability sampling approaches in quantitative studies. Probability sampling involves random sampling, which enables a researcher to make generalisations to the population. In the context of this study, the researcher made use of non-probability sampling, as non-random sampling was utilised to select the research participants. Non-probability sampling methods use convenient and purposive sampling strategies. Convenient sampling refers to the selection of participants who are accessible and available (Creswell, 2012:142). In this study, the researcher conducted research with a convenient and accessible sample, namely the 2016 first year Life Sciences pre-service teachers whom he taught (n = 56). Furthermore, the research purposively focused on Life Sciences pre-service teachers, as the researcher aimed to enhance his own classroom practice. The sampled participants thus represented the characteristics the researcher sought to study (McMillan & Schumacher, 2008:125). Non-probability sampling cannot guarantee that the sample will be representative of the population and therefore no generalisations of the research findings could be made. It was, however, not the purpose of the study to generalise findings. The researcher merely aimed at determining the impact of a Thinking Maps intervention as part of his own classroom practice during teacher-training to enhance the development of critical thinking skills among first year pre-service Life Sciences teachers. With the small and geographically bound sample, the researcher envisaged achieving what Mouton (2009) indicates, namely that a small and geographically bound sample provides the possibility to obtain more reliable results to support the effectiveness of an intervention.

The sample was heterogeneous with regard to gender, home language, culture and the types of secondary schools attended (public/township/private). To eliminate the threat of using already formed groups that might be different, and to avoid researcher bias in the selection of the experimental and control groups, the researcher requested an independent person who was not involved in teaching the students and the research to assist with the random allocation of students to an experimental and a control group. As far as possible, the participants in the experimental group and control groups were comparable in terms of the following biographic variables: male/female, White/Black, public/private schools, and Afrikaans/English as language of instruction. A comparison of the pre-test results also assisted the researcher to establish whether the experimental and control groups were comparable.

4.4.5 Data analysis and interpretation

4.4.5.1 Multiple-choice test items

Within the context of this research, the researcher analysed nominal data and ratio data (Leedy & Ormrod, 2013:279). Nominal data use numbers only to identify different categories of people. In this research, nominal data were collected regarding the demographic composition of the sampled participants. Leedy and Ormrod (2013:213) conclude that ratio data classify order and measure data, and have a true zero point. This is apposite to this research, as pre-test and post-test scores that have true zero points were compared. In order to analyse the quantitative data obtained, the researcher made use of descriptive statistics as well as inferential statistics (Creswell, 2012:182; Pietersen & Maree, 2010a:183; Pietersen & Maree, 2010b:198).

Descriptive statistics were used to organise and summarise the nominal and ratio data in a meaningful way in order to promote an understanding of the statistics (Pietersen & Maree, 2010a:183). The nominal data were organised and summarised as frequencies and percentages, whereas the ratio data were organised and summarised as frequencies, percentages, averages (means) and standard deviations and presented in tabular and graphical format.

Inferential statistics were used as the researcher wanted to go beyond just summarising and describing the data collected (Pietersen & Maree, 2010b:198). Inferential statistics enabled the researcher to compare means of the test data and to make inferences about the effectiveness of the Thinking Maps intervention (Leedy & Ormrod, 2013:213).

For the purpose of quantitative data analysis by means of inferential statistics, it was important to determine which type of statistical analysis, parametric or non-parametric, would be suitable for the type of test data. According to Pietersen and Maree (2010d:225), parametric methods are used where the sample size is larger than 30 and assumptions can be made that the study variable is normally distributed (bell-shaped curve) in the wider population. There are, however, researchers who feel that a minimum of 100 participants is required to check for sampling error (Strydom, 2011b:225). Although the researcher's sample only comprised 56 participants (Experiment 1, 29 participants, Experiment 2, 27 participants), he was able to make assumptions about the wider population and therefore applied parametric statistical procedures (Cohen *et al.,* 2007:415). The independent statistician who assisted the researcher with the data analysis and interpretation confirmed that the skewness and kurtosis of the data supported the use of parametric statistics (*cf*. 6.2.1).

To determine the statistical significance of the differences between the test results, t-tests were used and p-values calculated. All p-values smaller than 0.05 ($p < 0.05$) were regarded as significant and p-values larger than 0.05 ($p > 0.05$) were regarded as non-significant (Pietersen & Maree, 2010d:225).

The effect size was also calculated for statistical significant differences, which is a standardised, scale-free measure of the magnitude of the difference or correlation being tested between variables (Pietersen & Maree, 2010b:211). When looking at mean differences, the effect size is denoted by *d*, also known as Cohen's *d*. Effect sizes ranging from 0 to 0.2 are interpreted as a small effect size, while 0.5 is regarded as a medium effect size and 0.8 is a large effect size (Pietersen & Maree, 2010b:211).

4.4.5.2 Open questions

The verbatim transcripts of the responses to the open questions were checked to explore the **clarity, accuracy, precision, depth, breadth, relevance, significance** and **logic** of the reasoning of the participants. Chapter 6 provides examples of the responses to the open questions (*cf*. 6.6).

4.4.6 Quality criteria

As part of a quantitative study, a researcher has to ensure the validity and reliability of the research findings. The following section clarifies how the researcher upheld criteria for validity and reliability.

4.4.6.1 Validity

The validity of a measurement instrument refers to the extent to which the instrument measures what it intends to measure (Leedy & Ormrod, 2013:89; Pietersen & Maree, 2010c:216). In the context of a quantitative study, a researcher has to uphold criteria for validity regarding the implementation of the research design as well as for the data collection instruments (Leedy & Ormrod, 2013:92). According to McMillan and Schumacher (2008:125), securing **validity of a quantitative research design** comprises four aspects, namely: internal, external, construct and statistical validity.

Validity of the quantitative research design

Internal validity of a research study focuses on the degree to which its design and the data allow the researcher to draw precise conclusions between the independent and dependent variables and relationships within the data (Leedy & Ormrod, 2013:101; McMillan & Schumacher, 2008:134). According to Maree and Pietersen (2010a:151), internal validity allows the researcher to have control over the variables. Examples of variables in this research are gender, home language, culture and secondary schools attended. The researcher did not have control over the influence of variables as the subgroups of the different biographical variables comprised too few participants and did not allow the researcher to conduct statistical analyses to control for the influence of the variables (*cf.* 6.3).

McMillan and Schumacher (2008:134) conclude that **external validity** refers to the ability to generalise the results and conclusions to other individuals who belong to the entire population (Maree & Pietersen, 2010a:151; Leedy & Ormrod, 2013:103). The experiment was done in a real-life setting and this enhanced the external validity. External validity was however threatened by the fact that this research was conducted at one university with a sample that was not randomly selected. This limited the generalisation of the research findings to the entire population, and compromised the external validity of the research.

Construct validity refers to using more than one collection method to validate the research results (Pietersen & Maree, 2010c:217). In this research, pre-tests and post-tests were used on a rotational basis with experimental and control groups in two experiments to support construct validity. Although the responses to the open questions in the test, as well as the assessment of the students' Thinking Maps, were not regarded as primary methods of data collection, the researcher provides an overview of how the data played a supporting role in providing some insight into the development of the participants' critical thinking skills after completing a Thinking Maps intervention.

McMillan and Schumacher (2008:134) concur that **statistical conclusion validity** is about the appropriate use of statistical tests to ensure that the correct and valid relationships can be formed. In the context of the study, statistical conclusion validity was ensured by utilising the correct statistical procedures as suggested by the Statistical Consultation Services and the study leader (Creswell, 2012:162).

Validity of the tests

Validity of the test items was guaranteed by addressing various forms of validity, namely face, content, construct and criterion validity (Delport & Roestenburg, 2011:173; Leedy & Ormrod, 2013:89; Pietersen & Maree, 2010c:217). Leedy and Ormrod (2013:89) and Pietersen and Maree (2010c:217) agree that **face validity** is the extent to which the instrument looks as if it is measuring a particular characteristic and whether it measures what it has to measure. The aim of this research study was to determine the impact of a Thinking Maps intervention to enhance critical thinking skills (analysis, synthesis, evaluation) among first year pre-service Life Science teachers. The pre-tests and post-tests complied with face validity, as the focus of these tests was to determine the effectiveness with which the pre-service teachers applied skills to analyse, synthesise and evaluate subject information.

According to Leedy and Ormrod (2013:89), **content validity** is the extent to which the measuring instrument represents specific content that has to be measured. Pietersen and Maree (2010c:217) state that content validity refers to the covering of the complete content of the construct the test wants to measure in equal proportions. Content validity was ensured by asking questions that required the pre-service teachers to analyse, synthesise and evaluate information in equal proportions in the pre-tests and post-tests (*cf*. Table 6.11).

Construct validity refers to the data collection method's ability to measure a characteristic that cannot be directly observed, but must be inferred from patterns in the data (McMillan & Schumacher, 2008:134). This form of validity was ensured by conducting a small scale, informal, dynamic pilot study (Brace, 2008:15) prior to data collection to establish the construct validity of the test items (*cf.* 4.4.6.2).

Regarding criterion **validity**, Delport and Roestenburg (2011:173), Leedy and Ormrod (2013:90), and Pietersen and Maree (2010c:217) explain that it is the extent to which the results of the instrument correlate with an external criterion, or data collection instrument known to measure the same construct. No criterion validity could be guaranteed in this research, as the researcher made use of researcher-developed tests and was not aware of any other subject-specific test in Life Sciences for critical thinking against which he could measure the results of his test instrument.

Validity of the experimental research

Validity of the experimental research was ensured in the following ways:

Internal validity

In this research, the researcher, who is a trained facilitator in Thinking Maps, conducted the implementation of the intervention. The researcher did not make use of other researchers to implement the intervention in order to avoid the influence of experimental effects (Lodico *et al*., 2010:249).

The implementation time was kept short, as a shorter, more focused and intense implementation time for an intervention reduces the chance of other factors like history, maturation and experimental mortality affecting the result (Lodico *et al*., 2010:244). To avoid researcher bias in the assigning of participants to the experimental and control groups, the researcher requested a colleague who was not involved in the research to assist with the allocation of students to an experimental group and a control group, according to the same criteria (Cohen *et al*., 2007:156-159; Lodico *et al.,* 2010:244). The pre-test result was used as a measure to determine whether the groups were similar and comparable (Lodico *et al.,* 2010:244).

The use of a control group assisted the researcher to control for the effects of pre-testing on the results, maturation of the participants, statistical regression and events that could have occurred outside the study and that could have affected the dependent variable (Lodico *et al.,* 2010:244).

In order to address the influence of mortality (participants dropping out) the data analysis only involved the responses of the participants who wrote all the pre-tests and post-tests (Lodico *et al.,* 2010:244).

External validity

As the intervention was a first pilot study, it was conducted at one university only with a sample that was not randomly selected. The generalisation of the research findings to the entire population was therefore limited (Cohen *et al*., 2007:156-159).

In order to enhance the external validity, the researcher described the independent variables adequately, to make future replications of the experimental conditions possible (Cohen *et al.,* 2007:156).

The researcher was aware of the influence of the Hawthorne effect that could contaminate experimental treatments when participants become aware of the fact that they are participants in an experiment where a change in behaviour is desired (Cohen *et al*., 2007:156). Simply being part of a study can influence one's feelings, behaviour and attitudes (Lodico *et al*., 2010:249). Without deceiving the participants, they were informed that they were going to be exposed to a new teaching strategy of which the effects would be monitored, specifically indicating the improvement of critical thinking skills (analysis, synthesis and evaluation) as the focus.

In order to avoid treatment diffusion (Lodico *et al.,* 2010:249), the researcher requested the participants of the experimental group who received the intervention first, to limit communication and sharing of information with the participants of the control group. The control group was informed that they would get their opportunity to take part in the intervention. Participants wrote all tests at the same time, to minimise the threat of information about the test being provided to other participants. To avoid the pre-test results influencing the post-test results, the latter covered different content, but still focused on the application of the same critical thinking skills as in the pre-test. Cohen *et al.* (2007:432) state that a pre-test may have questions which differ in form or wording from the post-test, though the two tests must be pitched at the same difficulty level. Furthermore, to avoid differential implementation of the intervention to the experimental and control group respectively, the researcher ensured identical implementation of the intervention with both groups.

External validity was enhanced by the fact that participants were not exposed to multiple treatment interactions to enhance their critical thinking skills (Lodico *et al*., 2010:249). The researcher focused on establishing the difference that resulted due to the implementation of one treatment only (Thinking Maps).

4.4.6.2 Reliability

As the tests used in the research did not comprise Likert-scale items, but multiple-choice items with one correct answer, the Statistical Consultation Services that assisted the researcher with the capturing and analysis of data indicated to the researcher that the format of the data collection items would not be suitable for computing Cronbach Alpha coefficients, and that the use of an informal pilot study would be suitable to assess the reliability of the test items.

A small scale, informal, dynamic pilot study (Brace, 2008:15) was conducted prior to data collection to establish the construct validity of the test items. The tests were distributed to specialists in the field (three Life Science lecturers), to verify whether the tests items measured analysis, synthesis and evaluation of information in Life Sciences, assess the difficulty level of the test items, check the wording for clarity and establish the suitablility of the completion time of the tests. The researcher adapted and reformulated the test items based on the suggestions and recommendations received from the specialists in the field, before administering the tests to the students.

In order to avoid threats to the reliability with respect to marking, the researcher ensured that:

- marking, adding and transfer of marks were double-checked by a colleague;
- he was the only marker, to avoid problems with interpreter reliability; and
- objective tests were used to avoid inconsistency in marking (Cohen *et al.,* 2007:159).

4.4.7 Ethical considerations

According to Strydom (2011a:113), “research should be based on mutual trust, acceptance, promises and well-accepted conventions and expectations between all parties involved in a research project”. Ethical issues anticipated in this research as indicated by Creswell (2009:88;2012:23), are discussed below.

4.4.7.1 Research problem

A research problem should have benefits not only for the researcher, but also for the participants (Creswell, 2009:88). The participants in this research could benefit, as they might acquire skills through the Thinking Maps intervention, which would enhance the development of their critical thinking skills so that they could become more successful at learning. In this research, there was no marginalisation or disempowerment of participants, as the intervention was implemented on a rotational basis with the experimental and control groups.

4.4.7.2 Purpose of research

According to Creswell (2009:88) and Strydom (2011a:113), deception involves the misleading of participants, deliberately misrepresenting facts or withholding information to ensure participation. The participants in this research were informed and had full disclosure of the purpose of the study: why and how they were selected to take part, that participation was voluntary and they could withdraw at any time, and the risks and benefits involved in participating (see Informed Consent, Appendix B).

4.4.7.3 Data collection

This research was done as a research project for a Master's degree under the guidance of a study leader at a university and ethical clearance was obtained from the university's Ethics Committee. The students who were willing to participate were provided with an informed consent form to complete before the research commenced (*cf*. Appendix B). The researcher made use of a knowledgeable independent person, Mrs. D Strauss, who dealt with recruitment, obtaining informed consent and administering of the tests. Confidentiality was guaranteed by ensuring that the data could not be linked to individual participants and that only the researcher, the study leader and the independent statistician had access to the data obtained. The data were at all times locked up in a cupboard in the researcher's office, where nobody could get hold of or tamper with the data. Final data were stored on a password protected computer. The participants completed the pre-tests and post-tests anonymously. The identities and contact numbers of the researcher and study leader were provided should the participants have had any questions (McMillan & Schumacher, 2008:143).

The intervention was presented to all participants on a rotation basis. Therefore, all the first year pre-service Life Science teachers benefited from the intervention. All informed consent forms and the tests were bilingual (Afrikaans and English) to ensure that language did not pose any barrier to the understanding and completion of the consent forms and test items.

To avoid unethical practice the following also applied during this research:

- The researcher taught to a broader domain, according to the outcomes of Life Sciences (the LIFE 111 module), and not to the tests, to enhance the validity and reliability of the test results.
- The researcher, as a competent and qualified lecturer, compiled and scored the tests.
- Students wrote all tests simultaneously to avoid test content being leaked.
- The tests consisted of multiple-choice questions and a follow-up open question for each multiple-choice answer where the students were required to motivate an answer, thus

promoting clear and objective marking and grading protocols, to avoid misinterpretation of responses.

- Participants were ensured that the test results would not in any way influence their passing/failing of the module (Cohen et al., 2007:432-433).

4.4.7.4 Data analysis and interpretation

The data analysis was done by an independent statistician at the NWU, Vaal Triangle Campus, without identifying any of the participants. The participants were assured that the data would be kept safe by the researcher in line with the Ethical Policy of the university, for a reasonable period (5-10 years). The researcher informed the participants that he would make the results of the study available to the participants once the study had been completed and examined (Creswell, 2009:91).

According to Strydom (2011a:126), researchers should never manipulate results, falsify or invent findings, as this is regarded as a serious scientific misconduct. The research report provided an accurate and a true account of the data obtained, to avoid misappropriation by the participants, public and colleagues.

The participants in this research could benefit as they might acquire critical thinking skills through the use of Thinking Maps, to enable them to analyse, synthesise and evaluate information more effectively, which could improve their academic performance. Furthermore, the findings could be utilised to make recommendations regarding the improvement of the teaching practices of Life Science teachers in order to enhance critical thinking skills in classrooms at school.

4.4.7.5 Writing and disseminating research

Strydom (2011a:126) states that in order for research to have value, research findings should be presented to the public. The researcher, the participants and the North-West University are the owners of the data and results will be available to them. The participants' consent was obtained to utilise the data for conference presentations and journal articles. Care was taken that no biased language was used regarding gender, cultural and home language group, or school attended in the preparation of the final research report.

4.5 CHAPTER SUMMARY

Chapter 4 focused on the research methodology what was employed in the context of the study (*cf*. 4.2 – 4.4).

The study was framed within a positivistic paradigm with a quantitative, quasi-experimental research design, as manipulation of a dependent variable (critical thinking skills) took place in an experimental context. The researcher used the non-equivalent groups pre-test-post-test control and comparison group designs as strategy of inquiry in a double experiment (*cf*. 4.4., 4.4.2).

The researcher used norm-referenced tests to collect data, as comparisons were drawn between the achievements of the control groups relative to the achievements of the experimental groups. The researcher developed tests with multiple-choice and open test items that were used to determine the extent to which the participants acquired the skills to execute critical thinking (analysis, synthesis, evaluation) in Life Sciences. Based on the pre-test results, the Thinking Maps intervention was developed to address the deficiencies noted in the pre-test results at the onset of the first six weeks and second six weeks of the first semester of 2016, before the implementation of the Thinking Maps interventions. The tests were piloted and refined before being administered to the sampled participants (*cf*. 4.4.3).

Non-probability sampling was employed to select the first year pre-service Life Science teachers (n = 56) at a South African university, who took part in the research. Non-probability sampling could not guarantee that the sample was representative of the population, therefore no generalisations of the research findings could be made. The researcher aimed to determine the impact of a Thinking Maps intervention as part of a pilot study in his own classroom practice during teacher-training to enhance the development of critical thinking skills among first year pre-service Life Science teachers (*cf*. 4.4.4).

The data derived from the pre-tests, post-tests and application of Thinking Maps were captured, analysed and interpreted with the assistance of an independent statistician from the NWU, Vaal Triangle Campus. The data analysis involved, firstly, the use of descriptive statistical procedures to summarise the data with frequencies, percentages, averages (means) and standard deviations. Secondly, inferential statistics were used to accept or reject the hypotheses stated at the onset of the study after comparing the means of the pre- and post-test data in order to make inferences about the effectiveness of the Thinking Maps intervention (*cf*. 4.4.5). The Thinking Maps that the participants constructed during the Thinking Maps intervention were assessed, to establish the effectiveness with which the students applied the thinking processes related to analysis, synthesis and evaluation to the subject content. The responses to the open questions in the tests provided initial data in relation to the effectiveness of the Thinking Maps intervention for enhancing the development of the participants' universal intellectual standards of reasoning (*cf*. 4.4.3).

The researcher adhered to quality criteria by ensuring that the study complied with reliability and validity criteria (*cf*. 4.4.6) and that he conducted the research according to ethical principles (*cf*. 4.4.7).

The following chapter, Chapter 5, provides detail about the twelve-week Thinking Maps intervention programme that was implemented during the first sememster of 2016.

CHAPTER 5

THE THINKING MAPS INTERVENTION PROGRAMME

5.1 INTRODUCTION

This chapter aims to provide a comprehensive overview of the Thinking Maps intervention programme that was implemented in the context of the research, and addresses the following issues:

5.2 Intervention research

- Definition
- The purpose of intervention research
- The stages of intervention research
- The stages of intervention research applicable for the study

5.3 The twelve-week intervention programme for Life Sciences

- The theoretical framework for the intervention programme
- The six-week intervention with the Experimental group 1 (Experiment 1)
- The six-week intervention with the Experimental group 2 (Experiment 2)

5.4 Chapter summary

As the focus of the study was on establishing the effects of a Thinking Maps intervention to enhance the development of critical thinking skills among first year pre-service Life Science teachers, the next section will provide detailed information about the intervention.

5.2 INTERVENTION RESEARCH

5.2.1 Definition

According to De Vos and Strydom (2011:475) and Fraser *et al.* (2009:157) intervention research is defined as "studies carried out for the purpose of conceiving, creating and testing innovative human services approaches". The following section will briefly explain the purpose of intervention research.

5.2.2 The purpose of intervention research

Fraser *et al*. (2009:157) concur that intervention research includes and incorporates programmes and activities intended to promote the application of programmes by researchers in their field of work. De Vos and Strydom (2011:475) add that the programmes and activities included in intervention research should solve or prevent problems to achieve set goals.

In this research, the researcher used Thinking Maps as an intervention strategy and concentrated on the following maps during the intervention: the Circle Map, the Tree Map and the Multi-Flow Map, as these maps provided opportunities for acquiring and enhancing the critical thinking skills on which the research focused, namely analysis, synthesis and evaluation.

The following section will describe the six stages of intervention research with emphasis on the first four stages applicable to this research.

5.2.3 The stages of intervention research

Intervention research comprises six stages (De Vos & Strydom, 2011:476). In the context of the study, the researcher implemented the first four stages. For the purpose of completeness, all the stages in intervention research will be briefly explained below, with the emphasis on how the first four stages applied to the present research.

5.2.3.1 Stage 1: Problem analysis and project planning

- **Identifying and involving clients**

According to De Vos and Strydom (2011:477), intervention researchers choose a suitable population whose issues or problems are of current interest to the researcher and to society.

In this research, the clients served by the intervention were the first year pre-service Life Science teachers as they had no prior exposure to Thinking Maps and their critical thinking skills appeared to be in need of enhancement.

- **Gaining entry and cooperation from settings**

De Vos and Strydom (2011:478) concur that cooperation and collaboration with the participants help to provide a sense of ownership of the research study. Conversations with the prospective participants help the participants to understand what is on offer and what the possible benefits are.

An independent person and an independent observer, designated by the lecturer teaching Life Sciences to the prospective clients, announced during a Life Science period that such an intervention would be offered to them during the first semester. An explanation of what the intervention would entail, followed. The reaction from the target group sampled was very positive as they realised that this intervention strategy could be of great advantage to them in their current and future studies.

- **Identifying concerns of the population**

De Vos and Strydom (2011:478) state that researchers must avoid projecting external and personal viewpoints of issues and solutions and should rather concentrate on issues of importance to the population and subsequently to the community.

The inability of many students to answer questions of analysis, synthesis and evaluation, is a source of great concern to both teachers at secondary schools and lecturers at university in South Africa and elsewhere (Lombard & Grosser, 2008:573; Zascavage, 2010:71). As pre-service Life Science teachers, the researcher and his colleagues also expressed the same concerns regarding the pre-service Life Science teachers.

- **Analysing concerns or problems identified**

According to De Vos and Strydom (2011:478), key questions such as the following, guide the process of problem analysis: What is the nature of the problem?; What are the negative and positive consequences of the problem for the population and community?; Who will benefit? and How will the participants benefit?

The CAPS was implemented in 2011 and in Life Sciences aims specifically to produce learners who are able to identify and solve problems and make decisions using critical and creative thinking. The CAPS implementation has largely shifted teaching from being mainly knowledge-driven to being more scientific method-orientated learning that requires the application of critical thinking skills, which many teachers find difficult to teach. The reasons for the inability of teachers to teach in the scientific method may be linked to the following:

- They might not understand the principles of the scientific method.
- They possibly have not received proper training regarding the implementation of the scientific method or did not attend such training.
- Little or no direct attention might have been devoted to helping teachers develop the skill they need to promote the application of critical thinking skills that are important for working according to the scientific method or with problem-based content in the classroom.

The direct benefits for the research participants by taking part in the Thinking Maps intervention could be the following:

- They could acquire critical thinking skills to analyse, synthesise and evaluate information more effectively.
- The Thinking Maps strategy could assist participants to learn and study better and possibly improve their academic performance in any subject.
- Participants would probably come to possess an effective teaching strategy that could be used when they start teaching.

The indirect benefits will probably be that:

- Researchers could be informed about the possible benefits of Thinking Maps as teaching strategy to develop critical thinking skills, and conduct further studies to conclusively confirm the merits of Thinking Maps for enhancing the development of critical thinking skills.
- Research findings could be used to make recommendations to the Department of Basic Education regarding the possible improvement of the teaching practices of Life Science teachers.
- The teaching practice of the greater population of Life Science teachers could benefit if the Thinking Maps strategy holds merits for developing critical thinking in Life Science.

- **Setting goals and objectives**

The final operation in Stage 1 is to set achievable and measureable goals and objectives. Goals refer to the outcomes desired by the community. Objectives refer to the specific changes in programmes or practices to reach the desired goals (De Vos & Strydom, 2011:479).

In this research, the researcher aimed to establish the merits of Thinking Maps for enhancing the development of critical thinking. The researcher envisaged to:

- conduct a literature review about previous studies on Thinking Maps to estalblish their impact on enhancing critical thinking skills;
- conceptualise and define critical thinking skills and Thinking Maps;
- reinforce the use of the Circle Map, the Tree Map and the Multi-Flow Map with Experimental groups 1 and 2 on a rotational basis as a teaching strategy to enhance the development of the application of the critical thinking skills to analyse, synthesise and evaluate information more effectively.
- evaluate the impact of Thinking Maps for enhancing critical thinking by administering researcher-developed pre- and post-tests to Experimental groups 1 and 2 prior to and after the implementation of a Thinking Maps intervention.

- draw conclusions and make possible suggestions flowing from this research that could influence future training of Life Science teachers to become capable of applying teaching strategies like Thinking Maps to enhance the development of critical thinking.
- equip pre-service teachers with a strategy that could with appropriate usage enhance their critical thinking skills.

5.2.3.2 Stage 2: Information gathering and synthesis

- **Using existing information sources**

De Vos and Strydom (2011:480) as well as Fraser and Galinsky (2010:462) agree that the literature review consists of an examination of selected empirical research and reported practice to identify possible resources, risk, promotive and protective factors related to the particular problem being studied. De Vos and Strydom (2011:481) indicate that intervention research should contribute to the development of new knowledge and insight about a topic under investigation.

The researcher used a variety of literature searches conducted by the Academic Information Service of the NWU, Vaal Triangle Campus. These literature searches could locate only three research studies conducted nationally and internationally that determined the effectiveness of Thinking Maps (*cf*. 1.1). Qualitative and quantitative research on improving critical thinking skills by means of intervention programmes have been conducted nationally and internationally among a variety of participants at all school levels, learners with special needs, undergraduate students and at management level. The focus areas include Technology, special needs, Natural sciences, Mathematics, Web Design, Physical Sciences and Computer Science. None of the aforementioned studies evaluated the impact of Thinking Maps for enhancing the critical thinking skills of pre-service Life Science teachers (*cf.* 1.1).

De Vos and Strydom (2011:480) mention that studying natural examples is a useful source of information and relates to observing how community members faced with a similar problem have attempted to solve it. Interviews with people who have experienced this problem/issue, such as service providers and other colleagues, provide insights into which interventions might be successful and which variables must be considered (De Vos & Strydom, 2011:480).

In this research study, the opinions of colleagues and the Life Science specialists who were involved in the pilot study and who observed the same lack of critical thinking skills among learners and students as well as the literature review conducted, served as natural examples that highlighted the need to address the problem.

- **Identifying functional elements of successful models**

Once information has been gathered, researchers must analyse previous attempts and programmes to solve problems or issues. Researchers should examine existing programmes, models or practice that have been used and have been successful in changing the problem or issues, and identify potentially useful elements of an intervention (De Vos & Strydom, 2011:482; Fraser & Galinsky, 2010:462).

The researcher used Thinking Maps as the main component in the intervention programme as they have been designed to help students develop critical thinking processes and habits. The researcher could not locate any evidence of other programmes that were successful in enhancing the critical thinking skills of pre-service Life Science teachers.

5.2.3.3 Stage 3: Design

According to De Vos and Strydom (2011:482), researchers must design a way of observing the events related to the problem/issues, find a method to determine the extent of the problem/issues and detect the results after the intervention was applied. The outcomes may be measured and the type of measurement chosen depends on the number of participants, and the length of observation and duration within the observational sessions (De Vos & Strydom, 2011:483). By observing the problem and studying innovations of interventions, researchers should identify procedural elements during the intervention. These procedural elements should include the use of information, skills and recruitment of participants (De Vos & Strydom, 2011:483).

The researcher made use of an independent person and observer to recruit the participants during the first period of the 2016 academic year and used two intact, preselected groups of participants. One group, the control group, received lectures during the normal class period as allocated by the university, being one period once a week (1 hour 20 minutes). The experimental group was lectured during another period determined by the participants themselves and received additional exposure to the use of Thinking Maps. Pre-tests and post-tests were administered by an independent person to both the experimental and control groups. Based on the results of the pre-tests, an intervention programme was developed to address the problems or issues identified in the pre-tests. The following procedural programme was followed during the first semester of 2016, with 12 teaching weeks divided between Experiment 1 and 2, as indicated in Table 5.1 below.

Table 5.1: Procedural programme

<table>
<tr><td colspan="4">Day 1: Recruitment of participants</td></tr>
<tr><td colspan="4">Weeks 1-6: Semester 1 – Experiment 1</td></tr>
<tr><td>Pre-test 1</td><td>Experimental group
Thinking Maps Intervention: 6 weeks</td><td>Control group
Normal class teaching: 6 weeks</td><td>Post-test 1
Post-test 1B</td></tr>
<tr><td colspan="4">Groups rotate
Weeks 7-12: Semester 1 – Experiment 2</td></tr>
<tr><td>Pre-test 2</td><td>Experimental group (control group of Experiment 1)
Thinking Maps intervention: 6 weeks</td><td>Control group (Experimental group of Experiment 1)
Normal class teaching: 6 weeks</td><td>Post-test 2
Post-test 2B</td></tr>
</table>

5.2.3.4 Stage 4: Early development and pilot testing

According to De Vos and Strydom (2011:483), this phase includes the "development of a prototype or preliminary intervention concept, conducting a pilot test and applying design criteria to the intervention concept".

- **Developing a prototype or preliminary intervention**

During this phase, the researcher developed a prototype of the intervention programme. In the context of the study, the Thinking Maps intervention programme was developed during the second semester of 2015.

- **Conducting a pilot test**

De Vos and Strydom (2011:484) and Fraser and Galinsky (2010:464) assert that pilot tests are designed to determine whether the intervention will be successful and should be administered in similar settings to that in which the intervention will be used. Pilot tests help to determine the effectiveness of the intervention programme. Any problems which may arise, or amendments suggested by participants during pilot testing, should form part of the intervention process (De Vos & Strydom, 2011:484). As the present study served the purpose of a pilot study, the observations made during the implementation of the intervention and the results obtained will be used to refine, amend and adapt the Thinking Maps intervention.

5.2.3.5 Stage 5: Evaluation and advanced development

This stage comprises the following step:

- **Selecting an experimental design**

According to De Vos and Strydom (2011:485), experimental designs help to show possible relationships between the intervention programme and the related target (participants). The choice of design depends on the goals and outcomes sought by the researchers.

The researcher envisages to assess the merits of the Thinking Maps intervention on a larger scale, using true experimental research in different contexts, after refining and adapting the intervention.

5.2.3.6 Stage 6: Dissemination

De Vos and Strydom (2011:487) concur that once the intervention has been field-tested, it is ready to be disseminated to the community and other target groups. The findings should be published in academic journals, read by practitioners, consumers and policy- makers. It can be difficult to publish treatment manuals, guides and training manuals due to high costs of publication versus yielding low profits (Fraser & Galinsky, 2010:465).

The researcher will pay attention to wider dissemination of the research findings in relation to the merits of the Thinking Maps intervention to enhance the development of critical thinking, after the implementation of the intervention in true experimental contexts.

As part of the present study, the preliminary findings obtained from the pilot study will be published in academic, peer-reviewed journals, and communicated at relevant conferences.

5.2.4 The stages of intervention research applicable to the study

Table 5.2 provides a visual summary of the stages of intervention research applicable to this research.

Table 5.2: Visual summary of the intervention research

Stages	Activities
4. Early development and pilot	Keeping the learning outcomes and assessment standards of Life Sciences in mind (LIFE 111), activities were designed for the different study units that focused on mastering the learning content and critical thinking skills by means of the following Thinking Maps: 1. Circle Map 2. Tree Map 3. Multi-flow Map
3. Design	The intervention was designed according to the Thinking Maps learning strategy developed by Dr. David Hyerle, and implemented on a rotation basis with an experimental and control group for 12 weeks (6 weeks per group).
2. Information gathering and synthesis	The researcher executed a wide literature search, which confirmed that not much research had been done regarding improving the critical thinking skills of pre-service Life Science teachers by means of Thinking Maps. The intervention programme focused on the use of Thinking Maps as learning strategy to nurture the following critical thinking skills: analysis, evaluation and synthesis.
1. Situation analysis and project planning	The importance of critical thinking skills to study and teach Life Sciences is reported widely in the literature. Based on pre-test results an intervention that focused on the use of Thinking Maps to nurture critical thinking skills among first year pre-service teachers was planned.

The following section gives an overview of the detailed intervention programme followed for twelve weeks.

5.3 THE TWELVE-WEEK INTERVENTION PROGRAMME FOR LIFE SCIENCES

The researcher, who received training in the application of Thinking Maps from an accredited Thinking Maps trainer, implemented the Thinking Maps intervention on a rotational basis with experimental and control groups as part of two experiments during the first semester of 2016 for a period of twelve weeks, six weeks per group. The teaching of both groups took place at separate times and in separate venues. The control groups received lectures during a normal class period (1 hour and 20 minutes) as allocated by the university once a week. The experimental groups received normal lectures and additional instruction in the use of Thinking Maps once a week, during another period (1 hour and 20 minutes) determined by the participants themselves to avoid any inconvenience. At the onset of the Thinking Maps intervention, the participants received training in the use of Thinking Maps. During each lecture, the use and application of the Thinking Maps were revised, before students were requested to use the Thinking Maps. Furthermore, both groups received normal teaching during the practical component of Life Sciences, which was excluded from the research. Pre-tests and post-tests were administered to both the experimental and control groups. The researcher (as lecturer) lectured the module content to achieve the learning outcomes as specified in the LIFE111 module to both the experimental and control groups. Examples of the lessons based on the Thinking Maps intervention are available of the CD at the back of the dissertation.

5.3.1 The theoretical framework for the intervention programme

Considering the learning theories discussed in Chapter 2, the researcher identified cognitivism and cognitive constructivism as the most appropriate learning theories to underpin the use of Thinking Maps as teaching strategy in the intervention programme.

5.3.1.1 The learning theory underpinning the intervention programme

The aforementioned learning theories shifts the locus of control over learning to the student, equipping them with cognitive skills to be actively involved in constructing meaning of information by selecting, analysing and evaluating information (Wallace *et al.,* 2007:128) (*cf.* 2.7.1.2, 2.7.1.3.). The principles of cognitivism and cognitive constructivism enable students to be involved in meaning making and thinking that could contribute to better understanding and learning. Students must apply knowledge, they must work to solve problems and discover information which creates opportunities for the development of higher cognitive and metacognitive thinking skills, such as analysis, synthesis and evaluation (*cf*. 2.7.1.5).

5.3.1.2 The teaching method and strategies underpinning the intervention programme

In support of the cognitive and constructivist learning theory, independent teaching and learning through the use of Thinking Maps as teaching strategy guided the implementation of the intervention programme. Independent teaching and learning is an act of independent construction of knowlege, driven by students themselves. The learning process involves the students' metacognitive abilities of planning, monitoring and reflection in order to apply the new knowledge or information. The use of the independent teaching method is in line with the requirements set out in the CAPS document (*cf*. Tables 2.1 and 2.2), which specifically specify the use of the scientific and inquiry methods to enrich and enhance students' scientific language.

Thinking Maps support the working of the brain in creating patterns from content specific information. This makes learning meaningful for students because it links the information they are learning to their own emotional frames of reference and gives them ownership of their thinking processes and their learning. Thinking Maps give explicit pathways for thinking about thinking, resulting in improved student performances (Hyerle, 2014:169) (*cf*. 3.5.3).

5.3.1.3 The Thinking Maps used in the context of the intervention

The interrelated application of the Thinking Maps that was promoted during the intervention, is explained below.

- **Circle Map** – The Circle Map is used to organise and reorganise knowledge, thus focusing on applying the skills of analysis and synthesis (*cf.* Figure 3.5).
- **Tree Map** – The Tree Map focuses on the skills to analyse and synthesise information by means of classification (*cf*. Figure 3.8).
- **Multi-Flow Map** – The Multi-Flow Map is used for analysing and evaluating cause and effect relationships (*cf.* Figure 3.11).

The Thinking Maps encouraged the students to become involved in a personal process to discover meaning in information by linking the information to underlying thought processes (Ertmer & Newby, 2012:55; Powell & Kalina, 2009:241; Wallace *et al.*, 2007:28) (*cf.* 2.7.1.3, 2.7.1.2).

The next section provides a comprehensive overview of the teaching plan that was followed during the first semester of 2016.

5.3.2 The six-week intervention with Experimental Group 1 and 2

The following intervention programme with Experimental group 1 (*cf*. Table 5.3) was followed during the first six weeks of the first semester of 2016. The control group received normal classroom lectures. The groups rotated and the intervention was applied for the next six weeks of the first semester to Experimental group 2 (*cf*. Table 5.4). The control group of experimental group 1 now became the experimental group, and the experimental group became the control group who received normal classroom lectures.

The Thinking Maps intervention had to fit into a time-limited schedule, and the researcher had to strive to relate results/findings in the time he had available, namely one semester comprising 12 weeks.

The researcher had to employ a multi-group design – 2 groups following another, as participants had to enter the intervention at different levels due to logistical and time constraints. This was done in order to give all the participants the opportunity to be exposed to the Thinking Maps intervention and to have a control group as part of the research.

The intervention had to correspond with the regular Life Sciences programme, and as it was not possible on the timetable to provide for simultaneous but separate lecture opportunities for Experiment 1 and Experiment 2 during weeks 1-6 of the intervention without inconveniencing the students, the experiment had to be conducted on a rotation basis. This implied that the intervention with the second experiment had to correspond with the Life Science programme for weeks 7-12 of the first semester. The researcher therefore had to design two similar interventions that focused on different topics. The nature of the content was however similar (problem-based content and content related to working according to the scientific method). The thinking processes embedded in the content of both semesters were also similar, and emphasised the application of the critical thinking skills analysis, synthesis and evaluation.

In quasi-experimental research, a researcher can use naturally formed groups where conditions of treatment might slightly differ (Craighead & Nemeroff, 2002:1397). Although this type of design has less internal validity, it provides some support for causal inferences to be made (Rubin & Babbie, 2009:164)

Table 5.3: The six-week intervention programme with Experimental group 1

Week 1: Semester 1 – Experiment 1			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Thinking Maps Introductory scientific method Method remarks Data analysis	Use the Thinking Maps to summarise theory. Describe the scientific method and critically evaluate[1] its use. Be aware of the existence of other schools of thought in practising science. Plan and execute[2] an experimental investigation. Write a detailed report[3] of an experiment. Become acquainted with the ways in which data are presented in graph format. Become acquainted with the different ways of measurements in Life Sciences. Key for the underlined concepts/phrases: Critical thinking skills involved in this content: 1: Evaluate 2: Analyse 3: Synthesise	PowerPoint presentations on how to construct Thinking Maps and study sections 1.1 – 1.3. Handouts Thinking Maps – standard. Specific emphasis on Thinking Maps.	Make sure that you know the steps involved in a scientific investigation as stipulated in MADER, p 11 and Addendum 1. Draw a simple Thinking Map of the scientific method. Important concepts include hypothesis, manipulated or independent variables, responding or dependent variables, control experiments and theories. Study the logical consecutive steps that need to be followed when one writes a report on an experiment. SG* activity p 4 & 5. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

*SG Refers to “Study guide”.

Week 2: Semester 1 – Experiment 1			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Microscopy	Correlate the progress that has been made in the field of microscopy with the development of technology. Distinguish between the different kinds of microscopes and classify the ways in which they are used[1]. Identify the different parts that a compound light microscope is made of. Demonstrate the use, care and handling of a light microscope. Apply the relevant measuring units and skills[2] that are commonly used in cytology with understanding. Use the different techniques[3] that are necessary in preparing temporary and permanent slides for light microscope work. Choose the correct stains[1] that are used in making temporary and permanent slides. Key for clarifying the underlined concepts/phrases: Critical thinking skills involved: 1: Evaluate 2: Analyse 3: Synthesise	PowerPoint presentations on study sections 2.1. Specific emphasis on Thinking Maps.	Distinguish between: Different kinds of microscopes; and different kinds of light microscopes as well as the ways in which each one is used. Make very sure that you master the table in MADER, p 61. SG activity p 20 & 21. Make use of Thinking Maps (try to use at least 2 types) to summarise theory done in class.

Week 3: Semester 1 – Experiment 1			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Membrane structure and function; Diffusion and osmosis	Explain the fluid mosaic model of the membrane structure. Explain the structure and function of the cell membrane and illustrate it by means of diagrams[1]. Critically evaluate[2] the permeability and transmission of membranes. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Evaluate	PowerPoint presentations on study sections 2.3. Experimenting diffusion and osmosis. Specific emphasis on Thinking Maps and experiments regarding diffusion and osmosis.	Make sure that you are able to explain the fluid mosaic theory of membrane structures. Identify the following as being present in plasma membranes, as well as biological and chemical characteristics that underline its presence: Lipids; membrane protein; membrane carbohydrates; transportability of the membrane. List the functions of plasma membranes in your own words. Describe the functions of plasma protein in your own words with the aid of simple drawings. Identify the reasons why transmission takes place across membranes. Also identify the four (4) mechanisms whereby it occurs. SG activity p 33. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

Week 4: Semester 1 – Experiment 1			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Basic chemistry	Classify[1] the chemical and physical nature of matter. Describe important chemical phenomena and chemical equations[2] that are important to Life Sciences. Critically evaluate[3] the characteristics of mixtures. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Synthesise 3: Evaluate	PowerPoint presentations on study sections 2.4. Specific emphasis on Thinking Maps.	Revision SG p 36-37. Write down the definition of matter. Name the THREE (3) phases of matter. Briefly tabulate the differences between the three kinds. Also make use of a simple **Tree Map** that indicates the differences clearly. Complete a **Tree Map** that represents the classification of matter. Also write down a definition for every component. Draw a **Circle Map** of an atom with all its parts. Summarise all the relevant facts you have to know about on the basis of your drawing. Follow the same steps as set out on p 41 in SG and indicate how a covalent bond is formed in each of the given compounds. You have to facilitate this content to Grade 10 learners. Plan how you would go about doing it using a **Circle Map**. SG activity p 37 – 54.

Week 5: Semester 1 – Experiment 1			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Organic nutrients - Carbohydrates	Describe the structure, composition and the biological importance of the following organic carbohydrates, critically evaluate[1] them and where applicable, illustrate the composition by means of diagrams. Key for understanding the underlined concepts/phrases: Critical thinking skills involved: 1: Evaluate	PowerPoint presentations on study sections 2.5.2. Specific emphasis on Thinking Maps.	Revision SG p 59. Draw a labelled sketch of a carbon atom use the **Circle Map** as your basis and indicate all characteristics. What is a polysaccharide? Classify the following polysaccharides with regard to their monomers, structure and function. Draw a **Tree Map.** starch; glycogen; cellulose; and chitin. Food tests: Use the multi-flow map to illustrate cause and effect (scientific method). SG activity p 63 – 67. Make use of Thinking Maps (try to use at least 2 types) to summarise theory done in class.

Week 6: Semester 1 – Experiment 1			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Metabolism	Distinguish[1] between different kinds of energy; Explain the laws of thermodynamics; Describe the energy of the cell, ATP, with regard to structure, formation and functions. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse	PowerPoint presentations on study sections 2.6.1 – 2.6.2. Specific emphasis on Thinking Maps.	Revision SG p 77. Summarise the following questions: What is energy? Distinguish between different kinds of energy by referring to the flow of energy through a food chain. Define and describe the following: The TWO (2) laws of thermodynamics; and cells and entropy Distinguish between ADP and ATP. Draw a simple tree map to classify the structures of ATP and ADP. Make use of a simple chemical equation to demonstrate the formation of ATP,Then explain it briefly with the aid of an appropriate example. SG activity p 33. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

Table 5.4: The six-week intervention programme with Experimental Group 2

Week 7: Semester 1 – Experiment 2			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Thinking Maps Photosynthesis	Use the Thinking Maps to summarise theory. Describe the importance of energy[1] for organisms. Define the photosynthesis process; Critically evaluate[2] the importance of the photosynthesis process. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Evaluate	PowerPoint presentations on Thinking Maps and study sections 2.7. Handouts Thinking Maps – standard. : Specific emphasis on Thinking Maps.	Revision SG p 83 – 84. Write down the chemical equation of photosynthesis. Formulate the word definition of photosynthesis by making use of the chemical equation. Use the chemical equation and explain the biological importance of photosynthesis Use a single page to summarise this work. Pay attention to the following: the inner structure of a leaf; the outer and inner structure of the chloroplast; and the correlation between structure and function. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

Week 8: Semester 1 – Experiment 2			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Photosynthesis - continued	Describe the cyclic and non-cyclic photophosphorylation processes of the light-dependent phase of the photosynthesis process and illustrate them by means of diagrams[1]. Describe the light-independent phase of the photosynthesis process and illustrate them by means of diagrams[1]. Critically discuss[2] factors that influence the photosynthesis process. Briefly describe and classify[2] the other types of photosynthesis. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Synthesise	PowerPoint presentations on study sections 2.7.4-2.7.5. Specific emphasis on Thinking Maps.	Revision SG p 83 – 84. **Light-dependent phase of photosynthesis.** This phase is divided into the cyclic and non-cyclic photophosphorylation phases of photosynthesis. Use the tip I have given you above and make your own summaries. Also indicate what the role of the photosystems is. Factors that influence the photosynthesis process. **Light-independent phase of photosynthesis.** Summarise these sections and make them your own. Factors that influence the photosynthesis process. SG activity p 89 -90. Make use of Thinking Maps (try to use at least 2 types) to summarise theory done in class.

Week 9: Semester 1 – Experiment 2			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Respiration	Describe the structure of a mitochondrion and illustrate it by means of diagrams. Describe the course of the aerobic cellular respiration process (glycolysis, transition phase, Krebs cycle and terminal oxidation) and illustrate it by means of diagrams[1]. Describe the anaerobic cellular respiration in plant and animal cells and illustrate it by means of diagrams[1]. Describe the role that yeast and lactic fermentation plays in the preparation of food and spirits. Classify the characteristics[2] aerobic and anaerobic cellular respiration. Classify the characteristics of[2] the photosynthesis and aerobic cellular respiration processes and illustrate the correlations by means of flow diagrams. Describe and critically evaluate[3] the correlation between photosynthesis and respiration. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Synthesise 3: Evaluate	PowerPoint presentations on study sections 2.8. Specific emphasis on Thinking Maps.	Revision SG p92-93. Use a single sheet of paper to summarise this work. Pay attention to the following: The inner structure of the mitochondrion; and the correlation between structure and function. Now compare the anaerobic and aerobic respiration processes in table format. Now compare photosynthesis and aerobic cellular respiration by creating the schematic representations of the two processes next to each other. SG activity p 96 – 100. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

Week 10: Semester 1 – Experiment 2			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
DNA	Bring the applicability of DNA in context with technological developments[1]. Describe the formation and structure of a di-nucleotide and a polynucleotide and illustrate them by means of diagrams[2]. Describe the formation, structure, characteristics and functions of a DNA molecule and illustrate them by means of a diagram[2]. Describe replication of DNA and illustrate it by means of a diagram[2]. Describe the composition and functions of rRNA, mRNA and tRNA and illustrate them by means of diagrams[2]. Key to understand the underlined concepts/phrases: Critical thinking skills involved. 1: Synthesise 2: Analyse	PowerPoint presentations on study sections 3.1.1 – 3.1.3. Specific emphasis on Thinking Maps.	Revision SG p104. Make sure that you know what is meant by di-nucleotide and polynucleotide. Make use of simple line diagrams and indicate the structure and formation of di-nucleotide and polynucleotide respectively. Make use of Internet sources and draw the parallels between technological developments and the discovery of DNA. Study RNA under the following sub-headings: Structure and function; Kinds of RNA and the role each one plays in protein synthesis. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

Week 11: Semester 1 – Experiment 2			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
RNA - continued	Discuss the important role that this nucleic acid molecule plays in the protein synthesis process; Describe the course of the protein synthesis and illustrate it by means of appropriate diagrams[1]. Define the terms genes and genetic code and describe the characteristics of both. Critically evaluate[2] the role that DNA and RNA play not only in the survival of an organism, but also in the survival of a species. Link relations between DNA, the medical and forensic industry and possible bio-ethical issues that originate from them[3]. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Evaluate 3: Synthesise	PowerPoint presentations on study sections 3.1.4 – 3.1.6. Specific emphasis on Thinking Maps.	Revision SG p110 – 111. Study the genetic code by referring to the definition and characteristics. Summarise the course of the process and attempt conceiving the process visually. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

Week 12: Semester 1 – Experiment 2			
Study section	**Outcomes**	**Lecturer activities**	**Student activities**
Cell division	Describe chromosome structure and illustrate it by means of suitable diagrams[1]. Define the following concepts and where appropriate, illustrate them by means of suitable diagrams[1]: homologous pairs of chromosomes, a karyogram and the karyotype of a cell, autosomal and gonosome chromosomes, haploid and diploid cells. Fully describe the following structures that play a role during the cell division processes, namely a centriole, centrosome and a spindle. Describe the cell cycle and illustrate it by means of a diagram[1]. Describe the consecutive phases in the course of the mitosis process and its biological importance and illustrate and substantiate them by means of diagrams. Classify the ways in which[2] cytokinesis takes place in plant and animal cells. Key to understand the underlined concepts/phrases: Critical thinking skills involved: 1: Analyse 2: Synthesise	PowerPoint presentations on study sections 3.2. Specific emphasis on Thinking Maps.	Revision SG p114 – 115. Here you also have to use maps and write down the **definitions and functions**that they fulfil during cell division next to it or on the drawing itself, as far as it is possible. Study this section by paying attention to the following aspects: Centromere, Centrosome, Centriole, Spindle. Summarise the events that occur in a cell next to the symbol of each phase. The sketches of each stage of each phase are now given. Carry out the following instructions in this regard: Make sketches of all the phases and label them in full. Summarise the events of each phase in the space left vacant for that purpose. Make use of Thinking Maps (try to use at least two types) to summarise theory done in class.

5.4 CHAPTER SUMMARY

Chapter 5 initially briefly defined and described the six phases of intervention research. In the context of the study, the researcher implemented four steps, namely problem analysis and project planning; information gathering and synthesis; design; and early development and pilot testing.

The twelve-week Thinking Maps intervention programme was underpinned by cognitive and cognitive constructivist learning theories and implemented by means of independent teaching as teaching method, with Thinking Maps as teaching strategy. A comprehensive overview of the twelve weeks Thinking Maps intervention programme was provided (*cf*. 5.3.2).

The next chapter, Chapter 6, focuses on the data analysis and interpretation.

CHAPTER 6
DATA ANALYSIS AND INTERPRETATION

6.1 INTRODUCTION

This chapter presents the statistical analyses and the interpretations of the data obtained from the research participants in order to determine to what extent a Thinking Maps intervention programme in Life Sciences enhanced the development of their critical thinking skills (analysis, synthesis and evaluation).

The data analyses and interpretations will be dealt with in the following sequence:

6.2 Reliability of the tests

6.3 Biographic information of the participants

6.4 Data analysis and interpretation: Pre- and post-tests

- Introduction
- Data analysis and interpretation: Experimental group 1
- Data analysis and interpretation: Experimental group 2

6.5 Data analysis and interpretation: Comparison between participants from Experimental group 1 and 2

6.6 Data analysis and interpretation: Thinking Maps worksheets – Experiment 1 and 2

6.7 Data analysis and interpretation: Open responses – pre- and post-tests

6.8 Chapter summary

In the context of the data analysis, the following explanation applies:

Experiment 1 (E1) involved an experimental group and a control group. The experimental group received six weeks' exposure to lecturing and a Thinking Maps intervention, and the control group only received normal lecturing.

Experiment 2 (E2) involved an experimental group (control group of Experiment 1) and a control group (experimental group of Experiment 1). The experimental group received six weeks' exposure to lecturing and a Thinking Maps intervention, and the control group only received normal lecturing.

The next section reports on how the researcher ensured the reliability of the pre-tests and post-tests in the context of the research.

6.2 RELIABILITY OF THE TEST DATA

6.2.1 Skewness and kurtosis

Data related to skewness and kurtosis indicate the symmetry of the distribution of data, and guide the researcher in choosing parametric or non-parametric statistical procedures to analyse the data (Brown, 2008; Leedy & Ormrod, 2013:256).

The skewness of a distribution is a measure that describes how far the distribution of data deviates from the symmetry. According to Pietersen and Maree (2010a:189), the distribution of data may be skewed to the right, or **positively skewed** (longer tail to the right) or the data may be spread more to the left, or **negatively skewed** (longer tail to the left). If skewness is smaller than -1 or larger than 1, the distribution of the data is extremely skew. If skewness lies between -1 and -0.5 or between 0.5 and 1, the distribution of data is moderately skew. Finally, if the distribution of data is symmetrical, the skewness will lie between -0.5 and 0.5 (Brown, 2008).

The kurtosis of a distribution describes the amount of "peakedness" (leptokurtic) or "flatness" (platykurtic) around the mean and is directly related to the standard deviation of the distribution (Pietersen & Maree, 2010a:190). A normal distribution has kurtosis exactly 3 and is called **mesokurtic**. A distribution with kurtosis < 3 is called **platykurtic**. Compared to a normal distribution, its tails are shorter and thinner, and often its central peak is lower and broader. A distribution with kurtosis >3 is called **leptokurtic**. Compared to a normal distribution, its tails are longer and fatter, and often its central peak is higher and sharper (Brown, 2008).

Table 6.1 reports on the data obtained for skewness and kurtosis.

Table 6.1: Skewness and kurtosis

Application	Skewness		Kurtosis		Skewness	Kurtosis
Groups	**E 1**	**E 2**	**E1**	**E 2**	**E1 & E2**	
Sample size	29	27	29	27	56	
Pre-test 1	0.514	-0.518	-0.647	-0.365	-0.053	-1.043
Post-test 1	-0.696	0.298	0.991	0.323	-0.056	0.608
Pre-test 2	-0.088	-0.282	-0.564	-0.847	-0.041	-0.399
Post-test 2	1.033	-0.068	1.293	-0.771	0.425	0.000
Post-test 1B (Retention test)*	-0.246	-0.273	-1.134	-0.558	-0.247	-0.878
Post-test 2B (Retention test)**	-0.447	-0.597	-0.087	1.050	-0.515	0.414

* Pre-test 1 was administered twice.

** Pre-test 2 was administered twice.

The skewness for the data obtained for pre-test 1, post-test 1, pre-test 2, post-test 2, post-test 1B and post-test 2B for the entire group of participants (E1 & E2), lies between 0.5 and -0.5. This indicates that the distribution of data in all the tests is **symmetrical** (Brown, 2008). The kurtosis for the data obtained for pre-test 1, post-test 1, pre-test 2, post-test 2 and post-test 1B, include values smaller than 3 and are mostly negative (except post-tests 1, 2 and 2B), indicating **platykurtic** distributions (Pietersen & Maree, 2010a:190). The independent statistician confirmed that the measures of shape for the data, namely symmetrical and platykurtic distributions, allowed for the use of parametrical statistical data analysis procedures to analyse the test data (Pietersen & Maree, 2010d:225) (*cf*. 4.4.5). Platykurtic distributions do not have major fluctuations and fewer extreme outliers, and most of the values share the same frequency.

6.3 BIOGRAPHIC INFORMATION OF THE PARTICIPANTS

Experimental group 1 comprised 29 participants, and Experimental group 2 comprised 27 participants. Initially, 76 students took part in the research. However, many of the students did not write all the tests, and the statistician advised the researcher to only include the data of the students who completed all the tests for comparison purposes.

6.3.1 Biographic information of students

In Table 6.2 the biographic information of the participants regarding their **home language** is indicated.

Table 6.2: Home language

Language	Total group		Experiment 1		Experiment 2	
	f	%	f	%	f	%
Missing*	9	16	4	14	5	18
Afrikaans	5	9	2	7	3	11
English	1	2	1	4	-	-
Sesotho	22	39	9	31	13	48
Swati	1	2	1	3	-	-
Tswana	1	2	1	3	-	-
Xhosa	2	3	1	3	1	4
Zulu	15	27	10	35	5	19

*Number of participants who did not respond to this question.

Figure 6.1 below provides a graphical representation of the various language sub-groupings of the participants.

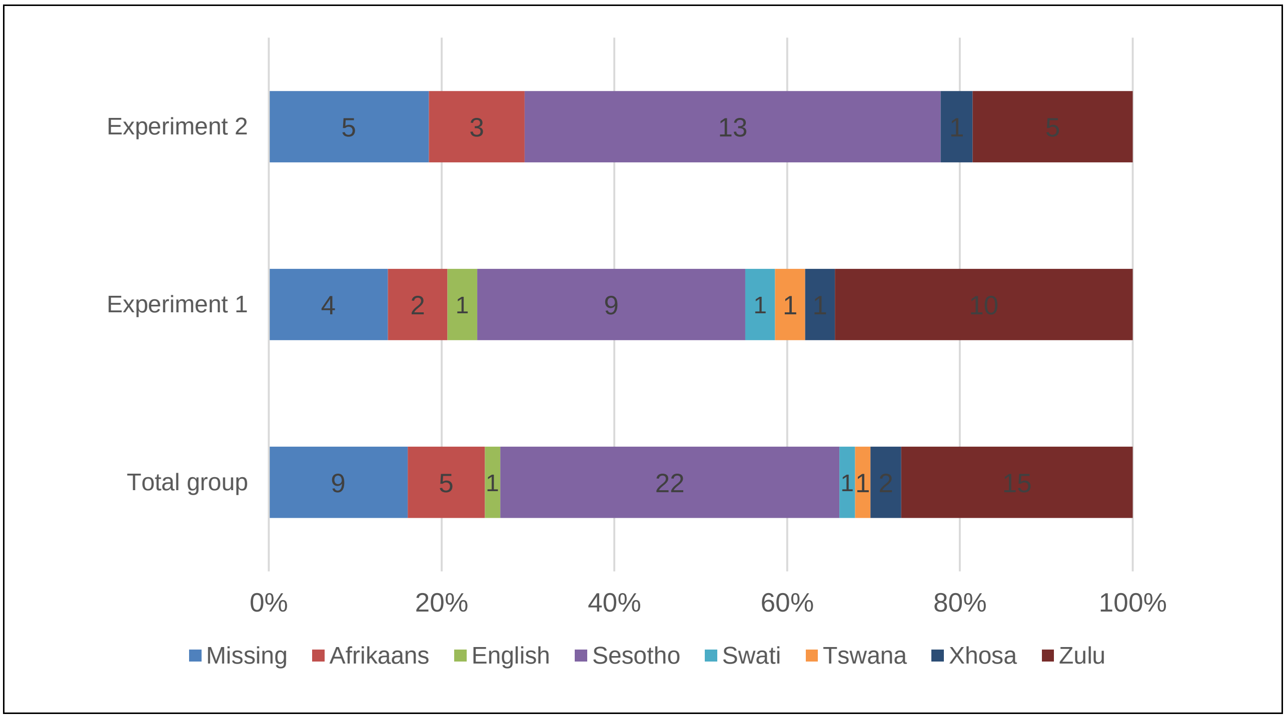


Figure 6.1: Home Language

Table 6.3 presents the biographic information of the participants regarding their **gender.**

Table 6.3: Gender

Gender	Total group		Experiment 1		Experiment 2	
	f	%	f	%	f	%
Female	33	59	15	52	18	67
Male	23	41	14	48	9	33

Figure 6.2 visually represent the gender of the participants who took part in the study.

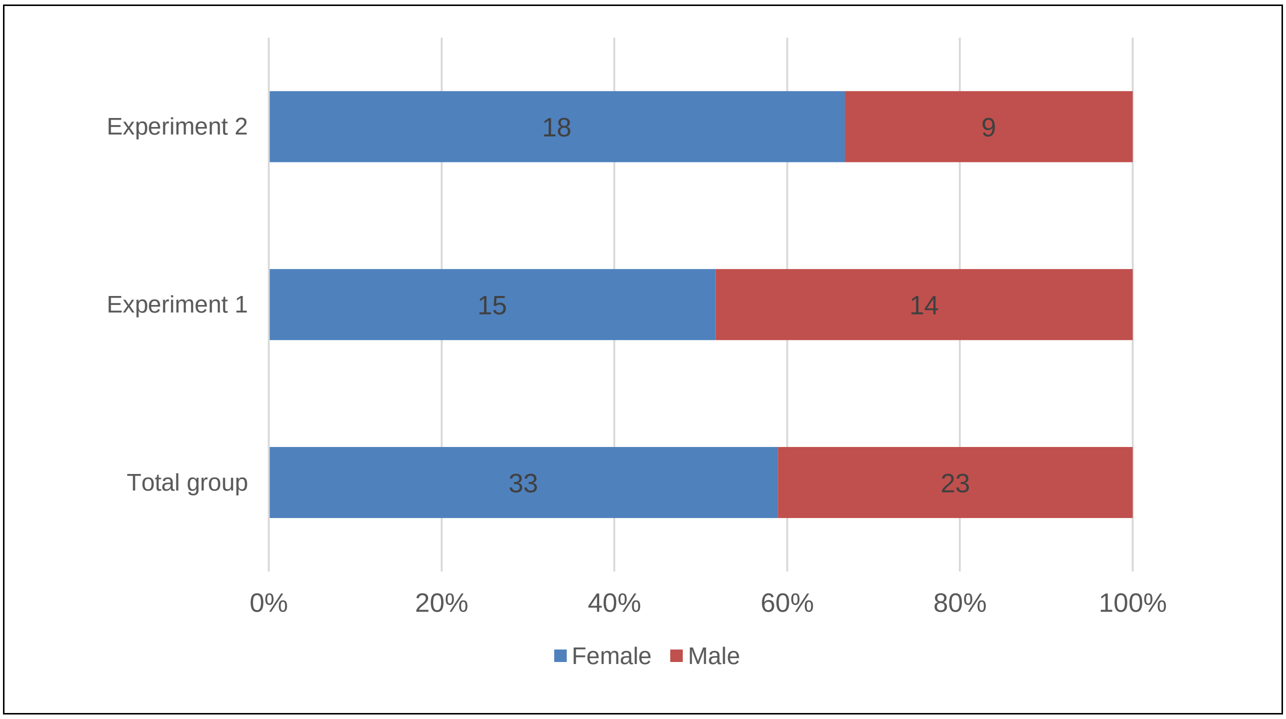


Figure 6.2: Gender

Table 6.4 presents the biographic information of the participants regarding their **type of school.**

Table 6.4 Type of school

Type of school	Total group		Experiment 1		Experiment 2	
	f	%	f	%	f	%
Missing*	9	16	4	14	5	18
Ex-Model C	8	14	3	10	5	19
Township	39	70	22	76	17	63

*Number of participants who did not respond to this question.

Figure 6.3 visually represent the type of school the participants attended.

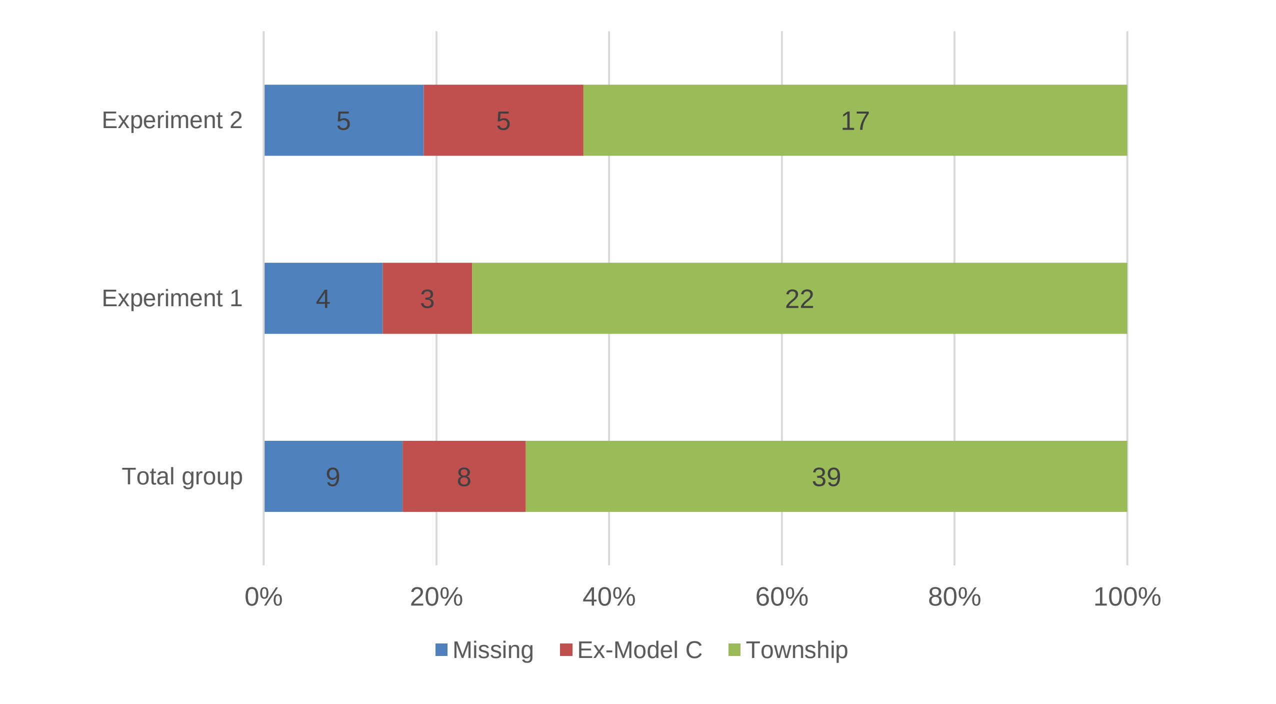


Figure 6.3: Type of school

Table 6.5 presents the biographic information of the participants regarding their **cultural group.**

Table 6.5: Cultural Group

Cultural group	**Total group**		**Experiment 1**		**Experiment 2**	
	f	%	f	%	f	%
Missing	9	16	4	14	5	19
African	41	73	22	76	19	70
White	6	11	3	10	3	11

Figure 6.4 visually represent the cultural groups of the participants.

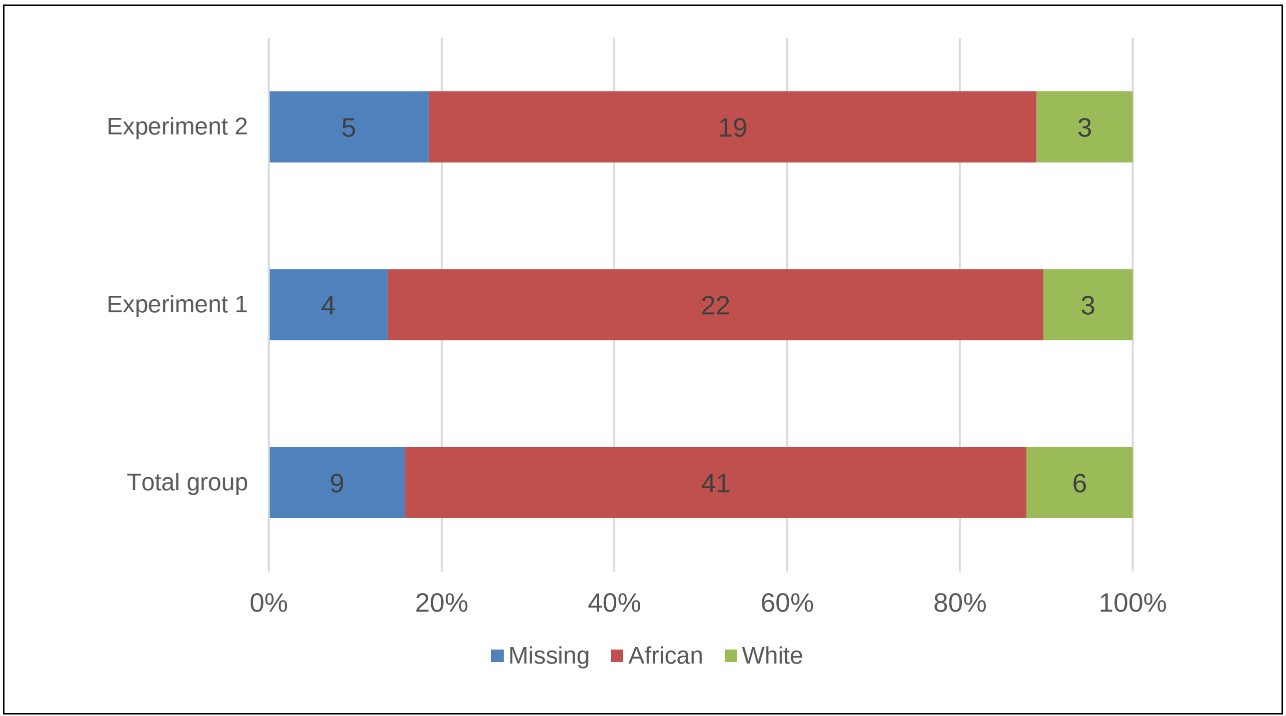


Figure 6.4: Cultural group

The numbers of participants in the sub-groups for the various biographic variables were too small to conduct statistical analyses to determine the influence of the biographic variables on the research findings.

In the following section, the researcher reports on the data obtained from the participants regarding the various tests for Experimental group 1.

6.4 DATA ANALYSIS AND INTERPRETATION: PRE- AND POST-TESTS

6.4.1 Introduction

By means of descriptive statistics, data were organised and summarised to promote an understanding of the data characteristics (Pietersen & Maree, 2010a:195).

This section presents the responses obtained from the students for each of the tests. Each test focused on three skills in relation to critical thinking in the Life Science classroom of first year B.Ed. Life Science students. Although all the tests focused on the application of the three critical thinking skills pertaining to this research, namely analysis, synthesis and evaluation, the contents of the various tests differed to align with the progression in the first semester subject content for first year Life Sciences. The different content also served the purpose of establishing if the participants could apply the skills that were possibly acquired during the intervention to different contexts, and to minimise the possible influence of the pre-test content that might remain known to the participants after the short six week implementation of the Thinking Maps intervention. Pre-test 1 was repeated as post-test 1B and pre-test 2 was repeated as post-test 2B, to establish the retention of the skills possibly acquired with the Thinking Maps intervention (Experiment 1) and after normal lecturing (Experiment 2).

The following content was addressed in the various test occasions:

- Pre-test 1: Gr. 12 Life Science syllabus: DNA, RNA, meiosis, reproduction of vertebrates, human reproduction, the nervous system, the endocrine system, homeostasis, Darwinism and natural selection, human evolution, and human impact on the environment.
- Post-test 1: Working according to the scientific method and problem-based content: data analysis, indigenous knowledge, microscopy, cells, membrane structure and function, diffusion and osmosis, cell division, basic chemistry, inorganic and organic compounds, energy and ATP and enzymes.
- Post-test 1B (repetition of pre-test1): Gr. 12 Life Science syllabus.
- Pre-test 2: Working according to the scientific method and problem-based content that was the focus of post-test 1.
- Post-test 2: Photosynthesis and related experiments, respiration and related experiments, DNA, RNA and cell division. Focus on problem-based content.
- Post-test 2B (repetition of pre-test 2): Scientific method and problem-based content.

The participants' responses to the various test occasions are reported in a table (Table 6.7), in order to explore different response patterns between the various test occasions (Pietersen & Maree, 2010a:185). The data obtained for the responses are summarised with frequencies, percentages, means and standard deviations. Inferential statistics were applied to determine the statistical significance of the differences noted between the various test occasions within and across the experimental and control groups in Experiment 1 and Experiment 2. If statistical significant differences were noted, Cohen's *d* was calculated to determine the effect of the difference in practice. In line with the advice provided by the Statistical Consultation Services at the university where the research was conducted, effect sizes are only reported for statistical significant differences. According to Leech *et al.* (2005:59), if the difference between means was not statistically significant, it is best not to make any comment about which mean was higher because the difference could be due to chance. Likewise, if the difference was not significant, Leech *et al.* (2005:59) recommend that effect size not be discussed or interpreted.

Graphical representations are used to visually highlight the prominent features that emanated from the responses. The data are interpreted according to the average percentage scored on the tests. The total raw score for each test occasion was 15.

Table 6.6 presents the time line for the various test occasions for Experiment 1 and Experiment 2.

Table 6.6: Time line for various tests

Test application	Date applied	Groups involved
Pre-test 1	Week 1	Experiment 1
Thinking Maps intervention		
Post-test 1 and Post-test 1B*	Week 6	
Pre-test 2	Week 7	Experiment 2
Thinking Maps intervention		
Post-test 2 and Post-test 2B**	Week 12	

*A repetition of pre-test 1 ** A repetition of pre-test 2

6.4.2 Data analysis and interpretation: Experimental group 1

Table 6.7 reports the data obtained for the various test occasions for Experimental group 1, and Figure 6.5 indicates the various test score percentages for Experimental group 1.

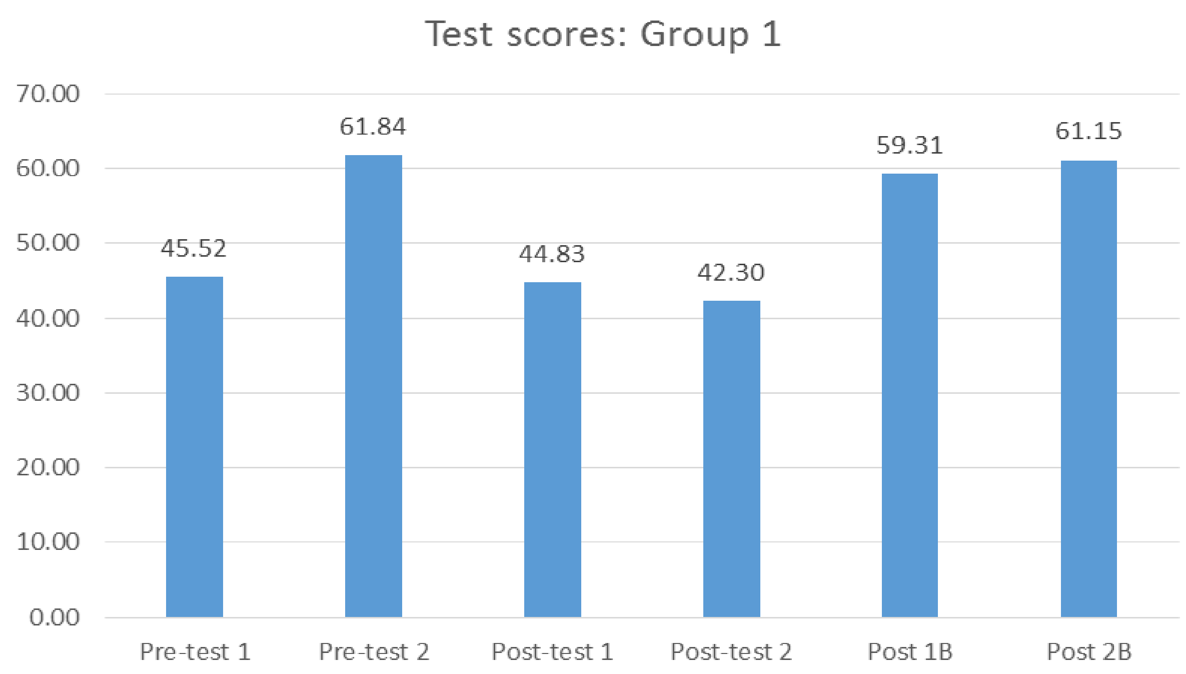


Figure 6.5: Comparison of test results: Experimental group 1

Table 6.7: Test data: Participants Experimental group 1

	Test application	n	$\bar{x}$ (15)	%	Mean difference	s	t	df	*p*	Cohen's *d*	Effect size
1	Pre-test 1	29	6.828	45.517	0.103	2.331	0.204	28	0.840	-	-
	Post-test 1	29	6.724	44.827		1.868					
2	Pre-test 1	29	6.828	45.517	-2.069	2.331	-5.021	28	0.000*	0.886	Large
	Post-test 1B	29	8.897	59.310		2.335					
3	Post-test 1	29	6.724	44.827	-2.172	1.868	-4.063	28	0.000*	0.930	Large
	Post-test 1B	29	8.897	59.310		2.335					
4	Pre-test 2	29	9.276	61.839	2.931	2.750	4.993	28	0.000*	1.066	Large
	Post-test 2	29	6.345	42.298		2.192					
5	Post-test 2B	29	9.172	61.149	-0.104	1.947	-0.208	28	0.837	-	-
	Pre-test 2	29	9.276	61.839		2.750					
6	Post-test 2B	29	9.172	61.149	2.827	1.947	5.938	28	0.000*	1.452	Large
	Post-test 2	29	6.345	42.298		1.192					

* Statistical significance: $p < 0.05$

A comparison between the means for **pre-test 1 ($\bar{x}$ = 6.828)** and **post-test 1 ($\bar{x}$ = 6.724)** revealed a statistically non-significant difference, p = 0.840 as the participants obtained more or less the same average percentage for both tests. A mean difference of 0.103 between pre-test 1 ($\bar{x}$ = 6.828) and post-test 1 ($\bar{x}$ = 6.724) was noted. The participants did not appear to be effective (in the context of the study, "effective" will refer to being successful in producing a result that indicates powerful improvement) at applying critical thinking in post-test 1 after completing the Thinking Maps intervention as the average for post-test 1 was lower than the average achieved for pre-test 1. To explain this finding, the researcher concluded that post-test 1 that focused on the subject content dealt with during weeks 1 – 6 of the Thinking Maps intervention and focused on problem-based content and working according to the scientific method, might have been too difficult, in comparison to pre-test 1, that focused on the subject content of Grade 12 Life Sciences that might have been more familiar to the students. In addition, the Thinking Maps strategy might not have been effective for dealing with problem-based content and working according to the scientific method. This finding supports the viewpoint of Illeris (2015:30) (*cf*. 2.6.2) who states that mislearning or a lack of understanding may lead to an inability to apply critical thinking skills.

A comparison between the means of **pre-test 1 ($\bar{x}$ = 6.828)** and **post-test 1B ($\bar{x}$ = 8.897),** a repetition of pre-test 1, revealed a statistically significance difference of $p < 0.05 = 0.000$ with a large effect in practice, d = 0.886. This result implied that the post-test 1B result was statistically significantly better than the pre-test 1 result. The researcher concluded that the six weeks of Thinking Maps intervention possibly enhanced the application of the students' critical thinking skills and they became more effective at applying critical thinking to the content of post-test 1B (Grade 12 Life Sciences). The data supported the effectiveness of the Thinking Maps intervention to enhance the critical thinking skills in Life Sciences and strengthened the findings of Hyerle (2009:155) (*cf*. 3.5.3), who states that Thinking Maps promote the development of thinking skills. This finding also aligns with the argument of Pritchard (2014:119-120) (*cf.* 3.2) that Thinking Maps support active learning and assists in organising information systematically, which contributes to enhanced performance in the application of thinking skills.

The sample mean for **post-test 1 ($\bar{x}$ = 6.724)** and **post-test 1B ($\bar{x}$ = 8.897)** highlighted an average increase of 14% in results. The researcher observed a mean difference of -2.172 and a statistically significant difference of $p < 0.05 = 0.000$ with a large effect in practice, d = 0.930. Post-test 1B was a retention test (a repetition of pre-test 1) and the researcher concluded that the six weeks of Thinking Maps intervention contributed to improvement noted in the application of the critical thinking skills that focused on Grade 12 subject content. Post-test 1 was also written after the Thinking Maps intervention, but the participants did not appear to be effective at the application of critical thinking skills in the context of this test. This finding revealed to the researcher that the critical thinking skills that were acquired through the Thinking Maps intervention were apparently not effectively transferred to the Life Science content that focused on problem-based learning and working according to the scientific method (post-test 1). The argument of Snyder and Snyder (2008:92) (*cf.* 2.7.2.4) might also hold true, namely that students need time to learn the process of thinking, to become effective at the application of critical thinking, and that the six weeks of the Thinking Maps intervention might have been too short to effectively acquire and retain critical thinking skills.

The sample mean for **pre-test 2 ($\bar{x}$ = 9.276)** and for **post-test 2 ($\bar{x}$ = 6.345)** reflected a decrease in average of 20% in post-test 2. A mean difference of 2.931 with a statistical significant difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 1.066$, was noted. Given the increase in the pre-test 2 result, it could be argued that the Thinking Maps intervention that preceded pre-test 2, benefitted the applicaton of critical thinking in the context of pre-test 2. Post-test 2 was written six weeks after pre-test 2 after six weeks of normal lecturing. The researcher concluded that the lack of emphasis during lectures on practising critical thinking using Thinking Maps possibly resulted in the decline of 19% in average. This finding supports the view of Paul and Elder (2006:10) (*cf*. 2.3.3) who confirm that the enhancement of critical thinking must be infused in the development of students' critical thinking through consistent use by the teacher. This statistical analysis strengthened the case that critical thinking skills involving analysis, synthesis and evaluation were apparently not learned by the direct teaching method that focused on lecturing, and memorising facts and new information. It could therefore be argued that new insights must be constructed by students' own attempts to bring meaning to and make sense of new information and knowledge (Burden & Byrd, 2010:139; Rüütmann & Kipper, 2011:110) (*cf*. 2.7.2.2).

Another explanation for the finding could be that the subject content on which pre-test 2 focused, namely problem-based learning and working according to the scientific method (content dealt with during weeks 1 – 6 of the research), was possibly better understood by the participants, in comparison to the subject content of post-test 2 that only focused on subject content linked to problem-based learning dealt with in weeks 1 – 7 of the intervention.

A comparison between the means for **post-test 2B ($\bar{x}$ = 9.172)** and **pre-test 2 ($\bar{x}$ = 9.276)** revealed a statistically non-significant difference, $p = 0.837$ as the participants obtained more or less the same average percentage for both tests. Both tests were similar as they focused on problem-based content and working according to the scientific method. No purposeful attention was paid to the use of Thinking Maps prior to the tests. The participants however did surprisingly well as the averages for both tests were almost the same. A small decline was however noticed in the post-test 2 B result, that could possibly be attributed to the absence of explicitly focusing on the use of Thinking Maps for making meaning of subject content. The researcher argues that it could be reasonable to assume that the critical thinking skills that were acquired during the first six weeks of the Thinking Maps intervention, to which the good result of post-test 1B and pre-test 2 testify, were possibly retained in the absence of purposeful focus on working with Thinking Maps, and transferred effectively to the content of post-test 2B.

Although lecturing was used for six weeks after pre-test 2, the findings could also support the view of Spence (2001:2) (*cf*. 2.7.2.3.1) who found that merely working in problem-based learning environments could contribute to enhancing students' critical thinking skills and knowledge acquisition.

The sample mean for **post-test 2B ($\bar{x}$ = 9.172)** and **post-test 2 ($\bar{x}$ = 6.345)** highlighted an average increase of 19% in results. The researcher observed a mean difference of 2.827 and a statistically significant difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 1.452$. Although post-test 2B and post-test 2 were written at the same time, the researcher finds it interesting that the participants seemingly were more effective at applying critical thinking skills to content that focused on problem-based learning and working according to the scientific method in post-test 2B, than they were at applying critical thinking skills to the problem-based content in post-test 2. It appears that the critical skills which they acquired through the six weeks Thinking Maps intervention were retained, which enabled them to be more effective at applying critical thinking to the information in post-test 2B, than what they were at applying critical thinking to the information in post-test 2 (Illeris, 2015:30; Pithers & Soden 2000:241) (*cf*. 2.6.2, 2.6.3). This finding could imply that the participants probably understood the content on which post-test 2B focused better than the problem-based content of post-test 2, which enabled them to be more effective at applying critical thinking skills to information in post-test 2B (Illeris, 2015:30; Pithers & Soden 2000:241) (*cf*. 2.6.2, 2.6.3). This argument of the researcher is confirmed by the good result received for pre-test 2, which focused on the same content as post-test 2B.

Improvement is noted for Experimental group 1 between the initial pre-test 1 **($\bar{x}$ = 6.828)** and the final post-test 2B result **($\bar{x}$ = 9.172)**, and the researcher cautiously assumes that the Thinking Maps intervention contributed to the improvement noted. The result however indicates that the students are still not master thinkers, but rather still challenged thinkers faced with significant problems in their thinking who try to improve to become beginning thinkers (Paul & Elder, 2006:19) (*cf.* 2.3.3).

The standard deviations for all the test occasions varied between s = 2.750 and s = 1.868 respectively, revealed that there was not a lot of variation between results of the various test occasions, and the results were not widely dispersed around the mean.

In summary, the findings in relation to **Experimental group** 1 strengthened the case that a Thinking Maps intervention can enhance the development of critical thinking skills (*cf.* pre-test 1, pre-test 2 results), which is confirmed by Stedman and Adams (2012:9) (*cf*. 2.3.4), who state that the purposive practise of higher order thinking skills contributes to students becoming capable of improving their critical thinking skills. The findings also supports the argument of Hyerle (2014:163) (*cf*. 3.5.3) that Thinking Maps hold potential for the development of critical thinking skills and confirm the argument of Hyerle and Yeager (2007:10) (*cf*. 3.5.5) that Thinking Maps drive the learning process and make information and learning more meaningful. It also became clear that the skills attained during the use of Thinking Maps were probably not retained and applied in the absence of the purposeful use of Thinking Maps (*cf.* post-test 2B results) (Stedman & Adams, 2012:9) (*cf.* 2.3.4). The argument of Pritchard (2014:119-120) (*cf*. 3.2), that Thinking Maps support active learning and assists in organising information systematically, which contributes to enhanced performance in the application of thinking skills, also seems to be supported by the test results obtained by Experimental group 1.

It was however clear to the researcher that the difficulty levels of post-test 1 and post-test 2 could have hampered the effective application of critical thinking skills. In addition, some of the problem-based content, used in post-tests 1 and 2, and the content related to working according to the scientific method in post-test 1, appeared to be problematic and not understood by the participants, possibly contributing to the poor results noted in the mentioned tests. This finding confirms the argument of Illeris (2015:30) (*cf*. 2.6.2) that a lack of understanding may lead to an inability to apply critical thinking skills. The participants however appeared to be more effective at applying critical thinking to the problem-based content and the scientific method of pre-test 2 and post-test 2 B (similar to pre-test 2), as well as the Grade 12 content that was the focus of pre-test 1 and post-test 1B (similar to pre-test 1).

The researcher cautiously also argues that the findings that emanated from Experiment 1 support the literature where it is argued that direct, passive teaching does not explicitly promote the development of critical thinking (*cf.* post-test 2 result) (Burden & Byrd, 2010:120; Kruger, 2002:109) (*cf.* 2.7.1.1, 2.7.2.1), and that skilful thinking must be cultivated with purposive practise (Costa, 2009:16) (*cf.* 3.5). During normal lecturing, there was no explicit emphasis on the enhancement of critical thinking skills. It can however not be excluded that normal lecturing could have contributed to the improvement noted in the post-test 2B result.

The following sections discusses the data analysis and interpretation of the research findings in relation to Experimental group 2.

6.4.3 Data analysis and interpretation: Experimental group 2

In the following section the researcher reports on the data obtained from the participants who took part in Experiment 2 regarding the various critical thinking skills that were addressed in the various tests, as indicated in Table 6.8.

Figure 6.6 indicates the test score percentages for the various test occasions for Experimental group 2.

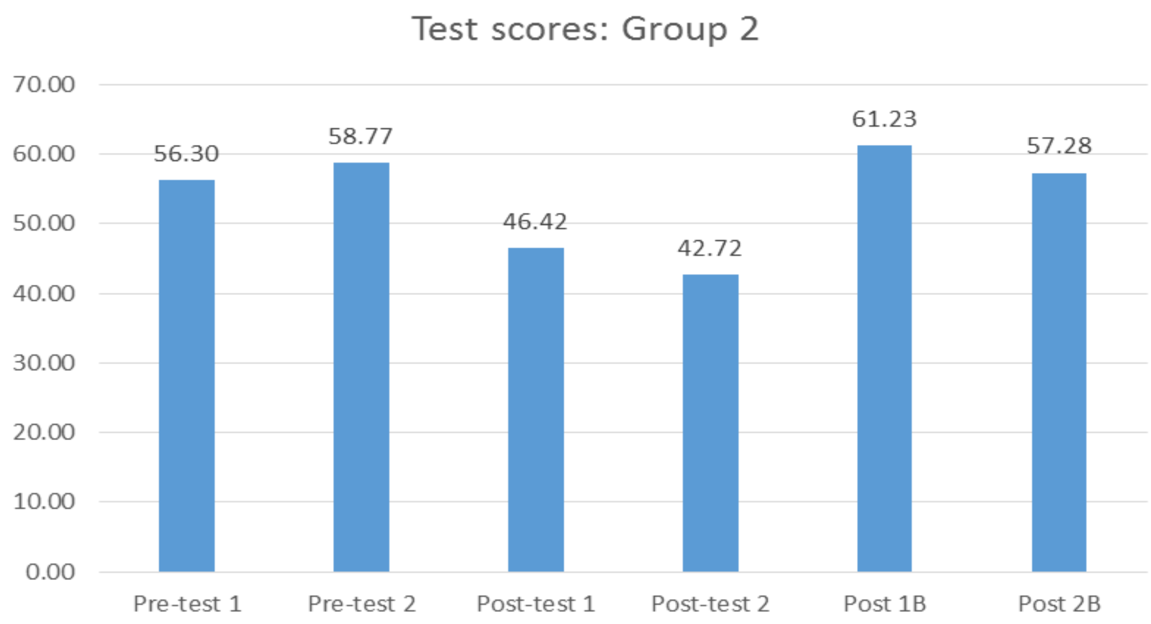


Figure 6.6: Comparison of test results: Experimental group 2

Table 6.8: Test data: Participants Experimental group 2

	Test application	n	$\bar{x}$ (15)	%	Mean difference	s	t	df	*p*	Cohen's *d*	Effect size
1	Pre-test 1	27	8.444	56.296	1.481	1.908	3.382	26	0.002*	0.665	Medium
	Post-test 1	27	6.963	46.419		2.227					
2	Pre-test 1	27	8.444	56.296	-0.741	1.908	-1.398	26	0.174	-	-
	Post-test 1B	27	9.185	61.234		2.386					
3	Post-test 1	27	6.963	46.419	-2.222	2.227	-5.273	26	0.000*	0.931	Large
	Post-test 1B	27	9.185	61.234		2.386					
4	Pre-test 2	27	8.815	58.765	2.408	1.961	5.003	26	0.000*	1.007	Large
	Post-test 2	27	6.407	42.716		2.390					
5	Post-test 2B	27	8.593	57.283	-0.222	2.043	0.700	26	0.490	-	-
	Pre-test 2	27	8.815	58.765		1.961					
6	Post-test 2B	27	8.593	57.283	2.186	2.043	-4.440	26	0.000*	0.915	Large
	Post-test 2	27	6.407	42.716		2.390					

A comparison between the means of **pre-test 1 ($\bar{x}$ = 8.444)** and **post-test 1($\bar{x}$ = 6.963)** results revealed a statistically significance difference of $p < 0.05 = 0.002$ with a medium effect in practice, $d = 0.665$. The researcher is of the opinion that normal lecturing seemingly did not contribute to enhancing the application of critical thinking skills and the participants were not effective at applying critical thinking in the context of post-test 1 that focused on the Life Science subject content dealt with during weeks 1 – 6 of sememster 1 (problem-based content and working according to the scientific method). This finding confirms the literature that direct teaching is not effective for developing critical thinking (Burden & Byrd, 2010:39; Rüütman & Kipper, 2011:110) (*cf.* 2.7.2.2.).The researcher concluded that the content of post-test 1 that focused on content dealt with during weeks 1 – 6 might have been misunderstood or understood in a distorted way and the students were therefore not effective at applying critical thinking. This conclusion supports the viewpoint of Illeris (2015:30) (*cf*. 2.6.2) who states that misunderstanding of information may lead to a lack in the ability to apply critical thinking skills.

A comparison between the means of **pre-test 1 ($\bar{x}$ = 8.444)** and **post-test 1B ($\bar{x}$ = 9.185)**, a repetition of pre-test 1, did not reveal a statistical significant difference between the two results, $p = 0.174$. Bearing in mind that post-test 1B was a repetition of pre-test 1, it appeared that the lecturing of subject matter and concepts during weeks 1 – 6 to Experimental group 2, assisted the participants to achieve a slightly better result with the application of the critical thinking skills the second time. This finding possibly supports the views of McCollister and Sayler (2010:42), Pithers and Soden (2000:243) and Qing *et al.* (2010:4598) (*cf*. 2.3.4), who indicate that it is possible to develop critical thinking skills in the course of teaching/lecturing subject-matter content and concepts.

For the comparison between the means of **post-test 1 ($\bar{x}$ = 6.963)** and **post-test 1B ($\bar{x}$ = 9.185)**, a repetition of pre-test 1, the researcher noted a statistical significant difference between post-test 1 and post-test 1B, $p < 0.05 = 0.000$, with a large effect in practice, $d = 0.931$. This implied that the post-test 1B result was statistically significantly better than the post-test 1 result. Post-test 1B was a repetition of pre-test 1 (Grade 12 Life Science content), and the researcher convincingly concluded that the six weeks of normal lecturing contributed to the improvement of students' ability to apply critical thinking skills in post-test 1 B. However, it is surprising that the participants were not effective at applying critical thinking in the context of post-test 1, that was written simultaneously with post-test 1B. As previously noted, the researcher carefully assumes that the nature of the content in post-test 1 was probably too difficult for the participants to grasp, which hampered the effective application of the critical thinking skills, and therefore contributed to the lower result in post-test 1.

A comparison of the sample means for **pre-test 2 ($\bar{x}$ = 8.815)** and for **post-test 2 ($\bar{x}$ = 6.407)** revealed an average decrease of 16% in the post-test 2 result with a statistically significant difference of $p < 0.05 = 0.000$, and a large effect in practice, d = 1.007. Post-test 2 was written after the six week Thinking Maps intervention during weeks 7 – 12 of the first semester, and focused mainly on problem-based content that was dealt with during weeks 7–12 of the intervention. Similar to the result noted for post-test 1, and compared to the low results obtained by Experimental group 1 for post-test 1 and post-test 2, it appeared that the understanding of subject content also might have influenced the poor results of Experimental group 2 for the mentioned tests. In addition, the poor result obtained for post-test 2 could also point to the ineffectiveness of the Thinking Maps intervention to enhance the application of critical thinking skills required for mastering certain problem-based content.

It is interesting to note that the result of pre-test 2, that was also written after the lecturing of subject content, were lower than the result of post-test 1B that was also written after normal lecturing. In this regard, the researcher also argues that the subject content (problem-based content and content related to the scientific method) that was the focus of pre-test 2, was apparently not well understood, and normal lecturing also did not seem to assist the students in applying critical thinking skills effectively to the unknown subject content. Similar to Experiemental group 1, the findings could be linked to the view of Snyder and Snyder (2008:92) (*cf*. 2.7.2.4) who state that students need time to learn the process of thinking critically, which was not the case during normal lecturing. In support of Snyder and Snyer (2008:92), Costa (2009:16) (*cf*. 3.5), concludes that skilful thinking must be cultivated with purposive practise, which was not the case as the participants merely received normal lectures without explicit emphasis on the enhancement of critical thinking skills. In line with the findings of Snyder and Snyder (2008:93) (*cf*. 2.7.2.5), it could be argued that the development of critical thinking requires more involvement from a student's personal discovery of information and knowledge.

A comparison between the means for **post-test 2B ($\bar{x}$ = 8.593)** and **pre-test 2 ($\bar{x}$ = 8.815)** revealed a statistically non-significant difference, p = 0.490 as the participants obtained more or less the same average percentage for both tests. A mean difference of -0.222 between post-test 2B ($\bar{x}$ = 8.593) and pre-test 2 ($\bar{x}$ = 8.815) was noted, with a small decline in the post-test 2B result. Both tests focused on problem-based content and working according to the scientific method, and in the presence of the Thinking Maps intervention prior to post-test 2B (a repetition of pre-test 2), the participants however obtained good results, as the averages were very similar for both tests. The researcher assumed that the six weeks of lecturing subject content prior to the Thinking Maps intervention could have contributed to maintaining good result in post-test 2B, although the result was slighty lower than the pre-test 2 result. This finiding possibly supports the view of Spence (2001:2) (*cf*. 2.7.2.3) who found that working in problem-based learning environments could enhance students' critical thinking skills and knowledge acquisition. In addition, the Thinking Maps intervention could also have assisted the students to apply critical thinking more effectively in post-test 2B, supporting the view of Stedman and Adams (2012:9) (*cf*. 2.4.5), who indicated that with purposive practising of higher order thinking skills, students are enabled to improve their critical thinking skills.

The sample mean for **post-test 2B ($\bar{x}$ = 8.593)** and **post-test 2 ($\bar{x}$ = 6.407)** highlighted an average increase of 15% in results. The researcher observed a mean difference of 2.186 and a statistically significant difference of p < 0.05 = 0.000 with a large effect in practice, d = 0.915. Although post-test 2B and post-test 2 were written at the same time, the researcher observed that the participants were more effective at applying critical thinking skills to problem-based content and content related to working according to the scientific method in post-test 2B, than they were at applying skills to the problem-based content in post-test 2. It appears that the critical thinking skills which the students acquired during the six weeks Thinking Maps intervention, and the skills possibly acquired during the six weeks of normal lecturing (the good pre-test 2 result testifies to this finding), were retained and more effectively applied to the information in post-test 2B, than in post-test 2 (Illeris, 2015:30; Pithers & Soden 2000:241) (*cf*. 2.6.2, 2.6.3). In addition, it might have been that the problem-based content on which post-test 2 focused was not familiar to or well understood by the participants, and they probably experienced difficulties in applying critical thinking to the information, or there was a difference in the difficulty levels of the post-test 2 and post-test 2B.

The standard deviations for all the test occasions varied between s = 2.390 and s = 1.908 respectively, revealed that there was not a lot of variation in the results of the various test occasions, and that results were clustered around the means.

In summary, similar to Experimental group 1, the findings obtained for **Experimental group 2** also strengthened the case that a Thinking Maps intervention can enhance the development of critical thinking skills (*cf*. post-test 2B result), as confirmed by the statements of Stedman and Adams (2012:9) (*cf*. 2.3.4), and that with purposive practise of higher order thinking skills, students apparently become capable of improving their critical thinking skills. The findings also confirm the argument of Hyerle and Yeager (2007:10) (*cf*. 3.5.5) that Thinking Maps drive the learning process and make information and learning more meaningful. It also became clear that the slight improvement in the application of critical thinking attained during the use of normal lecturing, as evidenced in the post-test 1B and pre-test 2 results, was probably retained and reinforced by the Thinking Maps intervention, as the post-test 2B result was only slightly lower than the post-test 1B and pre-test 2 results. This finding seems to contradict the findings of

Burden and Byrd (2010:120) and Kruger (2002:109) (*cf.* 2.7.2.1), that passive teaching does not promote the development of critical thinking.

Similar to Experiment 1, the findings also revealed that some of the problem-based learning content and content that focused on working according to the scientific method seemed to have influenced the effectiveness with which the participants applied the critical thinking skills (*cf.* post-test 1 and post-test 2 results).

As was noted with Experimental group 1, Experimental group 2 was also more effective at applying critical thinking to the Grade 12 Life Science content in pre-test 1 and post-test 1B, not forgetting that the content might have been known to the students and therefore they found it easier to apply critical thinking to the Grade 12 Life Science content.

In the following section, the researcher reports on the data obtained for the comparison between the Experimental group 1 and 2 for the various test occasions.

6.5 DATA ANALYSIS AND INTERPRETATION: COMPARISON BETWEEN PARTICIPANTS – EXPERIMENTAL GROUP 1 AND 2

Figure 6.7 and Table 6.9 below compares the data obtained for the various test results obtained by Experimental group 1 and 2. The two Thinking Maps interventions were not completely identical in terms of the topics on which the interventions focused, and therefore makes a comparison difficult. However, the nature of the content (problem-based, scientific method) and the underlying critical thinking skills that were addressed, were similar (*cf*. 5.3.2), The researcher also noted similar trends between Experimental group 1 and 2 in the results obtained for some of the tests, and therefore cautiously reports on the data related to a comparison between Experimental group 1 and 2.

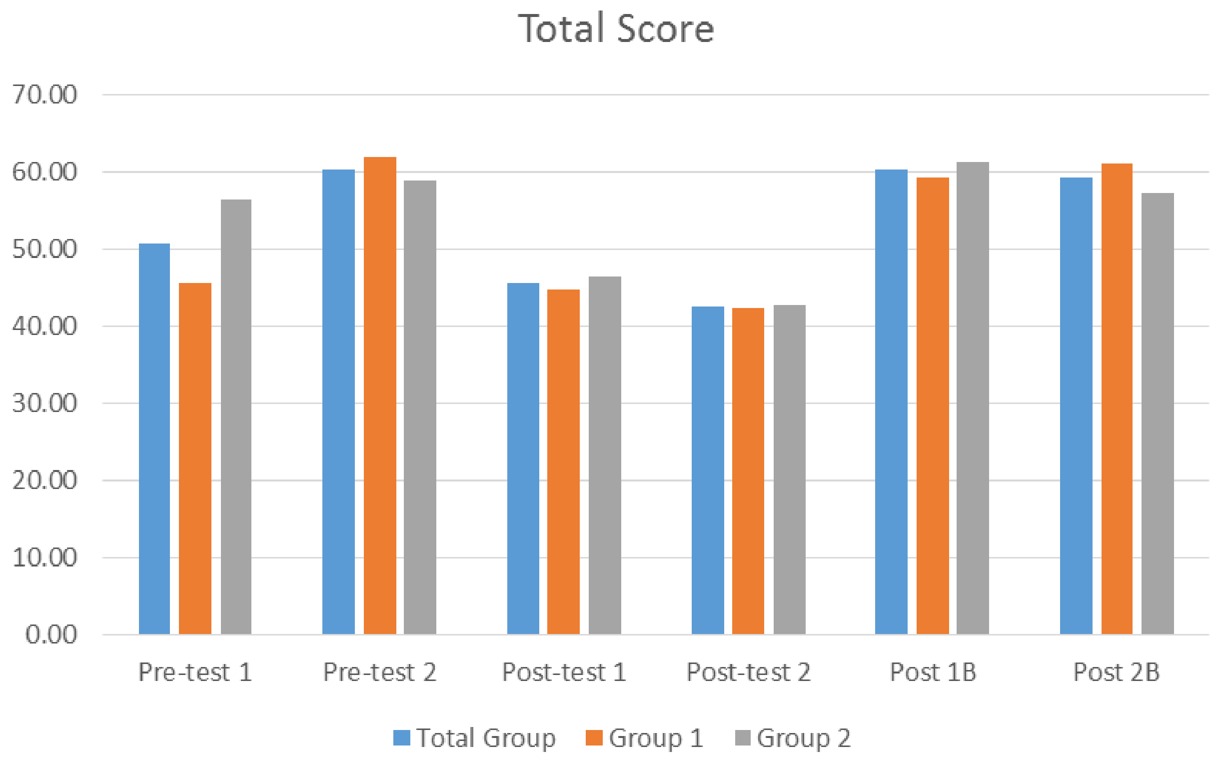


Figure 6.7: Comparison of test results: Experimental group 1 and 2

Table 6.9: Test data: Comparison Experimental group 1 (E1) and Experimental group 2 (E2)

	Test	Groups	n	$\bar{x}$ (15)	%	Mean difference	s	f	t	df	*p*	Cohen's *d*	Effect size
1	Pre-test 1	E1	29	6.828	45.517	-1.616	2.331	1.054	-2.828	54	0.007*	0.693	Medium
		E2	27	8.444	56.296		1.908						
2	Pre-test 2	E1	29	9.276	61.839	0.461	2.750	2.928	0.717	54	0.476	-	-
		E2	27	8.815	58.765		1.969						
3	Post-test 1	E1	29	6.724	44.827	-0.239	1.868	0.890	-0.436	54	0.665	-	-
		E2	27	6.963	46.419		2.227						
4	Post-test 2	E1	29	6.345	42.298	-0.062	2.192	0.735	-0.102	54	0.919	-	-
		E2	27	6.407	42.716		2.390						
5	Post-test 1B	E1	29	8.897	59.310	-0.288	2.335	0.020	-0.457	54	0.649	-	-
		E2	27	9.185	61.234		2.386						
6	Post-test 2B	E1	29	9.172	61.149	0.579	1.947	0.051	1.087	54	0.282	-	-
		E2	27	8.593	57.283		2.043						

* Statistical significance: $p < 0.05$

The sample mean for **pre-test 1,** Experimental group 1 **($\bar{x}$ = 6.828)** and Experimental group 2 **($\bar{x}$ = 8.444)** clearly indicated that the participants in Experimental group 2 obtained a 11% higher average percentage in results. Furthermore, the researcher observed a mean difference of -1.616 between the pre-test 1 results of Experimental group 1 and Experimental group 2 with a statistically significant difference of $p < 0.05 = 0.007$, and a medium effect, $d = 0.693$, in practice. Based on the data, it appeared that Experimental group 2 was more capable of applying critical thinking skills than Experimental group 1 at the onset of the research. It appears as if the participants in Experimental group 2 probably acquired some critical thinking skills at school-level, and were able to retain these skills in the context of the Grade 12 content that was the focus in pre-test 1. The critical thinking skills appeared to be on a low (Experimental group 1) to average (Experimental group 2) level of development.

A comparison between the **pre-test 2** results however indicated that Experimental group 1 **($\bar{x}$ = 9.276)** performed better than Experimental group 2 **($\bar{x}$ = 8.815).** However, mean difference of -0.461 did not reveal a statistically significant difference, $p > 0.05 = 0.476$. The improvement in the result of Experimental group 1 (although not yet statistically significant) could be attributed to the exposure they received during the Thinking Maps intervention programme, but could also have been due to chance. Experimental group 2 received normal lecturing during the first six weeks and seemingly did not benefit greatly from the development of critical thinking skills, as there was only a slight improvement in their pre-test 2 result, compared to the pre-test 1 result. A reason for the slight decline in the pre-test 2 result might be linked to the fact that the researcher placed emphasis on content related to problem-based learning and working according to the scientific method, which was dealt with during weeks 1 – 6 of the first semester, which seemingly did not benefit the students to improve the application of critical thinking.

Post-test 1 revealed a statistically non-significant difference between Experimental group **1 ($\bar{x}$ = 6.724**) and Experimental group 2 **($\bar{x}$ = 6.963),** $p > 0.05 = 0.665$. Both groups obtained lower results than in pre-test 1, which indicated that neither the Thinking Maps intervention nor normal lecturing contributed to enhancing the application of critical thinking in post-test 1. As the content of post-test 1 focused on problem-based learning and working according to the scientific method, it could also be argued that the participants might have found the content more difficult than the Grade 12 content on which pre-test 1 focused. The pre-test 1 and post-test 1 results of Experimental group 1 remained more or less similar, although the post-test 1 result was slightly lower than the pre-test 1 result. However, the post-test 1 result for Experimental group 2 was much lower than their initial pre-test 1 result, which possibly point to the fact that normal lecturing did not contribute much to enhance the development and application of critical thinking.

The **post-test 2** results of both Experimental group 1 **($\bar{x}$ = 6.345)** and Experimental group 2 **($\bar{x}$ = 6.407),** were lower than the pre-test 1 and post-test 1 results, indicating that the students could not apply critical thinking skills effectively. The difference between the two results indicated a statistically non-significant difference of $p > 0.05 = 0.919$. The result of Experimental group 1, who received normal lecturing before writing post-test 2, was slightly lower than their pre-test 1 and post-test 1 results, and the improvement noted in their pre-test 2 result was not maintained. Experimental group 2, who received the Thinking Maps training before writing post-test 2, also scored lower in post-test 2 than in pre-test 1 and post-test 1. The researcher argues that the difficulty level of post-test 2, and the nature of the content that only focused on problem-based learning, might have influenced the effectiveness with which the students applied critical thinking in post-test 2

In **post-test 1B**, both experimental groups achieved better results than in pre-test 1 and post-test 1. Post-test 1 B was a repetition of pre-test 1, that focused on Grade 12 Life Science content. A comparison between the two groups however revealed a statistical non-significant difference, $p > 0.05 = 0.649$ between the two groups. In comparison to all their other test results, Experimental group 1 **($\bar{x}$ = 8.897)** achieved the second highest result in post-test 1B. This finding could imply that the skills acquired during the Thinking Maps intervention, which possibly also contributed to the increase noted in their pre-test 2 result, were also applied in the context of post-test 1B, as the post-test 1B result **($\bar{x}$ = 9.172)** indicated an improvement in comparison to the pre-test 1 result **($\bar{x}$ = 6.828)**. However, the lower post-test 2 result of Experimental group 1, after a six week absence of purposeful focus on Thinking Maps, **($\bar{x}$ = 6.345)**, possibly indicated that the critical thinking skills acquired during weeks 1 – 6 of the semester were not retained. It could also imply that the content of pre-test 1 and post-test 1B which was similar, allowed for more effective application of critical thinking skills than the content related to problem-based learning and working according to the scientific method of pre-test 2 and post-test 1, as well as the exclusive focus on problem-based content in post-test 2. In addition, the participants could have remembered the test content of pre-test 1, given the short six week Thinking Maps intervention, and that this could have contributed to the improved post-test 1B result.

Of all their test results, Experimental group 2 achieved the best results in post-test 1 B after normal lecturing, which apparently also contributed to the slight increase also noted in pre-test 2. In addition, it appeared that Experimental group 2 did not benefit as much as Experimental group 1 from the Thinking Maps intervention, as their post-test 2 result after the Thinking Maps intervention **($\bar{x}$ = 6.407)** was lower than their pre-test 1 result at the onset of the study **($\bar{x}$ = 8.444)**.

Post-test 2B revealed a statistically non-significant difference between Experimental group 1 **($\bar{x}$ = 9.172)** and Experimental group 2 **($\bar{x}$ = 8.593)**, $p > 0.05 = 0.282$. Experimental group 1 achieved better results in post-test 2B, in comparison to pre-test 1, post-test 1 and post-test 2 This finding points to the possible positive effect that the first six weeks of Thinking Maps intervention had on the participants' ability to apply critical thinking skills to new information and knowledge and retain the skills in the absence of the intervention. Although post-test 2B was written after six weeks of normal lecturing, the participants appeared to be more able to apply the critical thinking skills in the context of problem-based learning and working according to the scientific method that was the focus of post-test 2B, than what they were when writing pre-test 2 that focused on the same subject content.

Experimental group 2 obtained lower results in post-test 2 **($\bar{x}$ = 6.407)** and post-test 2B **($\bar{x}$ = 8.593)** than in post-test 1B **($\bar{x}$ = 9.185)**, which indicated that the Thinking Maps intervention appeared to have had very little influence on enhancing the application of their critical thinking skills.

As the final post-test 2B result for Experimental group 1, **($\bar{x}$ = 9.172),** was higher than the pre-test 1 result, **($\bar{x}$ = 6.828)**, the researcher concludes that the Thinking Maps intervention possibly contributed to the improved results noted for Experimental group 1, with a slight chance that normal lecturing that preceded post-test 2B, might have contributed to the improvement noted in post-test 2B.

For Experimental group 2, it appeared as if the combination of normal lecturing and the Thinking Maps intervention collaboratively contributed to the slight enhancement of the participants' critical thinking skills that were noted in the post-test 2B result, **($\bar{x}$ = 8.593)**, in comparison to the pre-test 1 result **($\bar{x}$ = 8.444)**.

In all instances the standard deviations noted were low, and varied between s = 2.390 and s = 1.908, which did not indicate a wide dispersion of scores around the mean.

The results obtained for the various tests indicated that Experimental group 1 apparently benefitted more from the intervention than Experimental group 2 when comparing the initial pre-test 1 results **($\bar{x}$ = 6.828, $\bar{x}$ = 8.444)**, and the final post-test 2B results **($\bar{x}$ = 9.172, $\bar{x}$ = 8.593)**.

The Thinking Maps intervention as well as normal lecturing seemed to be effective for both experimental groups respectively in the context of Grade 12 Life Science content due to the improvements noted in the post-test 1B results (a repetition of pre-test 1). However, the Thinking Maps intervention did not appear to hold any benefits for any of the experimental groups where critical thinking had to be applied to the problem-based content and content related to the scientific method of post-test 1 (Experimental group 1) and the problem-based content of post-test 2 (Experimental group 2). It also seems reasonable to conclude that Experimental group 1 possibly retained the critical thinking skills acquired during weeks 1 – 6 of the Thinking Maps intervention, which enabled them to be effective at the application of critical thinking in post-test 2B.

In light of the findings noted for both **Experimental group 1 and 2**, the researcher argues that the participants could have had other learning style preferences, preconceptions about the subject, or learning resistance towards the subject, which, according to Illeris (2015:30) and Snyder and Snyder (2008:93) also inhibit critical thinking ability (*cf.* 2.6.3).

Given the background of the participants who do not speak English as their home language, it could also be argued that their lack of academic language proficiency possibly inhibited their application of critical thinking to certain subject content (Lun *et al*., 2010:606) (*cf.* 2.6.5).

Interestingly, the researcher noted that normal lecturing, as well as the use of Thinking Maps, possibly encouraged opportunities for developing critical thinking. However, in the context of using Thinking Maps as a teaching strategy, more opportunities should be created for emotional engagement and reasoning during learning in order to enhance the development of critical thinking skills in the context of problem-based content and content related to working according to the scientific method (Browne & Freeman, 2000:304; Howie & Bagnall, 2015:350; McGonigal, 2005:1; Spence, 2001:3; Rüütman & Kipper, 2011:110; VanGundy, 2005:169-340) (*cf*. 2.7.1.4; 2.7.1.5, 2.7.2.1, 2.7.2.2).

In comparison, the final post-test 2B result **($\bar{x}$ = 8.593)** and the initital pre-test 1 result **($\bar{x}$ = 8.444)** of Experimental group 2 does not reveal a lot of improvement, and the researcher is of the opinion that Experimental group 2 did not seem to benefit much from the Thinking Maps intervention. The group of students still appears to be challenged thinkers who need more exposure to develop critical thinking skills to become master thinkers for which good thinking habits have become second nature (Paul & Elder, 2006:19) (*cf*. 2.3.3).

The Thinking Maps intervention as well as normal lecturing seemed to be effective for both experimental groups respectively in the context of Grade 12 Life Science content due to the improvements noted in the post-test 1B result (a repetition of pre-test 1). However, the Thinking Maps interevention did not appear to hold any benefits for any of the experimental groups where critical thinking had to be applied to the problem-based content and content related to the scientific method of post-test 1 (Experimental group 1) and the problem-based content of post-test 2 (Experimental group 2).

The findings noted for both **Experimental group 1** and **2** supported the argument of Hyerle and Yeager (2007:8-16) (*cf*. 3.5.5) who state that Thinking Maps drive students' learning processes and progress, improving the developing of critical thinking skills. However, the findings also indicate that in the absence of the purposeful practising of critical thinking skills, the improvement noticed may not last (Ijaija *et al.,* 2010:358; Saavedra & Opfer, 2012:7; Stedman & Adams (2012:9) (*cf*. 2.3.4, 2.6.2). In contrast to what literature reveals, the researcher cannot conclude conclusively that traditional lecturing did not have a limited influence on the development of critical thinking (Saavedra & Opfer, 2012:7; Tsui, 2002:742) (*cf.* 2.6.2). In this regard, Spence (2001:2) (*cf.* 2.7.2.3) argues that merely working in a problem-based learning environment, as was the case in the context of the research, can promote the development of critical thinking. In addition, McCollister and Sayler (2010:42), Pithers and Soden (2000:243) and Qing *et al.* (2010:4598) (*cf*. 3.3.4) argue that lecturing subject content can develop critical thinking skills.

The problem-based content and working according to the scientific method on which many of the tests focused was probably difficult for the students to comprehend and could have affected the acquisition and application of critical thinking skills (Illeris, 2015:30; Pithers & Soden, 2000:246; Sternberg, 1987:458) (*cf.* 2.6.2, 2.6.3). The final post-test 2B results of both experimental groups indicate that both groups still appear to be in need of more purposeful efforts to enhance the development of their thinking skills.

The findings could also point to the absence of important critical thinking dispositions, such as self-confidence in reasoning, thinking reflectively and open-mindedly, working accurately and systematically and resisting impulsiveness, that could have influenced the effectiveness with which critical thinking skills were applied (Illeris, 2015:30; Pithers & Soden, 2000:242; Snyder & Snyder, 2008:93; Sternberg, 1987:458) (*cf.* 2.6.2, 2.6.3)

More guidance from an teacher might also be required to effectively apply critical thinking when constructing Thinking Maps in the context of problem-based content and working according to the scientific method (VanGundy, 2015:169) (*cf*. 2.7.2.2). Greater involvement of the students through the presence of the purposeful use of open-procedural questioning during the independent structuring of Thinking Maps, possibly would have contributed to the critical thinking skills being enhanced more effectively (Green & Murris, 2014:127; McCollister & Sayler, 2010:43; Pithers & Soden, 2000:242; Tsui, 2002:742) (*cf*. 2.7.2.3, 2.6.2, 2.6.3).

The following section reports on initial data obtained with the Thinking Maps that participants constructed during the Thinking Maps intervention.

6.6 DATA ANALYSIS AND INTERPRETATION: THINKING MAPS WORKSHEETS -EXPERIMENT 1 AND 2

Although the Thinking Maps constructed by the students were not regarded as primary sources of data collection during the research, the researcher includes a short discussion about the progress of the students noted in working with the Thinking Maps.

The researcher used Thinking Maps as an intervention strategy to enhance the development of critical thinking skills. During the intervention, the students worked independently, and decided which of the three Thinking Maps (Circle Map,Tree Map, Multi-Flow Map) would be the most appropriate to use to synthesise and make meaning of the subject content that was presented during lessons. Examples of the students' Thinking Maps are included in Appendix D.

At the onset of the study, the researcher familiarised the participants with the Thinking Maps, the thinking processes that they represent, and how to structure the layout of the Thinking Maps. Each follow-up lecture revised and reinforced this information. Lectures during the Thinking Maps intervention more or less followed the structure presented below in Figure 6.8, that focus on the input, elaboration and output phases of the learning process. In the absence of the Thinking Maps intervention only lectures with explanations of information and concepts characterised the teaching and learning, without explicit focus on the development of thinking skills. A DVD with all the lesson presentations is included at the back of the dissertation.

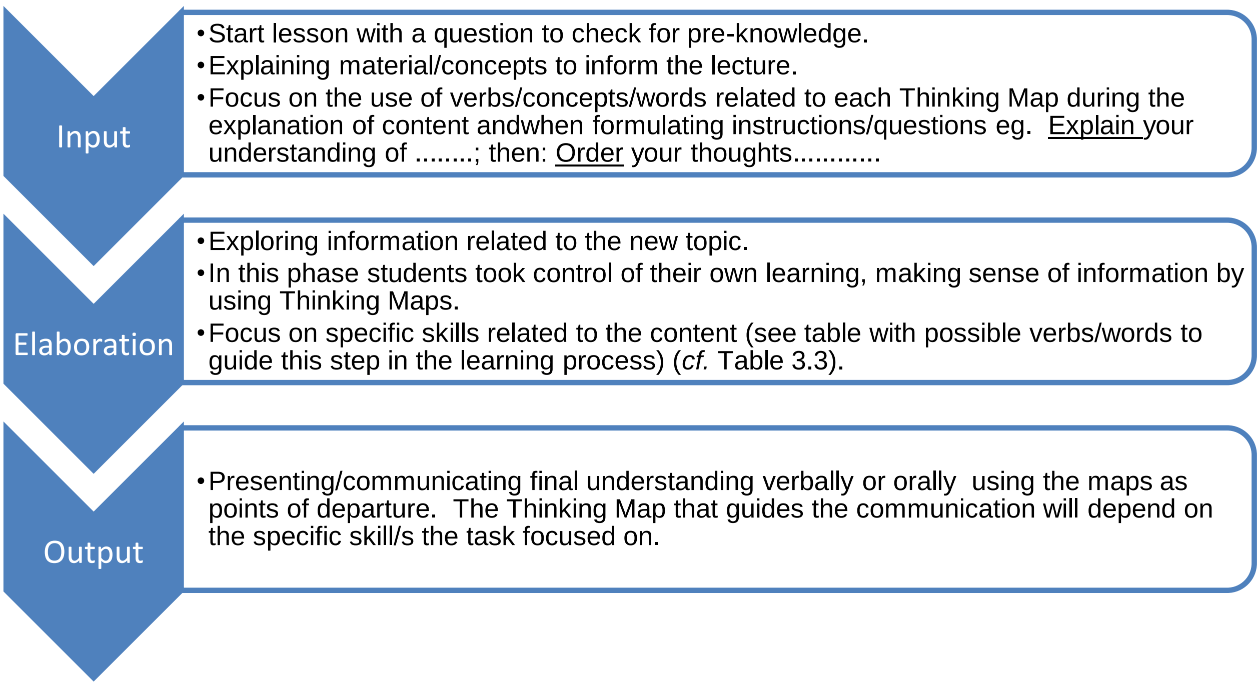


Figure 6.8: Lesson structure during the Thinking Maps intervention

As indicated in Figure 6.8, the input phase of the teaching learning process was also characterised by normal lectures during the Thinking Maps intervention but with greater focus on the thinking processes that underpin the mastering of the content. However, during the elaboration and output phases of the learning process, students were independently involved in making meaning of the lectures through the use of the Thinking Maps that captured their individual meaning-making processes and understanding of the content.

The specific criteria used to assess the Thinking Maps were: sufficiency/fluency of ideas, thought process (verb or keyword linked to Thinking Map), collaborative development, flexibility, originality, elaboration and layout of the Thinking Map (*cf*. Table 3.2) (*cf*. 3.5.6). A second table provides an example of the criteria used to holistically assess the Thinking Maps in terms of relevancy and elaboration (detail). Marks were linked to the specific criteria: not achieved (1), elementary achievement (2), moderate achievement (3), adequate achievement (4), substantial achievement (5), meritorious achievement (6) and outstanding achievement (7) (*cf*. Table 3.4) (*cf*. 3.5.6).

The researcher provided the students with the assessment criteria, (*cf*. Table 3.2, Table 3.4) (*cf.* 3.5.6) to guide them in constructing their Thinking Maps. The researcher also used the criteria to monitor and gauge students' progress in linking Life Science content and thinking processes to relevant Thinking Maps.

Table 6.10 reports the data obtained for the comparison between Experimental group 1 and Experimental group 2 regarding the Thinking Maps worksheets that were constructed each week. Two maps (A and B) were constructed on a weekly basis, except for week 1 and 7, which focused on introducing the Thinking Maps to the two experimental groups. Each Thinking Map was scored out of 7.

Table 6.10: Comparison Participants Experiment 1 and 2: Thinking Maps worksheets

Week	**n**	$\bar{x}$ **(7)**	$\bar{x}$ **Average */week***
Experimental group 1			
W1	36	3.194	3.194
W2A	34	3.059	2.824
W2B	34	2.588	
W3A	26	3.115	2.904

Week	n	$\bar{x}$ (7)	$\bar{x}$ Average /week
W3B	26	2.692	
W4A	27	3.556	3.413
W4B	26	3.269	
W5A	16	3.688	3.407
W5B	16	3.125	
W6A	33	3.606	3.591
W6B	33	3.576	
Experimental group 2			
W7A	33	3.333	3.167
W7B	33	3.000	
W8A	29	4.276	4.242
W8B	29	4.207	
W9A	35	4.286	4.315
W9B	35	4.343	
W10A	32	4.719	4.657
W10B	32	4.594	
W11A	30	4.200	3.850
W11B	30	3.500	
W12A	26	4.524	4.435
W12B	26	4.346	

*A and B indicate that two maps were constructed during the particular week.

The sample means of week 1 for both Experimental groups 1 and 2 revealed similar results, ($\bar{x}$ = 3.194) and ($\bar{x}$ = 3.167). The Thinking Maps were constructed in class directly after the presentations on the construction and use of Thinking Maps and the students' first introduction to theory in Life Sciences.

As from weeks 2 to 6, the sample means for **Experimental group 1** clearly indicated that participants obtained better and improved results from week 2 ($\bar{x}$ = 2.824) to week 6 ($\bar{x}$ = 3.591). The researcher assumed that with time the students mastered the ability to make meaning of information, organise the information and acquired a thought process through the use of the Thinking Maps. Costa (2009:16) (*cf.* 3.5) confirms that Thinking Maps is a teaching strategy that teaches students how to think and reason more effectively. The improved performance noted in the construction of the participants' Thinking Maps and the fact that the Thinking Maps probably benefited the application of critical thinking skills were also evident in the participants' improved results for post-test 1B, pre-test 2 and post-test 2B.

A comparison of the sample means for **Experimental group 2** also revealed better and improved results from week 7 ($\bar{x}$ = 3.167) to week 12 ($\bar{x}$ = 4.435), with the best result noted during week 10 ($\bar{x}$ = 4.657). The researcher concluded that the students were able to link the information they acquired to a relevant Thinking Map, which gave them ownership of their thinking processes. This is in line with Hyerle (2014:169) (*cf.* 3.5.5), who states that Thinking Maps give pathways for thinking and students acquire skills and strategies to enhance all elements of critical thinking. The improved results in the construction of the Thinking Maps for Experimental group 2 however did not correspond with the findings noted for post-test 2 after the Thinking Maps intervention, and possibly confirm that the students need more time to learn the process of thinking (Snyder & Snyder, 2008:92) (*cf.* 2.7.2.4). The result noted for post-test 2B ($\bar{x}$ = 8.593) however, indicated an improvement when compared to post-test 2 ($\bar{x}$ = 6.407), which provides an indication that the Thinking Maps intervention possibly contributed to the effective application of critical thinking in the context of post-test 2B.

Bearing in mind that weeks 5 and 11 were also used for semester tests, the researcher concluded that the lower means of Experimental groups 1 (week 5) and 2 (week 11) were due to time constraints regarding the generation of Thinking Maps.

The assessment of the Thinking Maps revealed to the researcher that the students became more skilful at thinking using the Thinking Maps and that the purposive practice of constructing Thinking Maps aided the cultivation of the application of the thinking skills on which the study focused (Costa, 2009:16; Stedman & Adams, 2012:9) (*cf.* 3.5, 2.3.4). The Thinking Maps also enabled the students to organise information more effectively and systematically (Pritchard, 2014:119-120) (*cf.* 3.2). Students' own attempts to construct Thinking Maps enabled them to increasingly make sense of new information (Burden & Byrd, 2010:139; Rüütmann & Kipper, 2011:110) (*cf.* 2.7.2.2). The aforementioned argument of the researcher is based on the fact that the assessment criteria used to assess the Thinking Maps intentionally encouraged and probed the students to construct maps that *inter alia* complied with fluency, elaboration, originality and flexibility that are important features of critical thinking to solve problems effectively (Pikulsky & Chard, 2005:512) for which detailed, flexible, unconventional and original thinking is required (Costa, 2009:21-23; MacFarlane, 2007:18; Niehuis *et al.*, 2001:120) (*cf.* 3.5.5).

The following section explores some of the initial trends noted in the open responses to the test questions. As stated in Chapter 1, the main purpose of including open questions was to obtain initial data that could be used in follow-up studies regarding the development of students' universal intellectual standards of reasoning. The main focus of this study was on the critical thinking skills and not the universal intellectual standards of reasoning.

6.7 DATA ANALYSIS AND INTERPRETATION: OPEN RESPONSES – PRE- AND POST-TESTS

According to Norris and Ennis (1989:157), open-ended testing can provide information on critical thinking dispositions but not on specific aspects of critical thinking. The open responses did not contribute to the final research findings, and the researcher therefore did not aim to undertake a deep analysis of the open responses, but merely wanted to:

- make notes of strengths and weaknesses within individual responses;
- gather initial data on the presence or absence of the universal intellectual standards of reasoning; and
- prevent students from guessing.

The responses to the open-ended questions were analysed to explore the **clarity, accuracy, precision, relevance, significance depth, breadth** and **logic** of the participants' reasoning prior to and after the Thinking Maps intervention. In relation to the universal intellectual standards of reasoning, the researcher checked the motivations that the students provided for their answers to find evidence of the following:

- **Clarity:** Clarifying answers by providing improved elaborations or expressions.
- **Accuracy**: Answers should be really true.
- **Precision**: Answers should provide specific detail.
- **Relevance**: Answers should be connected or applicable to the question.
- **Significance:** Answers should focus on the central idea of the problem.
- **Depth**: Answers should capture the complexities or difficulties of a question.
- **Breadth**: Answers should add another viewpoint or perspective.

- **Logic**: Answers should put ideas together that make sense (Paul & Elder, 2006:12).

The participants were expected to formulate motivations for their answers that complied with all or most of the above-mentioned universal intellectual standards of reasoning for each of the test items in the various tests.

Due to the large volumes of data that were obtained to the open questions (Tables 6.12 - 6.15), the researcher provides the ideal answer and examples of three good motivations and three poor motivations (according to the researchers' judgement) that the participants presented to motivate their answers in relation to some randomly selected questions in the tests that focused on the application of the critical thinking skills analysis, synthesis and evaluation. A breakdown of the questions in the various tests that focused on analysis, synthesis and evaluation respectively, is provided in Table 6.11 below. Examples of the open responses to all the test items are included in Appendix E. The Afrikaans responses were translated into English, as this research is reported in English. It also has to be kept in mind that English is not the home language of many participants who replied in English, and the verbatim examples of responses therefore might contain language and spelling errors.

Table 6.11 below summarises the breakdown of the test questions to address the skills on which the study focused.

Table 6.11: Breakdown of test questions

Test	Analysis questions	Synthesis questions	Evaluation questions
Pre-test , Post-test 1B	3, 5, 8, 9, 12,13	2, 4, 7,10,14	1, 6, 11 15
Post-test 2	7, 8, 14, 15	4, 5, 9, 10, 12, 13	1, 2, 3, 6, 11
Pre-test 2, Post-test 2B	2, 6, 7, 9, 10	1, 4, 5, 11, 12	3, 8, 13, 14, 15
Post-test 2	3, 4, 5, 6, 14	2, 8,12, 13	1, 7, 9,10, 11,15

6.7.1 Open responses Experimental group 1 and 2

6.7.1.1 Pre-test 1 and Post-test 1 B

In this section, the researcher reports on the students' application of the universal intellectual standards of reasoning to motivate their responses to the questions in pre-test 1 and post-test 1 B that focused on the same subject content (Grade 12 Life Sciences). Tables 6.12 – 6.15 summarise some of the verbatim examples of the participants' response as they appeared on the tests.

Table 6.12: Pre-test 1 and Post-test 1B – Examples of motivations

	Question number and ideal answer	Examples of good motivations	Examples of poor motivations
E1 Evaluation	1.Steps are given in diagram.	*"When a person is conducting a scientific investigation, he should undergo the same steps as shown"; "for every experiment carried out, there are certain steps to follow"; "it includes steps to follow".*	*"Not all the investigations include water"; "… because the lettuce plant grow bigger"; "it has all the components of a good experiment".* Many students did not provide any motivation for their answer.
E2 Evaluation		*"When conducting an experiment, there are steps that needs to be followed"; "… the scientific method are used in every scientific investigation"; "… because the steps must be followed".*	*"In scientific investigations, the scientific method is the best"; "… the steps include different stages"; "… it has no aim".*
E1 Synthesis	4.Statement with cause and effect.	*"…a scientific prediction which involves both the dependent and independent variables"; "it is a statement"; "… a prediction that should be proved".*	*"Because plant will grow bigger"; "because scientists wants to test the theory of water"; "the question of the experiment was about…"*
E2 Synthesis		*"It has not yet been proven"; " ..a statement that needs to be proven"; " … is a statement".*	*"... a possible outcome"; "… because water fertilises the roots"; "… because that is what the investigator suspected".*
E1 Anaysis	8. Heat causes sugar to dissolve.	*"In order for more sugar to dissolve the water must be heated"; "… sugar depends on cup of heated water"; " ...for sugar to dissolve depend on heat".*	*"Sugar is the one that's going to be tested"; "… it does not depend on water or sugar"; "… it does not depend on anything".*
E2 Analysis		*"The sugar dissolving is dependent on the heat"; "… the water need to be heated for the sugar to dissolve"; " … sugar depends on hot water to dissolve".*	*"The cup of water depends on the heat for the sugar"; "… sugar is dependent on cup of water"; "… the cup of water will depend on the amount of heat".*

	Question number and ideal answer	Examples of good motivations	Examples of poor motivations
E1 Synthesis	10. Must be the same in cause and effect.	*"It is not effected during the experiment"; "… cup of water does not change"; "… cup of water must be constant".*	*"Because this experiment is about the water carrying ability"; "… so the result could be more appropriate"; "… the results of the experiment".*
E2 Synthesis		*"Accept for sugar and hot water, all other variables must be constant"; "… amount of water must stay the same"; "… same cup and amount of water has to be used".*	*"Cup of water should be kept constant"; "… because without water, sugar cannot dissolve"; "… because there are different volumes in sol".*
E1 Evaluation	11. According to the introduction.	*"…the experiment was done in order to check the water-carrying capacity"; "… from the introduction…"; "… the scientist is investigating the water-carrying capacity".*	*"The soil type were placed in funnels"; "… the soil types differ"; "… dependent and independent variables are there".*
E2 Evaluation		*"… scientist is investigating the water-carrying capacity of soil"; "… question based on different soil types"; "… comparing the water-carrying capacity of soil".*	*"Water was added in all three types of soil"; "… it is the aim of the investigation"; "… the longer the soil is dipped in water, the greater the filtration".*
E1 Analysis	12. Variable that causes the effect.	*"Different types of soil were used"; "… the volume of filtrate depends on the soil type"; "… soil sample is independent".*	*"The time determines the volume.."; "… because it changes the whole experiment"; "… time only will tell us the best…".*
E2 Analysis		*"it's the variable that cause the effect"; "… soil type can be changed"; "… soil types are different, making the time of filtration different".*	*"it determines how much water is absorbed"; "… time does not depend on the volume"; "… the volume of the filtrate was observed".*

6.7.1.2 Post-test 1

In this section, the researcher reports on the students' application of the universal intellectual standards of reasoning to the motivation that they had to provide for their response to the questions in post-test 1, which focused on problem-based content and the scientific method, which were dealt with during weeks 1 – 6 of the first semester 2016. Table 6.13 summarises some of the verbatim responses of the students.

Table 6.13: Post-test 1 – Examples of motivations

	Question number and ideal answer	Examples of good motivation	Examples of poor motivation
E1 Evaluation	2. Contains more proteins.	*"Has much protein in food"; " ... the more proteins, the faster growth"; "… more amount of protein…".*	*"Because it has lots of fats"; "… because there are more carbohydrates and fewer proteins"; " ... it does not contain fats".*
E2 Evaluation		*"They have more proteins"; "… proteins are responsible for growth"; "… more proteins found here which …"; "… contains the most proteins".*	*"because they contain a lot of oil"; "… because the pie chart line is in the middle"; "… because fats influence growth".*
E1 Evaluation	6. Body temperature / optimum temperature for catalase.	*"Enzyme function best at optimal temperature which is 37ºC"; "… enzymes usually most effective at body temperature"; "… that is the suitable temperature for catalase".*	*"Because enzyme function best at optimal temperature"; "… the temperature is high"; "… because water is boiling".*
E2 Evaluation		*"Enzymes most active at body temperature"; "… enzyme function best at optimum temperature"; "… the temperature seems at optimal…".*	*"it changes as more variables are added"; "… catalyst speed up reaction under high temperature"; "… what can be controlled".*
E1 Analysis	8. Variable that cause an effect.	*"The temperature of the water bath"; "… the temperature is the cause"; "… because temperature is the one that cause…".*	*"The condition of the chicken liver"; "… the amount of hydrogen provided…"; "… it is what must be observed".*
E2 Analysis		*"The condition of the chicken liver depends on temperature"; "… we have to use different temperature…"; "… temperature has an effect".*	*"The chicken liver is the one that reacts"; "… hydrogen peroxide determines the reaction"; "…the amount of bubbles formed".*
E1 Synthesis	9. Dependent variable.	*"The variable that has to stay the same"; "… it varies according to the temperature"; "… it is a dependent variable".*	*"Because the amount of liquid oxygen…"; "… the amount of liquid displaced was not a variable"; "… liquid in different beakers".*

	Question number and ideal answer	Examples of good motivation	Examples of poor motivation
E2 Synthesis		*"The condition of the liver"; "… different temperatures"; "… water temperature"; "… during different temperatures".*	*"The amount of hydrogen peroxide"; "… because it is not weight"; "… the liquid that was displaced".*
E1 Synthesis	13. No reduction of chromosome number.	*"The chromosomes have been halved in meiosis I"; "… crossing over had already occurred in prophase I"; "… chromatid moving from centre".*	*"…so that the daughter cell has both maternal and paternal material"; "… sister chromosomes align at equator"; "… chromosomes align in pairs".*
E2 Synthesis		*"Chromosomes line up on equator"; "… reduction has halved the number of chromosomes"; "…the chromatids are about to split".*	*"The metaphase of meiosis"; "… telophase has not occurred"; "… chromosomes are in homologous pairs".*
E1 Ananlysis	15. Hypertonic low water potential.	*"The water drains from the solute"; "… the water exits the vacuole"; "… hypertonic is the higher solute and less water concentration".*	*"Water enters the cell"; "… the vacuole moves towards the cell membrane"; "… because water exits".*
E2 Analysis		*"Higher solute concentration"; "… the cell shrinks"; "… cell expands as water enters".*	*"Water exits…"; "… will go to the point of high concentration …"; "… the cell will change its shape".*

6.7.1.3 Pre-test 2 and post-test 2B

In this section, the researcher reports on the students' application of the universal intellectual standards of reasoning to the motivation that they had to provide for their response to the questions in pre-test 2 that focused on problem-based content and working according to the scientific method, dealt with in the weeks 1 – 6 of the first semester 2016. Table 6.14 summarises some of the verbatim responses of the students.

Table 6.14: Pre-test 2 and post-test 2B – Examples of motivations

	Question number and ideal answer	Examples of good motivation	Examples of poor motivation
E1 Analysis	2. Effect of temperature.	*"Results are depending on the temperature"; "… the results depend on the temperature"; "… results after washing depends on the temperature in order for the enzymes to function".*	*"The size of the blood stain"; "… different temperature cause different results"; "… temperature depend on the time".*
E2 Analysis		*"The result after washing and is dependent on enzyme activity"; "… the results depend on the temperatures"; "… it depends on the different temperatures".*	*"The stains are not measured"; "…the size of the blood stains are observed"; "… there cannot be results without the experiment".*
E1 Synthesis	4. 33% = 0.33 van 18 = 6.	*"33/100 X 18 = 6"; "5.94; 33/100 x 18".* The only correct answer.	*"It is six portions of the total consumed"; "… they are the highest that were consumed"; "… because we have to consume 3 meals /day".*
E2 Synthesis		*"Because 33% of 18 is 6"; "... 33% of 18 is 5.94".*	*"Because it is the biggest portion per day"; " …if 4 comes from fruit, the rest comes from 18".*
E1 Evaluation	8. Explain sequence of graph.	*"According the shape of the graph…"; "… enzyme function low at low temperature and as the temperature increases, they speed up the function"; "… enzyme activity started at low temperature and rise to a point of optimum".*	*"This sequence best describe the shape"; "… it started at low temperature and increases"; "… at the beginning of the graph, there is no enzyme activity…".*
E2 Evaluation		*"Steps follow line of graph"; "… sequence starts with low temperature and rises as temperature rises"; "… according to the graph".*	*"The graph shows that enzymes are inactive at low and again at high temperature"; "… the enzyme temperatures start at low"; "… when temperatures increase, the enzyme reaction increases".*

	Question number and ideal answer	Examples of good motivation	Examples of poor motivation
E1 Analysis	9. Effect of temperature	*" …different temperatures different number of bubbles..."; "… it depend on the temperature of the water"; "… they are depending on the temperature".*	*"Temperature of water depend on the number of gas bubbles"; "… the temperature of the water depend on the rate of photosynthesis"; "… temperature of water is dependent".*
E2 Anaysis		*"They are effected by the temperature"; "… the number of gas bubbles is the effect"; "… the gas bubbles will indicate the effect".*	*"Temperature will be determined by the amount of heat provided"; "… the effect of water temperature"; "… it is the variable that can be changed".*
E1 Synthesis	11. Optimum – max reaction.	*"The graph reaches its peak at 35ºC"; "… the number of bubbles are more at 35ºC"; "… it produces the most gas bubbles".*	*"The maximum height; optimal temperatures"; "… as gas bubbles decrease, water content also decreases"; "… this is the highest temperature".*
E2 Synthesis		*"Temperature where most bubbles are formed"; "… from graph and use ruler with vertical line drawn from 35ºC"; "… maximum bubbles appear at 35ºC".*	*"Because that is the moderate temperature"; "… at 30ºC the amount of gas bubbles are higher"; "… because the graph shows at 40ºC".*
E1 Evaluation	14. 30 – 20 min = 10 min.	*"The race ended at 20 minutes, continued to increase until 30 minutes which means 10 minutes"; "… it continued to increase from 20 to 30".* The only correct answer.	*"Lasted for 50 minutes"; "… as in line graph"; "… it took 10 minutes to decrease"; "… because it become higher".*
E2 Evaluation		*"Lactic acid concentration increased after 10 minutes"; "…* 30 – 20 min = 10 minutes".	Wrong calculations were provided as answers.

6.7.1.4 Post-test 2

In this section, the researcher reports on the students' application of the universal intellectual standards of reasoning to motivate their responses to the questions in post-test 2. Table 6.15 summarises some examples of the verbatim responses of the students.

Table 6.15: Post-test 2 – Examples of motivations

	Question number and ideal answer	Examples of good motivation	Examples of poor motivation
E1 Evaluation	1. Tinfoil prevent sunlight from entering and green part contain chlorophyll.	*"Leaf covered with tin foil and contain green part"; "… sunlight and plant colour…"; "… variegated leaf test chlorophyll and covered part test sunlight".*	*"CO_2 and sunlight were tested"; "… to test whether chlorophyll is necessary for photosynthesis"; "… test was performed with a variegated leaf"; "… colour of leaf will change if CO_2 is present".*
E2 Evaluation		*"Part of leaf was covered with tin foil and other parts contain chlorophyll"; "… plants require sunlight and chlorophyll to photosynthesise"; "… the foil is testing whether sunlight is necessary and green if chlorophyll is essential".*	*"Because CO_2 and sunlight are essential …"; "… the plant colour was white and green"; "… these factors are essential for photosynthesis".*
E1 Synthesis	2 Contain both correct cause and effect.	*"Plant needs both for photosynthesis"; "… they were both tested; the statement mention the two variables tested".*	*"Sunlight is the main source that allows photosynthesis"; "… they indicate if photosynthesis has occurred"; "… sunlight and CO_2 are…".*
E2 Synthesis		*"A statement with both variables"; "… testable statement with cause and effect"; "… both dependent and independent variables in prediction".*	*"CO_2 is necessary for photosynthesis"; "… that is what the investigation is about"; "… that is what you change in the experiment".*
E1 Analysis	3. Cause of an effect.	*"Chlorophyll depends on sunlight"; "… they both cause the effect"; "… they do not change nor depend on any variable".*	*"CO_2 and sunlight depend on nothing"; "… the leaf depends on sunlight"; "… they are both effected".*
E2 Analysis		*"They are factors that cannot be changed"; "… both causes the effect; can be controlled".*	*"CO_2 and sunlight are needed"; "… the leaf depends on CO_2 and sunlight …"; "… CO_2 and sunlight are the ones causes the effects".*

	Question number and ideal answer	Examples of good motivation	Examples of poor motivation
E1 Analysis	6. 50 – 40 = 10 units of light.	*"it already has 8 units of glucose and only needs 2 to make 10".* The only correct answer.	*"20/4 = 10"; "… it will be able to produce 4 more glucose units"; "… if more light is added the plant will produce more food*".
E2 Analysis		*"It already has 8 units of glucose and only needs 2 to make 10".* The only correct answer.	*"The more the units of light, the better"; "… 20 units…"; "… more light results in more glucose produced".*
E1 Synthesis	12. Respiration since oxidation is the loss of electrons and reduction is the gain of electrons.	*"Respiration undergoes reduction to produce H_2O"; "… because the end products of photosynthesis are needed"; "… the breaking down of carbohydrates".*	*"Because during photosynthesis oxidation takes place before reduction"; "… because this is a reduction process that take place"; "… because in A the molecules are large and in B they are smaller".*
E2 Synthesis		*"Glucose is oxidized and reduced to CO_2 and H_2O"; "… glucose was oxidized since it lost electrons"; "O_2 was reduced because it gained electrons".*	*"Indicates the equation of photosynthesis"; "… O_2 is being oxidized"; "… the by-product are the same of that of photosynthesis".*
E1 Evaluation	15. All the factors are limiting photosynthe-sis.	*"Because they all contribute to photosynthesis"; "… photosynthesis requires the presence of all mentioned"; "… they are all limiting the process".*	*"More CO_2 has been taken in and used for photosynthesis"; "… when H_2O is available it works hand in hand with CO_2"; "… because water availability causes a light reaction".*
E2 Evaluation		*"All three important in the process of photosynthesis"; "…all the factors may limit photosynthesis"; "… they are all contributing factors".*	*"Some of the factors must be absent"; "… H_2O is produced during the process"; "… more glucose is produced since there is enough sunlight".*

In summary, the researcher observed the following initial trends in the majority of the responses. The responses of the students did not testify to reasoning that reflected clarity, accuracy, precision, relevance, significance, depth, breadth and logic in all the tests that were administered. The following general trends were observed in the participants' responses:

- The motivations lacked clarity, as elaborations provided by the students were sometimes part of the questions or items from the questions given to them, and not phrased in their own words.
- Most of the motivations were not true and therefore not accurate.
- Some motivations provided insufficient and irrelevant detail.
- The motivations lacked relevance, as many responses were not connected or applicable to the questions.
- The motivations lacked significance where responses were repetitions of the actual questions or items from the questions.
- Some questions were probably too difficult (depth) and some participants provided no motivations for their answers.
- Some questions were demonstrated by graphs to give more perspective to the applicable question, but were misinterpreted by many students.
- The motivations lacked logic, as facts/ideas did not follow in order and answers did not make sense.

The researcher concluded that neither the Thinking Maps intervention nor normal lecturing appeared to have sensitised the students to apply the universal intellectual standards of reasoning. The researcher therefore argues that the nurturing of the universal intellectual standards of reasoning appears to be a dimension of critical thinking that needs exclusive and purposive attention in order to develop.

An improvement in providing better reasoned motivations were noted regarding questions where graphs were used to clarify questions (pre-test 2 and post-test 2). This could possibly be due to the practice of using Thinking Maps as a visual strategy to better understand learning content.

A disturbing observation was that there were numerous multiple-choice questions not motivated by some participants at all. This trend not to motivate answers could be due to the problem-based content and content related to the scientific method, that the participants might not have understood.

The researcher argues that a major factor that possibly contributed to the apparent inability of the participants to comply with the universal intellectual standards of reasoning in their answers was the lack of probing questions used by the lecturer during the Thinking Maps intervention and normal lecturing. In this regard Paul and Elder (2006:8) argue that probing questions need to become infused in the thinking of students, and have to form part of their inner voice that would guide them to become more effective at reasoning. The following questions suggested by Paul and Elder (2006:7, 8), could have guided the thinking of the students during the construction of the Thinking Maps to intentionally focus on reasoning in accordance with the universal intellectual standards of reasoning:

Clarity: Could you give an example? Could you explain further? Could you express that in another way?

Accuracy: Are you sure that your answer is true? How could we know that the answer is true?

Precision: Could you provide more detail to your answer?

Relevance: How is this answer relevant to the question? How does this answer relate to the issue that we are discussing?

Depth: Are you sure you have identified all the significant facts?

Breadth: Could you answer the question in another way?

Logic: Are you sure your answer makes sense?

Significance: Could you indicate which of the facts that you identified are the most important and why?

The researcher concludes that most of the participants did not develop a command of the universal intellectual standards of reasoning during the research, as they were not effective at motivating their answers with clarity, accuracy, precision, relevance, significance depth, breadth and logic. In comparison, after reading through the motivations of the students, it appeared to the researcher that Experimental group 2 provided better motivations for their answers than Experimental group 1. In addition, Experimental group 2 performed better in comparison to Experimental group 1 regarding motvating questions that involved basic mathematics.

6.8 CHAPTER SUMMARY

In this chapter the results of the statistical analysis of the pre-tests, post-tests and assessment of Thinking Maps were reported and discussed.

In summary, the test results for Experimental group 2 revealed quite a different picture when compared to the results of Experimental group 1. At the onset of the research with pre-test 1, Experimental group 2 appeared to be more effective than Experimental group 1 with the application of the critical thinking skills. However, at the end of the 12-week intervention with the writing of post-test 2B, Experimental group 1 managed to achieve better results than Experimental group 2 (*cf*. 6.5).

In addition, the researcher noticed the same trends among Experimental groups 1 and 2, namely that after the Thinking Maps intervention and normal lecturing respectively; an increase was noticed in the pre-test 2 results, but not in the post-test 1 and post-test 2 results. Improvement for both groups was then again observed in the post-test 1 B and post-test 2B results, which could imply that the Thinking Maps intervention (Experimental group 1) and the normal lecturing (Experimental group 2) over time seemed to have contributed to the improved results (*cf.* 6.4.2, 6.4.3). It is noteworthy to mention that although post-test 1 and pre-test 2 focused on problem-based content and working according to the scientific method, none of the participants appeared to be effective at applying critical thinking in post-test 1, as the average for post-test 1 was lower than the average achieved for pre-test 2 for both Experimental group 1 and 2. As the post-test 2B results were higher than the pre-test 1 results for both experimental groups, the researcher concludes that the Thinking Maps intervention and normal lecturing contributed to enhancing the application of the participants' critical thinking skills.

The researcher concludes that the results obtained for the various tests, in particular for Experimental group 1, testify to the latent potential of Thinking Maps to enhance the development of critical thinking. The improved performance noted in the construction of the Thinking Maps of the participants of Experimental group 1 probably benefited the application of critical thinking skills that was observed in the improved results that they obtained for post-test 1B, pre-test 2 and post-test 2B (*cf*. 6.6).

The improved results in the construction of the Thinking Maps in particular for Experimental group 2 did not correspond with the findings noted for the various test results, as this group appeared not to have benefitted as much as Experimental group 1 from the Thinking Maps intervention, as evidence by their post-test 2 result (*cf*. 6.6).

Finally, the analysis of the open questions in the various tests indicated that most of the participants were not able to motivate their answers with clarity, accuracy, precision, relevance, significance, depth, breadth and logic (*cf.* 6.7).

The final chapter, Chapter 7, focuses on the summary and findings of the study and recommendations for enhancing the development of critical thinking through Thinking Maps.

CHAPTER 7
SUMMARY, FINDINGS AND RECOMMENDATIONS

7.1 INTRODUCTION

This study was conducted with the purpose of determining the impact of Thinking Maps on enhancing the development of critical thinking skills among first year pre-service Life Science teachers at a university in South Africa. The main aim, objectives and hypotheses formulated at the onset of the study are revisited in this chapter, in order to determine whether they were achieved.

It is essential that the literature study and the data gathered by means of tests and the Thinking Maps should have contributed in answering the primary and secondary questions on which this study was based, achieving its overall aim and objectives. This chapter addresses the following:

7.2 An overview of the study

7.3 Findings from the literature review

7.4 Findings from the empirical research

7.5 Findings in relation to the aim and objectives of the study

7.6 Hypotheses: Acceptance or rejection

7.7 Recommendations

7.8 Limitations of the study

7.9 Suggestions for further research

7.10 Contributions of the study

In the subsequent section, a brief overview of the study is provided.

7.2 OVERVIEW OF THE STUDY

The overview of the study intends to provide a brief summary of the essence of the preceding chapters.

7.2.1 Chapter 1

The purpose of the chapter was to familiarise the reader with the rationale, purpose statement, conceptual framework, research questions, aim and objectives, hypotheses and the empirical research design as well as data collection and analysis, and the Thinking Maps intervention (*cf*. 1.1 – 1.14).

The chapter began with a brief discussion to clarify what critical thinking is, and emphasised its importance to achieve the objectives of the South African CAPS and the subject Life Sciences. Completed national and international research studies reported that the development of critical thinking skills among pre-service teachers appears to be fragile and deficient. The use of Thinking Maps as a teaching strategy to develop the elements of critical thinking, namely cognitive skills, metacognitive strategies, dispositions/behavioural traits, intellectual traits and universal intellectual standards of reasoning (*cf*. 1.1) seems to be a possible solution to enhance the critical thinking development of pre-service teachers. This research focused on critical thinking and Thinking Maps as a teaching strategy to enhance critical thinking, therefore a number of research studies were consulted to establish gaps in the research field. Completed research in this regard has not yet established the effects of Thinking Maps on enhancing the development of critical thinking among pre-service Life Science teachers. Therefore, a gap in terms of specific research linked to Life Sciences as well as Thinking Maps for enhancing critical thinking was identified (*cf*. 1.1).

The research question and secondary research questions for the study were formulated and aligned with the aim and objectives of the study, which entailed determining to what extent pre-service Life Science teachers are effective at applying the critical thinking skills to analyse, synthesise and evaluate information, and if not, to investigate to what extent a Thinking Maps intervention could enhance the development of critical thinking skills among first year pre-service Life Science teachers (*cf*. 1.5).

The research was framed within a positivistic paradigm (***cf*.** 1.8.2), and employed quantitative, quasi-experimental research (*cf.* 1.8.3) with a non-equivalent pre-test-post-test control group strategy of inquiry in a double experiment (*cf*. 1.8.4). The sampling (*cf*. 1.8.5) involved non-probability convenient and purposive sampling of first year pre-service Life Science teachers at a South African university (n = 56). Data were collected by means of researcher-developed pre-tests and post-tests (*cf*. 1.9.1), that comprised closed and open test items. With the latter the researcher envisaged to establish the research participants' efficiency to comply with the universal intellectual standards of reasoning. Furthermore, the Thinking Maps generated by the students during the intervention and for homework were assessed to establish how the Thinking Maps contributed to the application of critical thinking skills among the growth and development students (*cf*. 1.9.2).

Criteria for upholding reliability of the research were adhered to (*cf*. 1.10.2), and the validity of this quantitative research design was ensured by complying with the four aspects of internal, external, construct and statistical validity (*cf*. 1.10.1.1). The tests were subjected to criteria for validity, and focused on ensuring face, content, construct and criterion validity (*cf.* 1.10.2). In addition, the validity of the experimental research design was ensured by adhering to criteria for internal and external validity (*cf*. 1.10.1.3).

The data analysis procedures involved descriptive and inferential statistics (*cf.* 1.11). Comparisons were made within and across experimental and control groups to establish the effect of Thinking Maps to enhance the development of critical thinking skills by comparing the pre-test and post-test results. The open questions were analysed to establish trends in participants' reasoning in relation to the universal intellectual standards of reasoning (*cf.* 2.2.4). The Thinking Maps that the students constructed during the intervention were assessed against criteria such as flexibility, originality, elaboration, fluency, layout and relevancy (*cf.* 3.5.5), that provided an indication of the growth and development of their critical thinking skills. Throughout the research principles for conducting ethical research were upheld (*cf.* 1.12).

7.2.2 Chapter 2

This chapter focused on a conceptualisation of critical thinking. Critical thinking involves the interrelated application of different elements, such as the core critical thinking skills and metacognitive strategies, critical thinking dispositions/behavioural traits, universal intellectual standards of reasoning and intellectual traits (Ennis, 2001:44; Facione, 2009:5, 6; McPeck, 1981:20; Paul, 1993:58) (*cf.* 2.2). In the context of the study, the main focus was on the interrelated core critical thinking skills (analysis, synthesis and evaluation) (*cf.* 2.2.2).

The importance of enhancing the development of critical thinking was linked to the objectives of the CAPS curriculum (Department of Basic Education, 2011:4, 5) (*cf.* 2.3.1), teaching and learning in the 21st century (Crockett, 2015:2; Saavedra & Opfer, 2012:5; Wagner, 2008:17 (*cf.* 2.3.2), the acquisition of critical thinking as a life skill (Brookhart, 2010:5; Hager & Kaye, 1992:27; Jacobson, 2014:31) (*cf.* 2.3.3) and the important role of critical thinking in achieving the objectives of Life Sciences. Teachers themselves need to be good critical thinkers before they can teach learners to think critically (Department of Basic Education, 2011:13; Snyder & Snyder, 2008:92) (*cf.* 2.3.4).

Research that established the critical thinking abilities of pre-service teachers within an international and national context revealed that school learning apparently does not prepare pre-service teachers to apply critical thinking skills (Allamnakhrah, 2013:200; Grosser & Lombard, 2008:1364; Uksw, 2014:163) (*cf.* 2.4.1, 2.4.2).

Different measuring instruments such as, multiple-choice, open-ended and commercially available tests to assess the development of critical thinking skills were explored in section 2.5 (Norris & Ennis,1989:101). In the absence of subject-related tests to establish the application of critical thinking in Life Sciences, the researcher decided to set his own subject-related tests comprising closed multiple-choice test items as well as open test items to establish the extent to which the students possessed the critical thinking skills on which the research focused, as well as to collect some initial data about the application of the universal intellectual standards of reasoning prior to, and after the Thinking Maps intervention. Data were also collected by assessing the Thinking Maps that the students constructed during the intervention to determine the effectiveness of the students in applying critical thinking skills to Life Science content (*cf.* 6.6).

Factors that could inhibit the development of students' critical thinking were discussed, namely political, educational, personal, behavioural, cultural and language factors. The importance of, in particular, teaching practices to enhance the development of critical thinking skills was highlighted (Grosser & Lombard, 2008:1367; Illeris, 2015:30; Lun *et al*., 2010:606; Pithers & Soden, 2000:241; Snyder & Snyder, 2008:92) (*cf*. 2.6.1 - 2.6.5).

Finally, different learning theories, teaching methods and teaching strategies and their relation to the development of critical thinking were described with the aim to identify a suitable teaching-learning framework that would guide the design and implementation of the intervention (*cf*. 2.7.1-2.7.2). Attention was given to behaviourism (Ertmer & Newby, 2013:48) (*cf*. 2.7.1.1), which is characterised by a "*drill-and-practice*" approach that is still at the order of the day in many educational institutions. Cognitivism (Pintrich & Schunk, 2002:143; Schunk, 2000:119) (*cf.* 2.7.1.2) regards students as information processors and Constructivism (Ertmer & Newby, 2013:55) (*cf.* 2.7.1.3) focuses on active involvement and creating meaning during learning. Attention was also given to the transformative learning theory (*cf.* 2.7.1.4), that postulates that dynamic relationships between teachers and students during learning promote personal development and growth (McGonigal, 2005:1). Finally, experiential learning theory (*cf.* 2.7.1.5) that involves the application of information received from the teacher to a student's experiences in real life, was explored (Steffens, 2015:41-45).

The following teaching methods were reviewed to identity a suitable method/methods to apply when implementing the Thinking Maps intervention programme. Direct, teacher-centered teaching involves an teacher who takes a central role during teaching and who spends most of the time talking (Arends, 2004:293; Burden & Byrd, 2010:120; Kramer, 2006:100) (*cf.* 2.7.2.1). Indirect teaching is a student-centered approach where the students are active participants and more in control of their own learning (Borich, 2003:94; Kramer, 2006:101; Kruger, 2002:110) (*cf*. 2.7.2.2). Independent teaching methods include those where students work by themselves and rely on their own efforts to accomplish a task or an assignment (Borich, 2007:17; Philpott, 2009:38) (*cf*. 2.7.2.3). Interactive teaching focuses on cooperation and participation during teaching, where meaning is constructed through collaboration (Burden & Byrd, 2010:151; Gawe, 2008:209; Sessoms, 2008:88) (*cf*. 2.7.2.4).

Flowing from the discussions in section 2.7 the researcher argued that a cognitive and a cognitive constructivist teaching and learning framework, and the facilitation of teaching and learning by means of independent teaching methods and strategies would provide the necessary opportunities for active learning and personal construction of meaning to enhance the development of critical thinking through the use of Thinking Maps.

7.2.3 Chapter 3

Chapter 3 focused primarily on clarifying the effectiveness of visual learning, what Thinking Maps are and their importance in developing critical thinking. Effective learning is an activity of constructing information in collaboration with others and involves the application of metacognitive and cognitive thinking skills (Grosser, 2007:38; Monteith, 2002:93; Pritchard, 2014:119-120) (*cf*. 3.2).

Different types of learning were identified, namely visual or sight-based (Gilakjani, 2012:105; Gilakjani & Ahmadi, 2011:469) (*cf*. 3.3.2), auditory or voice-based (Gilakjani, 2012:106; Gilakjani & Ahmadi, 2011:470) (*cf*. 3.3.3), kinaesthetic or movement-based (Gilakjani, 2012:106; Gilakjani & Ahmadi, 2011:470) (*cf*. 3.3.4) as well as learning through reflection (Pritchard, 2014:48) (*cf*. 3.3.5). Reflectors collect information and make observations before making decisions. This research explored the influence of Thinking Maps as a visual learning strategy (*cf*. 3.3.5).

Types of visual learning strategies were identified and explained, namely Mind Maps (Hyerle, 2009:155) (*cf.* 3.4.1), Concept Maps (Novak, 2006:1-2) (*cf*. 3.4.2), Graphic organisers (Ausubel, 1978:151-155) (*cf*. 3.4.3), charts and diagrams (Gilmartin & Rex, 1999:14) (*cf*. 3.4.4), as well as Thinking Maps (Hyerle, 2009:151) (*cf*. 3.5). The latter visual learning strategy was the focus of this research as Thinking Maps hold the potential to enhance the development of critical thinking skills (Hyerle & Yeager, 2007:2) (*cf.* 3.5.2). Thinking Maps could be regarded as more suitable to enhance the development of critical thinking, as they facilitate more explicitly the cognitive skills (defining, describing characteristics, contrasting, classifying, whole-part thinking, sequencing, cause-and-effect reasoning and analogical reasoning) and metacognitive strategies (reflection) involved in critical thinking (*cf*. Figure 2.1). Moreover, Thinking Maps encourage students to think with clarity, relevance, depth, breadth and logic when constructing the maps, thus promoting the development of the universal intellectual standards of reasoning. In addition, a number of critical thinking dispositions such as accuracy, open-mindedness, systematicity and persistence are required to construct good quality Thinking Maps.

The eight Thinking Maps based on the specific cognitive skills mentioned above are Circle Maps, Bubble Maps, Double Bubble Maps, Tree Maps, Brace maps, Flow Maps, Multi-Flow Maps and Bridge Maps (Hyerle & Yeager, 2007:26-66) (*cf.* 3.5.3.1-3.5.3.8). This research focused on the use of the Circle Map, Tree Map and Multi-Flow Map to enhance the critical thinking skills to analyse, synthesise and evaluate. The mentioned skills underpin the specific outcomes in Life Sciences that were the focus of the study.

7.2.4 Chapter 4

Chapter 4 focused on the research methodology that was employed in the context of the study (*cf*. 4.2 – 4.4).

The study was framed within a positivistic paradigm (*cf*. 4.2.2.1) and employed a quantitative, quasi-experimental research design (*cf.* 4.4.1.1), as manipulation of a dependent variable (critical thinking skills) took place in an experimental context. The researcher used the non-equivalent groups pre-test-post-test control and comparison group designs as strategy of inquiry in a double experiment (*cf*. 4.4., 4.4.2).

The researcher used norm-referenced tests to collect data, as comparisons were drawn between the achievements of the control groups relative to the achievements of the experimental groups. The researcher developed tests with multiple-choice and open test items to determine the extent to which the participants acquired the skills to apply critical thinking (analysis, synthesis, evaluation) in Life Science content. Based on the pre-test results, the Thinking Maps interventions were developed to address the deficiencies noted in the pre-test results at the onset of the first six weeks (Experiment 1) and second six weeks (Experiment 2) of the first semester of 2016. The tests were piloted and refined before being administered to the sampled participants (*cf*. 4.4.6).

Non-probability sampling was employed to select the first year pre-service Life Science teachers (n = 56) at a South African university, who took part in the research (*cf.* 4.4.4). Non-probability sampling could not guarantee that the sample was representative of the population, therefore no generalisations of the research findings could be made. It was, however, not the purpose of the study to generalise findings. The researcher aimed to determine the impact of a Thinking Maps intervention as part of a pilot study in his own classroom practice during teacher training to enhance the development of critical thinking skills among first year pre-service Life Science teachers (*cf*. 4.4.4).

The data derived from the closed and open questions in the tests and the Thinking Maps constructed by the participants during the intervention, were captured, analysed and interpreted with the assistance of an independent statistician from North-West University, Vaal Triangle Campus. The data analysis involved, firstly, the use of descriptive statistical procedures to summarise the data with frequencies, percentages, averages (means) and standard deviations. Secondly, inferential statistics were used to accept or reject the hypotheses stated at the onset of the study after comparing the means of the pre- and post-test data and making inferences about the effectiveness of the Thinking Maps intervention (*cf*. 4.4.5). The responses to the open questions in the test were checked to determine whether the students' thinking complied with the universal intellectual standards of reasoning (clarity, accuracy, logic, relevancy, depth, breadth, significance) (*cf.* 2.2.4). The Thinking Maps constructed by the participants were assessed against criteria for relevancy, elaboration, flexibility, originality and layout (*cf.* Tables 3.2, 3.3), to provide information about the extent fo which the students could apply critical thinking to Life Science content using Thinking Maps.

The researcher adhered to quality criteria by ensuring that the study complied with reliability and validity criteria (*cf*. 4.4.6) and ensured that he conducted the research according to ethical principles (*cf*. 4.4.7).

7.2.5 Chapter 5

Chapter 5 briefly defined and described the six phases of intervention research. In the context of the study, the researcher implemented four steps, namely problem analysis and project planning; information gathering and synthesis; design and early development and pilot testing.

The twelve-weeks Thinking Maps intervention programme was underpinned by cognitive and cognitive constructivist learning theories and implemented by means of independent teaching as teaching method with Thinking Maps as teaching strategy. A comprehensive overview of the twelve weeks Thinking Maps intervention programme was provided (*cf*. 5.3.2).

7.2.6 Chapter 6

The data obtained from the pre- and post-tests written by students were analysed and interpreted in this chapter, in which descriptive and inferential statistics were used to analyse the data. A succinct overview of the main findings reported in Chapter 6 follows:

- The findings in relation to Experimental group 1 (*cf.* Table 6.7) (*cf.* 6.4.2), highlighted the potential of Thinking Maps noted in the post-test 1B and pre-test 2 results, to enhance the development of critical thinking skills, as argued by Stedman and Adams (2012:9) (*cf.* 2.3.4) and Hyerle and Yeager (2007:10) (*cf*. 3.5.5). The findings that emanated from Experimental group 1 could also concur with the literature that direct, passive teaching does not promote the development of critical thinking (Burden & Byrd, 2010:120; Kruger, 2002:109) (*cf*. 2.7.2.1), taking into consideration the low post-test 2 result.
- The effectiveness of the Thinking Maps intervention was supported by the findings obtained for Experimental group 2 and noted in the post-test 2B results. (*cf*. 6.4.3). In addition, normal lecturing also appeared to assist the participants to develop critical thinking skills (*cf*. Table 6.8), evidenced by the improvement in the post-test 1B and pre-test 2 results. The findings obtained for Experimental group 2 therefore also strengthened the case that a Thinking Maps intervention can enhance the development of critical thinking skills, as confirmed by the statements of Stedman and Adams (2012:9) (*cf.* 2.3.4). This finding seems to contradict the literature that direct, passive teaching does not promote the development of critical thinking (Burden & Byrd, 2010:120; Kruger, 2002:109) (*cf*. 2.7.2.1), when observing the improvement in the post-test 1B result. The finding however could also support the literature, based on the low post-test 1 result that the participants obtained after normal lecturing.
- The findings obtained for Experimental group 1 and 2 revealed that the nature and difficulty level of some problem-based content and content related to working according to the scientific method seemed to have influenced the effectiveness with which the participants applied critical thinking skills (*cf*. 6.4.3) (post-test 1, pre-test 2, post-test 2).
- The researcher noticed a similar trend in the comparison between the participants of Experimental groups 1 and 2 (cf. Table 6.9) (cf. 6.5). After the Thinking Maps intervention (Experimental group 1) and normal lecturing (Experimental group 2) respectively, an increase was noticed in the post-test 1B and the pre-test 2 results of both groups, but not in the post-test 1 results. These results could imply that the Thinking Maps intervention (Experimental group 1) and the normal lecturing (Experimental group 2) seemed to have contributed to the improved application of the critical thinking skills. As post-test 1B was a repetition of pre-test 1, the content (Grade 12 Life Sciences), might have been familiar to the

students, which enabled them to apply critical thinking more effectively than in post-test 1 where questions were phrased around new problem-based content and content related to the scientific method that were dealt with during weeks 1 – 6 of semester 1.

- In comparison to post-test 2 (after normal lecturing (Experimental group 1); after the Thinking Maps intervention (Experimental group 2)), improvement for both groups was observed in the post-test 2B results, a repetition of pre-test 2. However, a comparison between pre-test 2 and post-test 2B revealed a slight decrease in the post-test 2B results. Both groups also scored higher results in the final test, post-test 2B, compared to pre-test 1 at the onset of the experiment. Therefore, the researcher concluded that the Thinking Maps intervention and normal lecturing possibly jointly contributed to the retention or transferability of the participants' critical thinking skills.
- The assessment of the participants' Thinking Maps constructed during the Thinking Maps intervention indicated that Experimental group 1 obtained better and improved results from week 2 to week 4 (*cf*. Table 6.10). It appeared that with time the participants were able to use the Thinking Maps to make meaning of information and organise the information. The results of Experimental group 2 for the construction of the Thinking Maps during their intervention also revealed better and improved results from week 7 to week 12. The researcher concluded that the students were able to make meaning of the information and took ownership of their thinking processes. However, the improved results in the construction of the Thinking Maps for Experimental group 2 did not correspond with the findings noted for the various test results, for example the low post-test 2 result after the Thinking Maps intervention. According to the test results, Experimental group 2 seemingly did not benefit as much as Experimental group 1 from the Thinking Maps intervention (*cf.* 6.6), as their post-test 2B result at the end of the intervention were only slightly higher than their pre-test 1 results at the onset of the research. Experimental group 1 however maintained higher results in post-test 2B than in pre-test 1 at the onset of the research.
- The analysis of the open responses in the questionnaire indicated that the participants in both experimental groups seemed to have experienced challenges to motivate their test answers, as their responses reflected an apparent inability to reason with clarity, accuracy, logic, relevance, significance, breadth and depth (*cf.* 6.7). It seems reasonable to conclude that the Thinking Maps intervention did not enhance the development of the universal intellectual standards of reasoning.

In the next section, the major findings that emanated from the literature review, are presented.

7.3 FINDINGS FROM THE LITERATURE REVIEW

The literature review focused on two concepts, the first being critical thinking and the second the development of critical thinking through visual learning and specifically the role of Thinking Maps.

A major finding from the literature revealed that the importance of critical thinking for teacher training is supported by the new CAPS and within the current school curriculum. Critical thinking can be linked with specific outcomes and assessment standards in the Life Science classroom (Department of Basic Education, 2011:4, 5) (*cf*. 2.3.1). Education systems need to increase their focus on developing students' 21st century skills to prepare them for life challenges (Crockett, 2015:2; Saavedra & Opfer, 2012:5; Wagner, 2008:17) (*cf*. 2.3.2). An important finding that emanated from the literature review is that critical thinking is a life skill which should be cultivated (Duron *et al.,* 2006:160; Paul & Elder, 2006:4) (*cf*. 2.3.3). A major factor influencing the nurturing of critical thinking in the classroom relates to teachers who purposively and persistently provide opportunities for students to practise critical thinking (Stedman & Adams, 2012:9) (*cf*. 2.3.4).

Further findings were revealed regarding the critical thinking abilities of pre-service teachers with an international and national perspective. Both perspectives revealed that pre-service teachers lack effective critical thinking skills (Allamnakhrah, 2013:199) and are unable to apply critical thinking skills (Lombard & Grosser, 2008:573) (*cf*. 2.4). Furthermore, findings revealed that the development of critical thinking skills is unlikely unless pre-service teacher education produces products of critical thinking (Allamnakhrah, 2013:200) (*cf*. 2.4).

The next major finding related to a concept clarification for critical thinking. Pioneers in the field of critical thinking argue that critical thinking is the ability to answer questions of analysis, synthesis and evaluation (Duron *et al.,* 2006:160; Paul, 1985:37; Paul & Elder, 2006:4) (*cf*. 2.3.3). Good critical thinking comprises interrelated core critical thinking skills and metacognitive strategies (Facione, 2009:5, 6; Brookhart, 2010:40), critical thinking dispositions/behavioural traits (Facione *et al.,* 2000:61), intellectual traits (Cheung *et al*., 2002:505), and universal intellectual standards of reasoning (Paul & Elder, 2006:10) applied to the elements of thought (Paul & Elder, 2006:6) (*cf*. 2.2.2-2.2.5).

The next major finding related to the assessment of students' critical thinking skills. Literature revealed that there are no commercially available critical thinking subject-related tests to establish the application of critical thinking in subject content. Therefore, the researcher developed this own multiple choice Life Science tests with closed and open questions (Norris & Ennis, 1989:101) (*cf*. 2.5.1).

The literature study also highlighted various factors that influence the development of critical thinking skills, which inhibit students' critical thinking. These factors include political (Ijaiya *et al.,* 2010:383), educational (Ijaiya *et al.,* 2010:384; Saavedra & Opfer, 2012:7; Snyder & Snyder, 2008:92), personal and behavioural (Pithers & Soden, 2000:241), cultural (Grosser & Lombard, 2008:1369) and language factors (Lun *et al*., 2010:606; Qing *et al*., 2010:4598) (*cf.* 2.6.1-2.6.5). This research emphasised the importance of educational factors related to the choice of teaching methods and strategies to enhance critical thinking, as the research was based on the assumption that Thinking Maps as a teaching strategy could enhance the development of critical thinking.

An exploration of the literature to identify a suitable teaching-learning framework that would guide the design and implementation of the Thinking Maps intervention (*cf*. 2.7), alerted the researcher to the importance of cognitivism (*cf.* 2.7.1.2) and cognitive constructivism (*cf.* 2.7.1.3) that focus on active involvement and creating meaning during learning (Ertmer & Newby, 2013:55) (*cf.* 2.7.1.3) to stimulate critical thinking.

A variety of teaching methods and strategies were reviewed to identity a suitable method and strategy which could be applied when implementing the Thinking Maps intervention programme (*cf.* 2.7). Flowing from the literature, the facilitation of teaching and learning by means of independent teaching methods and strategies seemingly would provide the necessary opportunities for active learning and personal construction of meaning to enhance the development of critical thinking through the use of Thinking Maps (*cf.* 2.7.2.3). A major finding indicated that the development of good critical thinking skills requires teaching to become less teacher-centred (direct) and to move towards a more student-centred (indirect/independent) classroom practice (Kruger, 2002:109) (*cf*. 2.7.2.2, 2.7.2.3). Furthermore, literature revealed that problem-based learning and inquiry-based learning involving the application of the scientific method as independent teaching strategies, promote students' self-directed learning skills (Hmelo-Silver *et al*., 2007:100; Snyder & Snyder, 2008:93) and increase students' critical thinking skills and knowledge acquisition (Spence, 2001:2) (*cf*. 2.7.2.3). Problem-based learning and the scientific method were part of the subject content taught to the Life Science research participants.

Essential to the development and nurturing of critical thinking is the classroom climate created by the teacher. Another issue teachers should be aware of is students' initial resistance to critical thinking (Duron *et al.,* 2006:161). Teachers should create a learning environment conducive to critical thinking (Snyder & Snyder, 2008:96) (*cf*. 2.7.3), characterised by psychological safety, creativity and dialogue, with well-trained teachers using good questioning and technology to support learning (Saavedra & Opfer, 2012:16-21; Snyder & Snyder, 2008:91-96) (*cf.* 2.7.3).

As this research employed a visual learning strategy, the literature study highlighted various types of learning styles, which include visual, auditory, kinaesthetic and learning through reflection (Gilakjani, 2012:105; Gilakjani & Ahmadi, 2011:469; Grosser, 2009:15; Pritchard, 2014:49) (*cf.* 3.3). As effective learning and thinking can be promoted through visual learning (Pritchard, 2014:119-120) (*cf.* 3.2) the following types of visual learning were also explored: Mind Maps, Concept Maps, Graphic Organisers, charts and diagrams (*cf.* 3.4). In comparison to the aforementioned visual strategies, Thinking Maps are regarded as the only visual strategy that scaffolds all the critical cognitive and metacognitive thinking skills and strategies to transform information into knowledge (Hyerle, 2009:151). In addition, literature pointed out that Thinking Maps provide the tools to combine learning with critical and creative meaning-making (Costa, 2009:16; Hyerle 2009:157) (*cf.* 3.5).

Thinking Maps is a teaching and learning strategy which consists of a set of eight visual tools designed to be used during instruction, to help students to develop critical thinking processes and habits (Hyerle & Yeager, 2007:2), across the curriculum, in all grades and in any subject (Hudson, 2013:9) (*cf.* 3.5.3). The Thinking Maps comprise Circle Maps, Bubble Maps, Double Bubble Maps, Tree Maps, Brace Maps, Flow Maps, Multi-Flow Maps and Bridge Maps (Hyerle & Yeager, 2007:24-66) (*cf.* 3.5.3). Thinking Maps are visual representations of cognitive thinking skills such as describing, comparing, categorising, seeing cause-and-effect relationships; analysing part-whole relationships and helping students see their own learning pathway or the thought processes utilised to solve a problem (*cf.* 3.5.3). The Circle Map, the Tree Map and the Multi-Flow Map provide opportunities for acquiring the skills on which the study focused, namely to analyse, synthesise and evaluate (*cf.* 3.5.4-3.5.5). Thinking Maps also enable pathways for thinking, drive and make learning meaningful, allow collaboration and provide students with lifelong thinking tools (Hyerle, 2014:173-174; Hyerle & Yeager, 2007:8-16) (*cf.* 3.5.4).

The following section summarises the major findings that emanated from the empirical research.

7.4 FINDINGS FROM THE EMPIRICAL RESEARCH

7.4.1 Experimental group 1

The researcher derived the following findings from the empirical research in relation to Experimental group 1.

- The pre-test 1 results that focused on Grade 12 Life Science content revealed that the critical thinking skills of the students were fragile and in need of development **($\bar{x}$ = 6.828).**

- The Thinking Maps intervention proved to be effective where participants had to apply critical thinking skills related to Grade 12 Life Science content, as revealed by the improvement in the post-test 1B result, a repetition of pre-test 1. In comparison to the pre-test 1 results **($\bar{x}$ = 6.828)** , the post-test 1B results revealed an improvement, **($\bar{x}$ = 8.897).**
- The critical thinking skills acquired during weeks 1 – 6 of the Thinking Maps intervention were also applied effectively to the context of pre-test 2 that focused on problem-based content and working according to the scientific method that were dealt with during weeks 1 – 6. The results noted for pre-test 2 **($\bar{x}$ = 9.276)** were better than the pre-test 1 and the post-test 1B results.
- The critical thinking skills acquired during weeks 1 – 6 of the Thinking Maps intervention were probably not retained and enhanced in the absence of the intervention during weeks 7 – 12 as low results were noted for post-test 2 **($\bar{x}$ = 6.345).** In addition, post-test 2 only focused on problem-based content that were dealt with during weeks 7-12, and appeared to be difficult for the students to understand, and possibly hampered the application of critical thinking skills. Normal lecturing that took place during weeks 7 – 12 also appeared not to assist the students to apply critical thinking skills effectively to problem-based content, of post-test 2.
- Students appeared to be more effective at applying critical thinking in the context of post-test 2B, a repetition of pre-test 2, that focused on a combination of problem-based content and working according to the scientific method. The results obtained for post-test 2B **($\bar{x}$ = 9.172)** were better that the results obtained for post-test 1 B **($\bar{x}$ = 8.897)**, and although the students had six weeks of lecturing only before writing post-test 2B, the critical thinking skills that they acquired during weeks 1 - 6 of the Thinking Maps intervention, were probably retained and effectively applied and transferred to the content related to problem-based learning and the scientific method of post-test 2 B. It is interesting to note, that the students were not effective at applying critical thinking to the problem-based content of post-test 2. The researcher argues that the difficulty level of the content in post-test 2 might have exceeded the difficulty level of pre-test 2/post-test 2B, and influenced the effectiveness with which the students applied critical thinking in post-test 2.

7.4.2 Experimental group 2

The researcher derived the following findings from the empirical research in relation to Experimental group 2.

- Experimental group 2 performed better that Experimental group 1 at the onset of the study. A comparison of the pre-test 1 results for the two groups revealed the following: Experimental group 1 **($\bar{x}$ = 6.828)** and Experimental group 2 **($\bar{x}$ = 8.444).**

- After normal lecturing during weeks 1 – 6 of the first semester, the post-test 1 results of Experimental group 2 **($\bar{x}$ = 6.963)** were lower that their pre-test 1 results. Normal lecturing appeared to be ineffective for enhancing the critical thinking skills, as the students were seemingly not effective at applying critical thinking to the content of post-test 1 that focused on problem-based learning and working according to the scientific method.
- With post-test 1 B, a repetition of pre-test 1 **($\bar{x}$ = 8.444)** that focused on Grade 12 Life Science content, the students improved again, and achieved higher results than in pre-test s namely **($\bar{x}$ = 9.185).** The researcher assumes that the six weeks of normal lecturing possibly enabled the participants to be effective at applying critical thinking to the Grade 12 Life Science content in post-test 1B.
- The application of critical thinking again appeared to be more effective in the context of pre-test 2 **($\bar{x}$ = 8.815)** after normal lecturing. Pre-test 2 focused on problem-based content and working according to the scientific method that were the the focus of the lecturing during weeks 1 – 6.
- Post-test 2 **($\bar{x}$ = 6.407)** that was written after the six weeks Thinking Maps intervention, revealed results that were lower than pre-test 1, post-test 1, post-test 1 B, pre-test 2 and post-test 2B. Post-test 2 only focused on problem-based content that was dealt with during weeks 7 – 12 when the students received the Thinking Maps intervention. The students appeared to find the application of critical thinking difficult to this content, and apparently the Thinking Maps intervention did not benefit the enhancement of the development of the critical thinking skills
- Post-test 2B that was a repetition of pre-test 2 again indicated that the students were effective at the application of critical thinking in the context of content that combined problem-based learning and working according to the scientific method. It could also be argued that the Thinking Maps possibly had some effect on the effective application of critical thinking in the context of post-test 2B as an increase was noted in the post-test 2B result in comparison to the post-test 2 results.

In relation to Experimental group 1 and 2 (*cf.* Table 6.7, Table 6.8) (*cf.* 6.4.2), the findings strengthened the case that a Thinking Maps intervention can enhance the development of critical thinking skills, which is confirmed by Stedman and Adams (2012:9) (*cf*. 2.3.4), who state that the purposive practise of higher order thinking skills contributes to students becoming capable of improving their critical thinking skills. The findings also confirm the argument of Hyerle and Yeager (2007:10) (*cf.* 3.5.5) that Thinking Maps drive the learning process and make information and learning more meaningful. The researcher aimed to promote indirect and independent learning with the use of the Thinking Maps. However, opportunities for social learning and emotional engagement during the use of the Thinking Maps were probably underscored and could have contributed to a more effective development and retainment of critical thinking skills (Browne & Freeman, 2000:304; Powell & Kalina, 2009:241) (*cf.* 2.7.1.3; 2.7.1.5). Although the findings that emanated from Experiment 1 seem to support the literature where it is argued that direct, passive teaching does not promote the development of critical thinking (Burden & Byrd, 2010:120; Kruger, 2002:109) (*cf*. 2.7.2.1), given the poor post-test 2 result, the improvement subsequently noted in the post-test 2B result could have been attributed to the joint influence of Thinking Maps and normal lecturing.

The findings obtained for Experimental group 1 and 2 also confirm the viewpoint of Stedman and Adams (2012:9) (*cf*. 2.3.4), that with purposive practise a Thinking Maps intervention can enhance the development of critical thinking skills. In addition, the findings also support the argument of Hyerle and Yeager (2007:8-16) (*cf*. 3.5.5) who state that Thinking Maps drive students' learning processes and progress, and improve the development of critical thinking skills.

The researcher noticed the same trends among Experimental groups 1 and 2, namely that after the Thinking Maps intervention (Experimental group 1) and normal lecturing (Experimental group 2) respectively, an increase was noticed in pre-test 2, but not in post-test 1 that was written one week prior to pre-test 2. Improvement for both groups was then again observed in the post-test 1B results, which could imply that the Thinking Maps intervention (Experimental group 1) and the normal lecturing (Experimental group 2) possibly contributed to the increase, not forgetting that the content (Grade 12 Life Sciences) might have been easier for the students and enabled them to apply critical thinking more effectively. It is also interesting to note that the average for post-test 1 was lower than the averages achieved for pre-test 2 in both experiments. The post-test 2B results were again higher than the pre-test 1 results for both Experimental group 1 and 2, the researcher concludes that the Thinking Maps intervention and normal lecturing could have collaboratively contributed to the enhancement of the participants' critical thinking skills noted in the final post-test 2 B results. Although the researcher argues that normal lecturing, as well as the use of Thinking Maps, possibly encouraged some openness towards thinking, more opportunities should be created for emotional engagement with learning and developing critical thinking skills (Browne & Freeman, 2000:304; Howie & Bagnall, 2015: 350; McGonigal, 2005:1) (*cf*. 2.7.1.4; 2.7.1.5).

The pre-test superiority of the control group in Experiment 1 diminished and was eliminated during the fial post-test, post-test 2B. The repetition of pre-test 1 assisted the researcher to assess the selection maturation of the participants (Lodico *et al.,* 2010:246), namely if they were maturing at different rates or at the same rates by observing the change from pre-test 1 to the repetition of pre-test 1 (post-test 1B). Normal maturation could have played a role in the case of Experimental group 1 whose pre-test 1 result **($\bar{x}$ = 6.828)** improved to **($\bar{x}$ = 8.897)** with the repetition of pre-test 1 (post-test 1B). On the other hand, Experimental group 2 entered the research with a pre-test 1 result of **($\bar{x}$ = 8.444**), and only a slight improvement was noted in the repetition of pre-test 1 (post-test 1B), **($\bar{x}$ = 9.185**). This result could imply that the two groups were possibly maturing at different rates.

The research participants did not come from extreme low or high performance groups as evidenced in the pre-test 1 results that could have contributed changes due to statistical regression towards the mean that threatened the internal validity of the study (Lodico *et al.,* 2010:246).

Both Experimental group 1 and 2 did not obtain good results for post-test 2 either, that followed the Thinking Maps intervention for Experimental group 2 and normal lecturing for Experimental group 1. It therefore seems that the problem-based content in post-test 2 and the combination of problem-based content and the scientific method addressed in post-test 1 posed problems to the students, and were probably not well understood, or the difficulty level of post-test 2 and post-test 1 need adjustment and be aligned to the difficulty level of pre-test 2 where the students were more effective at applying critical thinking to problem-based content and content related to the scientific method. In light of the findings for both experimental groups, the researcher argues that if there might have been misconceptions about the problem-based learning content, and content related to the scientific method, this could have influenced the participants' acquisition and application of critical thinking skills negatively (Illeris, 2015:30; Pithers & Soden, 2000:246) (*cf.* 2.6.2).

In light of the findings for both experimental groups, the researcher argues that if there might have been misconceptions about the problem-based learning content, and content related to the scientific method, this could have influenced the participants' acquisition of critical thinking skills negatively (Illeris, 2015:30; Pithers & Soden, 2000:246) (*cf.* 2.6.2). In addition, the participants could have had preconceptions about the subject, which, according to Snyder and Snyder (2008:93), also inhibit critical thinking ability (*cf.* 2.6.3). Given the background of the participants where English is not their home language, it could also be argued that their academic language proficiency possibly inhibited their application of critical thinking (Lun *et al*., 2010:606) (*cf.* 2.6.5). In addition, it appeared that the use of Thinking Maps to promote indirect and independent learning that are regarded as effective for developing higher order thinking (Spence, 2001:3; Rüütman & Kipper, 2011:110; VanGundy, 2005:169-340) (*cf.* 2.7.2.1; 2.7.2.2), probably lacked emphasis on exploration and reasoning to more effectively enhance the critical thinking skills on which the study focused.

In addition, the findings possilby indicate that in the absence of the purposeful practising of critical thinking skills, improvement noticed may not last (Stedman & Adams, 2012:9) (*cf*. 2.3.4). The findings could also point to the absence of important critical thinking dispositions, such as self-confidence in reasoning and systematic working ways that could have influenced the effectiveness with which critical thinking was applied (Pithers & Soden, 2000:242) (*cf.* 2.6.3). More guidance from an teacher might also be required to effectively apply critical thinking when constructing Thinking Maps in the context of problem-based content and the scientific method, where the application of critical thinking appeared to be problematic (VanGundy, 2005:169) (*cf*. 2.7.2.2). The absence of the purposeful use of open-procedural questioning during the Thinking Maps intervention and the exclusive focus on the independent structuring of Thinking Maps could possibly have contributed to the critical thinking skills being enhanced more effectively (Green & Murris, 2014:127; McCollister & Sayler, 2010:43) (*cf*. 2.7.2.3).

The researcher concluded that the six weeks Thinking Maps intervention that purposively focused on improving the practising of higher order thinking skills such as analysis, synthesis and evaluation through the use of Circle Maps, Tree Maps and Multi-flow Maps, possibly contributed to the improvement noted in the post-test 1B and pre-test 2 results of Experimental group 1, and the post-test 2B results of Experimental group 2. This finding is in line with the viewpoint of Pritchard (2014:119-120) (*cf*. 3.2) who states that critical thinking skills can be intentionally taught through Thinking Maps as they promote the effective organisation of information. However, this seemingly does not hold true in the context of some problem-based content, and content related to the application of the scientific method, where apparent misconceptions occurred and learning seemingly did not benefit from the use of Thinking Maps. In addition, insightfulness to express thinking seemed to be absent (Hyerle, 2009:155) (*cf*. 3.4.1). The absence of the explicit teaching of thinking by means of Thinking Maps during the six weeks of normal lecturing and the short implementation of the Thinking Maps intervention support the arguments of Snyder and Snyder (2008:93) and Hyerle (2009:155) that time and purposeful, continuous focus on enhancing critical thinking skills are important prerequisites for sustainable success (*cf*. 2.6.2, 3.4.1). Costa (2009:16) (*cf.* 3.5) supports this argument by indicating that thinking needs to be purposively cultivated and practised. As improved performance was not noted throughout the implementation of the Thinking Maps intervention in some of the test results, namely post-test 1 after the Thinking Maps intervention, and for Experimental group 2 after the Thinking Maps intervention in post-test 2, Hyerle's claim that Thinking Maps provide explicit pathways for thinking that result in improved performance, seems questionable (Hyerle, 2014:169:169) (*cf.* 3.5.5).

The sample means for the construction of the first Thinking Maps during week 1 and 7 for both Experimental groups 1 and 2 respectively, revealed similar results. However, the sample means for **Experimental group 1** clearly indicated that participants obtained improved results for their Thinking Maps from week 2 ($\bar{x}$ = 2.824) to week 6 ($\bar{x}$ = 3.591) (*cf*. 6.6). The researcher assumed that with time the students mastered the ability to make meaning of information, organise the information and acquired a thought process through the use of the Thinking Maps. Costa (2009:16) (*cf.* 3.5) confirms that Thinking Maps teach students how to think and reason. The post-test 1B and pre-test 2 results of Experimental group 1 that followed the Thinking Maps intervention possibly testify to the effectiveness of the Thinking Maps intervention for enhancing the application of critical thinking skills. In addition, the researcher also cautiously argues, that the skills acquired during the Thinking Maps intervention were possibly retained during the six weeks of normal lecturing and enabled the participants to be effective at applying critical thinking in the context of post-test 2 B.

A comparison of the sample means for the construction of Thinking Maps for **Experimental group 2** also revealed improved results from week 8 **($\bar{x}$ = 4.242)** to week 12 **($\bar{x}$ = 4.435)** (*cf.* 6.6). The researcher concluded that the students were able to link the information they were learning to a critical thinking process and this gave them ownership of their learning. This is in line with Hyerle (2014:169) (*cf*. 3.5.5) who states that Thinking Maps give pathways for thinking and students acquire skills and strategies to enhance all elements of critical thinking. However, the improved results in the construction of the Thinking Maps for Experimental group 2 did not correspond with the findings noted for their post-test 2 test results that followed the Thinking Maps intervention. However, their post-test 2B result provided some indication that the Thinking Maps intervention could have assisted them in being more effective at the application of critical thinking skills to the content of post-test 2B.

The findings that emanated from the open questions in the tests indicated that the reasoning of the participants did not comply with the universal intellectual standards of reasoning, and lacked clarity, logic, relevancy, breadth, depth and significance, and seemingly did not improve during the exposure to the Thinking Maps intervention (*cf*. 6.7).

At the onset of the study, the poor (Experimental group 1) to average (Experimental group 2) pre-test results of both experimental groups, seem to support the research findings of Grosser and Lombard, (2008), Lombard and Grosser (2004) and Lombard and Grosser (2008), that critical thinking is apparently not developed at school level. Based on the research findings the students who took part in the study seemingly did not develop good habits of thought during the intervention, but are rather still beginning thinkers who will have to improve their thinking with regular practice (Paul & Elder, 2006:19). Based on the means out of 15 obtained for the various tests, Experimental group 1 seemingly developed from a poor **($\bar{x}$ = 6.828)** to average **($\bar{x}$ =**

9.172) ability in applying critical thinking, and Experimental group 2 seemingly remained at the average ability level **($\bar{x}$ = 8.593)** with which they entered the study **($\bar{x}$ = 8.444)**.

In the next section, the researcher endeavours to revisit the aim and objectives of the study in order to ascertain whether they have been achieved.

7.5 FINDINGS IN RELATION TO THE AIM AND OBJECTIVES OF THE STUDY

The main aim of the study was to determine to what extent first year pre-service Life Science teachers are effective at applying critical thinking skills to analyse, synthesise and evaluate information, and if not, to establish how Thinking Maps can enhance the development of these critical thinking skills among first year pre-service Life Science teachers (*cf*. 1.5).

In order to achieve the main aim, the following objectives were formulated.

Objective 1: To determine what the development of critical thinking skills entails by means of a literature review.

This objective was achieved through a literature review that highlighted a number of aspects. According to Crockett (2015:2), and Saavedra and Opfer (2012:5) (*cf.* 2.3.2), students need to develop their critical thinking skills for success in the 21st century. This research predominately made use of the viewpoints of Facione (2009:6), and Paul and Elder (2006:4) on how critical thinking can develop. They state that "excellence in thought must be systematically cultivated" to enable someone to explain what he/she thinks and to draw conclusions.

For the purpose of the research, the researcher supported the following conceptualisation of critical thinking. In essence critical thinking is defined as being multidimensional in nature (Facione, 2009:5-6), and comprises the following elements: **cognitive skills and metacognitive strategies**, **dispositions/attitudes/habits of mind/behavioural traits**, **intellectual traits**, and universal intellectual standards of reasoning that are applied to the elements of thought (Ennis, 2001:44; Facione, 2009:5, 6; McPeck, 1981:20; Paul, 1993:58; Paul & Elder, 2006:5) (*cf.* 2.2.1 - 2.2.6). All the mentioned dimensions can be developed through purposive efforts to enhance the skills, strategies, dispositions, traits and universal intellectual standards of reasoning (McCollister & Sayler, 2010:42; Pithers & Soden, 2000:243; Qing *et al.*, 2010:4598) (*cf*. 2.2.4).

Objective 2: To determine which critical thinking skills are important for Life Sciences by means of a literature review.

This objective was achieved through a literature study that indicated that the New CAPS supports teaching and learning that nurture the cognitive and metacognitive processes and intellectual dispositions that stand central to effective critical thinking (Department of Basic Education, 2011:4, 5) (*cf*. Table 2.1) (*cf*. 2.3.1).

According to Table 2.2, developing critical thinking in Life Sciences involves the nurturing of three core critical thinking skills in an integrated manner, namely analysis, synthesis and evaluation (*cf*. 2.3.4). Analysis focuses on identifying relationships among information and comparing information to identify similarities and differences. Synthesis involves breaking information down into parts and joining different pieces of information together to constitute a new whole. Evaluation involves judging the value of statements, beliefs, opinions, situations or experiences; making claims about the worth of something and explaining reasons for or motivating claims (Brookhart, 2010:40; Facione, 2009:5, 6) (*cf.* 2.2.2).

Objective 3: To explain what Thinking Maps are by means of a literature review.

This objective was achieved through a literature review that indicated that Thinking Maps are cognitive tools to facilitate the development of specific thinking skills (Hyerle, 2009:151) (*cf*. 3.5.1). In addition, according to Hyerle and Yeager (2007:2) (*cf*. 3.5.2), Thinking Maps is a teaching strategy that consists of a set of eight visual tools designed to help students develop critical thinking processes and habits. Each map represents a specific cognitive process (*cf*. 3.5.3). In this research, the researcher concentrated on the following maps during the intervention: the Circle Map, the Tree Map and the Multi-Flow Map, as these maps provide opportunities for acquiring the skills to analyse, synthesise and evaluate in an integrated manner (*cf*. 3.5.3). The Circle Map enables one to organise and reorganise knowledge, thus applying the skills of analysis and synthesis (*cf.* Figure 1.1). The Tree Map focuses on the skills to analyse and synthesise information by means of classification. The Multi-Flow Map is used for analysing and evaluating cause and effect relationships (Hyerle & Yeager, 2007:24-60) (*cf.* 1.3.3).

Objective 4: To investigate how Thinking Maps can enhance the development of critical thinking skills in Life Sciences by means of a literature review

This objective was achieved through a literature review. To the researcher's best knowledge, no completed research studies have been done which involve pre-service Life Science teachers and establish the effects of Thinking Maps on enhancing the development of critical thinking skills (*cf*. 1.1). According to Hyerle (2014:173-174) and Hyerle and Yeager (2007:8-16) (*cf*.

3.5.4), Thinking Maps can enhance the development of critical thinking skills, because Thinking Maps drive learning, give pathways for thinking about thinking, make learning meaningful, require students to collaboratively access their knowledge and allow for accurate evidence of student performance over time, and encourage depth and breadth in thought. Students who consistently use the same visual pattern for a specific thought process soon have a visual pattern for thinking and become independent learners (Hyerle & Yeager, 2007:8) (*cf*. 3.5). Thinking Maps also help with the chunking of information and seeing connecions between information. Processing information on a Thinking Map moves information into the long-term memory and benefits the understanding of the information (Hyerle & Yeager, 2007:245) (*cf.* 3.5).

Objective 5: To determine how effective first year pre-service Life Science teachers are in applying the critical thinking skills of analysing, synthesising and evaluating by means of a pre-test.

This particular objective was achieved through an empirical study, in which the researcher administered pre-test 1 at the onset of the study. Pre-test 1 indicated that all the student participants appeared to have poor to average developed critical thinking skills that are still fragile and in need of development. Experimental group 1 appeared to be less effective in the application of critical thinking skills, **($\bar{x}$ = 6.828)**, in comparison to Experimental group 2 who obtained an average mean out of 15, **($\bar{x}$ = 8.444)** (*cf.* Table 6.7, Table 6.8). The students appeared to be challenged thinkers who are faced with significant problems in their thinking (Paul & Elder, 2006:19) (*cf.* 2.3.3).

Objective 6: To examine to what extent a Thinking Maps intervention can develop the critical thinking skills of analysing, synthesising and evaluating among first year pre-service Life Science teachers by means of a post-test and the Thinking Maps constructed by the pre-service teachers during the intervention.

This particular objective was achieved through an empirical study, in which the researcher administered post-tests to the first year pre-service Life Science teachers, after their exposure to the Thinking Maps intervention.

Experimental group 1: Experimental group 1 wrote post-test 1 and post-test 1 B (a repetition of pre-test 1) after the completion of a Thinking Maps intervention. The post-test 1 result **($\bar{x}$ = 6.724)** was lower that their pre-test 1 result **($\bar{x}$ = 6.828),** but the post-test 1B result however indicated an improvement **($\bar{x}$ = 8.897)** in comparison to the pre-test 1 and post-test 1 results. The students appeared to be effective at applying critical thinking in post-test 1 B, after the

Thinking Maps intervention. In addition, the pre-test 2 result that followed the Thinking Maps intervention also indicated improvement, **($\bar{x}$ = 9.276**).

Experimental group 2: Experimental group 2 wrote post-test 2 and post-test 2B (a repetition of pre-test 2) after the Thinking Maps intervention. The post-test 2 result **($\bar{x}$ = 6.407)** was lower than the pre-test 2 result **($\bar{x}$ = 8.815),** which indicated that the application of critical thinking possibly did not benefit from the Thinking Maps intervention. In post-test 2B however, improvement was noted **($\bar{x}$ = 8.593)** in comparison to the post-test 2 result **($\bar{x}$ = 6.407)**, but was slightly higher than the pre-test 1 result **($\bar{x}$ = 8.444)**. It could be argued that the Thinking Maps intervention possibly enabled the students to apply the critical thinking skills more effectively to the content of post-test 2B.

This objective as also achieved by assessing the Thinking Maps of the students which they constructed during the Thinking Maps intervention, and played a secondary role in data collection.

The Thinking Maps that were constructed by the students during the Thinking Maps intervention revealed the following regarding the development of the students' critical thinking skills. **Experimental group 1** obtained better and improved results from week 2 **($\bar{x}$ = 2.824)** to week 6 **($\bar{x}$ = 3.591)**, and **Experimental group 2** also obtained better and improved results from week 7 **($\bar{x}$ = 3.167)** to week 12 **($\bar{x}$ = 4.435)**, with the best result noted during week 10 **($\bar{x}$ = 4.657).** The improvement noted in the construction of the Thinking Maps was possibly reflected in the the improved results that Experimental group 1 obtained for post-test 1B, pre-test 2 and post-test 2B. The improved results in the construction of the Thinking Maps for Experimental group 2 however did not align with the findings noted for post-test 2 that followed the Thinking Maps intervention. Improved results were however noted for post-test 2B.

Objective 7: To examine to what extent there will be a difference in the pre- and post-test results of an experimental and a control group regarding the application of critical thinking skills after a Thinking Maps intervention, and in the absence of a Thinking Maps intervention, by comparing the pre-and post-test results of the different groups.

This particular objective was achieved through an empirical study, in which the researcher administered pre- and post-tests to first year pre-service Life Science teachers to establish to what extent a Thinking Maps intervention could enhance the development of their critical thinking skills (*cf.* 6.4, 6.5). Differences between the two groups (*cf.* Table 6.9) that were statistically significant, are reported below.

The researcher observed a mean difference of -1.616 between the **pre-test 1** results of Experimental group 1 and Experimental group 2, with a statistically significant difference of $p < 0.05 = 0.007$, and a medium effect, $d = 0.693$, in practice. Based on the data, it appeared that Experimental group 2 was more capable of applying critical thinking skills than Experimental group 1 at the onset of the research.

It however appeared that the statistical significant differences between the various pre- and post- test results did not occur between the groups, but rather within each of the experimental groups. No statistical significant differences were noted between Experimental group 1 and 2 for any of the comparisons between the different test occasions. It could therefore not be argued that one of the group seemed to have benefitted more from the Thinking Maps intervention or normal lecturing.

The statistical significant differences noted within each of the experimental groups are indicated below.

Experimental group 1 (*cf.* Table 6.7)

A comparison between the means of **pre-test 1 ($\bar{x}$ = 6.828) and post-test 1B ($\bar{x}$ = 8.897),** a repetition of pre-test 1, revealed a statistically significance difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 0.886$. This implied that the post-test 1B results were statistically significantly better than pre-test 1. The participants appeared to be able to transfer the application of the critical thinking skills acquired during the Thinking Maps intervention to the context of post-test 1B effectively.

The sample mean for **post-test 1 ($\bar{x}$ = 6.724) and for post-test 1B ($\bar{x}$ = 8.897)** highlights an increase in the post-test 1B results. The researcher observed a mean difference of -2.172 and a statistically significant difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 0.930$. They students appeared to be more successful in applying the critical thinking skills to the content of post-test 1 B, which was a repetition of pre-test 1 (Grade 12 Life Sciences), than in post-test 1. The researcher concludes that the content of post-test 1 might have been more difficult than the content of post-test 1 B, which possibly influenced the success with which the participants applied critical thinking.

The sample mean for **pre-test 2 ($\bar{x}$ = 9.276)** and **post-test 2 ($\bar{x}$ = 6.345)** reflected a decrease in average for post-test 2. A mean difference of 2.931 with a statistical significant difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 1.066$, was noted. The critical thinking skills acquired during the Thinking Maps intervention were apparently not retained in the absence of the Thinking Maps intervention before writing post-test 2, or the difficulty level of the content hampered the application of the critical thinking skills.

The sample mean for **post-test 2B ($\bar{x}$ = 9.172) and post-test 2 ($\bar{x}$ = 6.345)** highlighted an increase of 19% in the post-test 2B results. The researcher observed a mean difference of 2.827 and a statistically significant difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 1.452$. The participants were seemingly more effective at applying critical thinking skills to problem-based content and content related to the scientific method in post-test 2B, than they were with applying critical thinking skills to the problem-based content in post-test 2. Although post-test 2B was written after six weeks of normal lecturing, the skills which the students apparenty acquired during the six weeks Thinking Maps intervention, were possibly retained and enabled them to be more effective at applying critical thinking to the information in post-test 2B, than what they were in post-test 2.

Experimental group 2 (*cf*. Table 6.8).

A comparison between the means of **pre-test 1 ($\bar{x}$ = 8.444) and post-test 1 ($\bar{x}$ = 6.963)** results revealed a statistically significant difference of $p < 0.05 = 0.002$ with a medium effect in practice, $d = 0.665$. The researcher argues that normal lecturing seemingly did not contribute to enhancing the application of critical thinking skills in the context of post-test 1.

A comparison between the means of **post-test 1 ($\bar{x}$ = 6.963) and post-test 1B ($\bar{x}$ = 9.185)**, a repetition of pre-test 1 that focused on Grade 12 Life Science content, revealed a statistically significant difference between post-test 1 and post-test 1B, $p < 0.05 = 0.000$, with a large effect in practice, $d = 0.931$. Bearing in mind that post-test 1B was a repetition of pre-test 1, the researcher concluded that the six weeks of normal lecturing possibly contributed to the improvement in the students' ability to apply critical thinking skills in post-test 1B (Grade 12 Life Science content).

A comparison of the sample means for **pre-test 2 ($\bar{x}$ = 8.815) and post-test 2 ($\bar{x}$ = 6.407)** indicated a statistically significant difference of $p < 0.05 = 0.000$, and a large effect in practice, $d >= 1.007$. The Thinking Maps intervention that preceded the writing of post-test 2, seemingly did not enable the participants to acquire critical thinking skills that they could effectively apply to the problem-based content of post-test 2.

The sample mean for **post-test 2B ($\bar{x}$ = 8.593) and post-test 2 ($\bar{x}$ = 6.407)** highlighted an average increase of 15% in results. The researcher observed a mean difference of 2.186 and a statistically significant difference of $p < 0.05 = 0.000$ with a large effect in practice, $d = 0.915$. The researcher observed that the participants were more effective at applying critical thinking skills to problem-based content and content related to the scientific method in post-test 2B, than they were with applying skills to the problem-based information in post-test 2, that maily focused on problem-based content. It appears that skills which they acquired through the six weeks

Thinking Maps intervention, enabled them to be more effective at applying critical thinking skills in post-test 2B, than what they were in post-test 2.

Objective 8: To establish to what extent the Thinking Maps intervention contributed to the development of the universal intellectual standards of reasoning when applying critical thinking by means of open questions in the pre- and post-tests.

This particular objective, although it did not directly influence the findings of the research, was achieved through an empirical study. The researcher checked the open responses which the participants provided to motivate their answers to the closed questions in the various tests to gain initial insight into the participants ability to apply the universal intellectual standards of reasoning, namely clarity, accuracy, precision, relevance, significance, depth and breadth (*cf.* 2.2.4).

The results clearly indicated that both of the experimental groups were not very successful in applying the universal intellectual standards of reasoning before and after the Thinking Maps intervention (*cf.* 6.7).

After having reflected on and motivated the extent to which the aim and objectives set out at the onset of the study have been achieved, the researcher is of the opinion that he achieved the aforementioned aim and objectives of the study.

In the following section, the researcher revisits the tentative hypotheses formulated at the onset of the study in order to reject or accept them.

7.6 ACCEPTING OR REJECTING HYPOTHESES

H^0_1: In the context of the study, the null hypothesis, which indicates that there will be no statistically significant difference in the application of critical thinking skills between the pre- and post-test results after completion of the Thinking Maps intervention, is **rejected** and **accepted** for Experimental group 1 and Experimental group 2 (*cf.* Table 6.7, Table 6.8).

Statistical significant differences were noted between the means of the results obtained for **Experimental group 1**, that supported the potential benefits of the Thinking Maps intervention, and therefore the null hypothesis is **rejected.**

Rejection of null hypothesis: Experimental group 1:

- A comparison between **pre-test 1 ($\bar{x}$ = 6.828)** and **post-test 1B ($\bar{x}$ = 8.897)** revealed a statistical significant difference, $p < 0.05 = 0.000$. The researcher concludes that the participants effectively transferred the application of the critical thinking skills acquired during the Thinking Maps intervention to the context of post-test 1B, and that the improvement in the post-test 1B results was not due to chance. In addition, the critical thinking skills acquired during the Thinking Maps intervention were probably retained.

Acceptance of null hypothesis: Experimental group 1

The **null hypothesis** is **accepted** in the context of **Experimental group 1** as no statistical significant differences were noted between the pre-test 1 and post-test 1 results after the implementation of the Thinking Maps intervention.

- A comparison between **pre-test 1 ($\bar{x}$ = 6.828)** and **post-test 1 ($\bar{x}$ = 6.724)** that was written after the Thinking Maps intervention did not reveal a statistical significant difference, $p > 0.05 = 0.840$. The results of post-test 1 were lower than the results of pre-test 1.

Acceptance of null hypothesis: Experimental group 2

- The null hypothesis is accepted for **Experimental group 2**, as the statistical significant differences noted between **pre-test 2 ($\bar{x}$ = 8.815)** and **post-test 2 ($\bar{x}$ = 6.407)** after the Thinking Maps intervention, $p < 0.05 = 0.000$, indiated that the pre-test 2 results before the Thinking Maps intervention were better that the post-test two results after the Thinking Maps intervention.
- A comparison between **pre-test 2 ($\bar{x}$ = 8.815)** and **post-test 2B ($\bar{x}$ = 8.593)** that was written after the Thinking Maps intervention did not indicate a statistical significant difference, $p > 0.05 = 0.490$. Lower results were noted for post-test 2B that was written after the Thinking Maps intervention.

H^a_1: In the context of the study, the alternative hypothesis, which indicates that there will be a statistically significant difference in the application of critical thinking skills between the pre- and post-test results of participants after completion of the Thinking Maps intervention, is **accepted** as there were statistical differences noted between the means of the results obtained for teaching with the Thinking Maps intervention (*cf*. 6.7) for Experimental group 1.

Acceptance of alternative hypothesis: Experimental group 1

- A comparion between **pre-test 1 ($\bar{x}$ = 6.828) and post-test 1B ($\bar{x}$ = 8.897),** revealed a statistical significant difference, $p < 0.05 = 0.000$. The researcher concludes that the participants effectively transferred the application of the critical thinking skills acquired during the Thinking Maps intervention to the context of post-test 1B, and that the improvement in the post-test 1B results was not due to chance.

H^0_2: In the context of the study, the null hypothesis, which indicates that there will be no statistically significant difference in the application of critical thinking skills between the pre- and post-test results after normal classroom lecturing (in the absence of teaching with Thinking Maps), is **accepted** as there were no statistical significant differences between the means of the results obtained by **Experimental group 1 and 2** (*cf*. Table 6.7, Table 6.8) after normal classroom lecturing.

Acceptance of null hypothesis: Experimental group 1 (*cf.* Table 6.7)

- The sample mean for **pre-test 2 ($\bar{x}$ = 9.276)** and for **post-test 2 ($\bar{x}$ = 6.345)** reflected a decrease in average for post-test 2. A mean difference of 2.931 with a statistical significant difference of $p < 0.05 = 0.000$, was noted. Normal lecturing that preceded post-test 2 did not enhance the application of critical thinking skills, and the statistical significant difference noted between pre-test 2 and post-test 2 indicated that the pre-test 2 results obtained before normal lecturing was better that the post-test 2 results that followed normal lecturing.
- Similarly, a comparison between the **pre-test 2 ($\bar{x}$ = 9.276)** and the **post-test 2B ($\bar{x}$ = 9.172)** results did not indicate a statistical significant difference, $p > 0.05 = 0.837$. The post-test 2 B results that were obtained after the Thinking Maps intervention were lower than the pre-test 2 results, and the application of critical thinking in post-test 2B apparently did not benefit from normal lecturing.

Acceptance of null hypothesis: Experimental group 2

- A comparison between **pre-test 1 ($\bar{x}$ = 8.444)** and **post-test 1 ($\bar{x}$ = 6.963)** revealed a statistical significant difference, $p < 0.05 = 0.002$ for pre-test 1 that was written at the onset of the study. The application of critical thinking skills therefore did not benefit from normal lecturing that preceded post-test 1 B, and the null hypothesis is therefore accepted.
- A comparison between **pre-test 1 ($\bar{x}$ = 8.444)** and **post-test 1 B ($\bar{x}$ = 9.185)** did not reveal a statistical significant difference, $p > 0.05 = 0.174$. The application of critical thinking skills did not benefit from normal lecturing that preceded post-test 1 B, and the null hypothesis is therefore accepted.

H^a_2: In the context of the study, the alternative hypothesis, which indicates that there will be a statistically significant difference in the application of critical thinking skills between the pre- and post-test results after normal classroom lecturing (in the absence of teaching with Thinking Maps), is **accepted** as there were statistically significant differences between the means of the results obtained for normal classroom lecturing with **Experimental group 2** (*cf*. Table 6.8).

Acceptance of alternative hypothesis: Experimental group 2

- A comparison between the means of **pre-test 1 ($\bar{x}$ = 8.444) and post-test 1($\bar{x}$ = 6.963)** results revealed a statistically significance difference of $p < 0.05 = 0.002$. However, the pre-test 1 results at the onset of the study, were better that the post-test 1 result after normal lecturing. The researcher concluded that normal lecturing did not contribute to enhancing the application of critical thinking skills in the context of post-test 1 that was written after normal lecturing.

The following section addresses recommendations that flow from the literature study and the empirical research.

7.7 RECOMMENDATIONS

In the light of the empirical and literature review findings, the researcher recommends the following in order to enhance the development of the critical thinking skills analysis, synthesis and evaluation among first year pre-service Life Science teachers through the use of Thinking Maps.

7.7.1 Recommendations: Enhancing critical thinking

The specific problems revealed by the data pertaining to the pre-test and post-test results for Experimental group 1 and 2 include:

- A limited (Experimental group 1) to average ability (Experimental group 2) to apply critical thinking skills to Gr. 12 Life Science subject content (Grosser & Lombard, 2008:1364) (*cf*. 6.4.2-6.4.3) at the onset of the study.
- An inability to provide valid reasons to motivate answers in open-ended test questions that complied with the universal intellectual standards of reasoning, namely clarity, accuracy, precision, relevance, significance, depth and breadth (*cf*. 2.2.4, 6.7).
- Both groups of students appeared to be functioning as challenged thinkers who need more exposure to become practising thinkers (Paul & Elder, 2006:19) (*cf*. 2.3.3).

Specific recommendations to address these problems include:

- Students need to acquire the ability to think critically and analytically, which includes proficiency in comparing, contrasting, evaluating and synthesising information (Saavedra & Opfer, 2012:5) (*cf*. 2.3.2). The researcher suggests that in addition to using Thinking Maps as a teaching strategy, **problem-based learning** and working according to **the scientific method** should also purposively be emphasised to practise the specific critical thinking skills of analysis, synthesis and evaluation (Hmelo-Silver *et al*., 2007:100, Snyder & Snyder, 2008:92) (*cf.* 2.7.2.3). Problem-based learning and working according to the scientific method create opportunities for discovery of information, improves argumentation and nurture open-mindedness that are essential for developing critical thinking skills and dispositions (*cf.* 2.7.2.3). Problem-based learning and working according to the scientific method are useful to nurture and apply cognitive and metacognitive critical thinking skills and strategies such as interpretation, analysis, evaluation, making inferences, explanation and self-regulation (Spence, 2001:3) (*cf.* 2.7.2.3). Although problem-based content and working according to the scientific method were addressed during Thinking Maps intervention, no explicit focus was placed on assisting learners to make meaning of the subject content by using and practising the steps in problem-solving and the scientific method (*cf.* Table 2.9, Figure 2.5), but rather to make meaning of the subject content by using Thinking Maps. Combining the steps in problem-solving and the scientific method to make meaning of information, in addition to the Thinking Maps to organise and synthesise information, might have been more effective in developing the critical thinking skills, and making meaning of subject content. Literature reveals that problem-based learning and inquiry-based learning involve the application of the scientific method as an independent teaching strategy, that promotes students' self-directed learning skills (Hmelo-Silver *et al*., 2007:100; Snyder & Snyder, 2008:93) and increases students' critical thinking skills and knowledge acquisition (Spence, 2001:2) (*cf*. 2.7.2.3).

- Problem-based learning and working according to the scientific method, that was the focus of the content that the researcher dealt with during the twelve week intervention, could possibly have benefitted more if the **Flow Map** was included as a strategy to master the understanding of the subject content. The Flow Map specifically addresses learning content that involves sequencing and stages of events that characterise problem-based learning and working according to the scientific method (Hyerle & Yeager, 2007:54) (*cf*. 3.5.3.6).
- If teachers purposively and persistently, in addition to the use of Thinking Maps, practise higher order thinking skills for example dealing in class with **real-world problems, performing projects, investigations** and **inquiry-oriented experiments**, and encouraging open-ended class discussions, there is a good chance for the consequent development of critical thinking skills (Spence, 2001:41-45; Stedman & Adams, 2012:9) (*cf*. 2.3.4; 2.7.1.5).
- Another issue that could have hampered the students' application of critical thinking is a possible **resistance** to engage in critical thinking (Duron *et al.,* 2006:161), due to the content-driven nature of Life Sciences, and time constraints to complete the Life Science curriculum. A stronger **awareness** should therefore be created regarding the merits of teaching critical thinking skills in the classroom to achieve the Life Science objectives (Saavedra & Opfer, 2012:7) (*cf*. 2.6.2). Furthermore, the importance of being trained to

guide learners to apply critical thinking skills, should be emphasised (Lombard & Grosser, 2004:213; Walsh & Paul, 1986:49) (*cf*. 2.4 - 2.4.2).

- Emphasis should also be placed on developing critical thinking **dispositions/behavioural traits** and **intellectual traits** that qualify good thinking, for example developing a command over the own thought process, confidence in reasoning, empathy, perseverance and courage to formulate own rational viewpoints (Paul & Elder, 2006:16, 17) (*cf.* 2.2.3, 2.2.6).
- Opportunities should also be created to assist students to master the skill to question information, make inferences and consider the consequences of their reasoning (Paul & Elder, 2006, 6, 7) (*cf.* 2.2.5).

7.7.2 Recommendations: Using Thinking Maps as a teaching strategy

The specific problems revealed by the data pertaining to the assessment of Thinking Maps include:

- The pre-service teachers seemingly need time to master the ability to make meaning of problem-based subject content as well as content related to working according to the scientific method with appropriate Thinking Maps, as evidenced in the poor post-test 1 and post-test 2 results (*cf*. 6.6). The students appeared to be effective at applying critical thinking skills in relation to the problem-based content and content that focused on working according to the scientific method of post-test 2 B, and pre-test 2 as well as in the context of post-test 1 B (pre-test 1) that focused on Grade 12 Life Science content.
- The six week Thinking Maps intervention might have been too short to acquire and practise the application of critical thinking skills so that they are retained successfully (*cf.* 6.4).

Specific recommendations include:

- The literature supports the notion that memorisation of subject content and an teacher-centered teaching approach do not promote or support the development of critical thinking (Duron *et al.,* 2006:96; Snyder & Snyder, 2008:91) (*cf*. 2.7.3), which was supported by the findings of the research. Teachers therefore need to be trained to guide learners to apply critical thinking skills (Lombard & Grosser, 2004:213; Walsh & Paul, 1986:49) (*cf*. 2.4) through the choice of teaching strategies (*cf.* 2.7.2). The use of Thinking Maps as a teaching strategy to foster independent learning (Arsal, 2015:141; Gebhart *et al.*, 2012:4; Hofstein *et al.,* 2001:193) (*cf.* 2.7.2.3) that would benefit the development of critical thinking is highlighted in the literature (Hudson, 2013:9) (*cf*. 3.5.2). The researcher however observed that the application of Thinking Maps as a teaching strategy purely to promote independent learning did not provide sufficient opportunities to acquire and develop critical thinking skills.

The following suggestions could enhance the use of Thinking Maps for developing critical thinking.

- Opportunities for **emotional engagement** during learning (Browne & Freeman, 2000:304) (*cf.* 2.7.1.5) that involves interaction, collaborative learning and meaning-making among students (Powell & Kalina, 2009:241, 242; Slavin, 2003:61) (*cf*. 2.7.1.3) as well as voicing and sharing opinions, should be created (Burden & Byrd, 2010:151; Gawe, 2008:209; Howie & Bagnall, 2015; 350) (*cf*. 2.7.1.4; 2.7.2.4). Including opportunities for emotional engagement during the construction of Thinking Maps might be more beneficial to developing critical thinking skills than mainly emphasising students' independent construction of Thinking Maps. The researcher therefore argues that a combination of independent learning (*cf*. 2.7.1.3) and **collaborative/interactive learning** (*cf.* 2.7.1.4) might be more effective to enhance the development of critical thinking skills. The use of Thinking Maps as an independent strategy to learn, should be combined with opportunities to engage in collaborative discovery and meaning-making of information that is an important prerequisite for developing thinking (Vygotsky, 1978:84) (*cf.* 2.7.1.3).
- The lack of **self-reflection** opportunities during the Thinking Maps intervention possibly constrained understanding of subject content. Opportunities to become aware of own assumptions that could constrain understanding (Mezirow, 1991:167) (*cf.* 2.7.1.4) and careful consideration of information before conclusions are made (Pritchard, 2014:48) (*cf.* 3.3.5) need to be created in conjunction with the use of Thinking Maps to enhance the development of critical thinking. For this purpose, the researcher acknowledges that he should have placed more emphasis on the **Frame of Refence** around each of the Thinking Maps (*cf.* 3.5.3.9) that promote self-reflection and metacognitive thinking (explaining one's own thought process).
- More attention should be given to constructive **feedback** to students about their Thinking Maps to enhance the quality of student learning and allow teacher and students to engage in dialogue to discuss criteria and standards to which the Thinking Maps need to comply (Duron *et al*., 2006:161-163), as well as learn from one another in order to extend and adapt their Thinking Maps.
- The findings of the study also made the researcher aware that the construction of Thinking Maps should be accompanied by open **questioning** to effectively enhance the development of critical thinking (Green & Murris, 2014:127; McCollister & Sayler, 2010:43)(*cf*. 2.7.2.3). In the context of the study, the participants were responsible for making decisions in relation to the choice of Thinking Maps that would capture their understanding of the content and the cognitive processes underlying the Life Science content taught independently, thus placing students in control of their own learning and

thinking (Rüütman & Kipper, 2011:110; VanGundy, 2005:69:169-130) (*cf.* 2.7.2.2). The purposeful use of open questioning during the construction of the Thinking Maps could have extended the participants' opportunities to apply thinking skills, enhanced specific thinking skills and addressed inquiry (McCollister & Sayler (2010:43), thus raising the thinking level during teaching and learning (*cf*. 2.7.2.3). Clarifying questions could have checked for the understanding of content and reasoning questions could have alerted participants to the application of the universal intellectual standards of reasoning (clarity, logic, significance, relevance, depth, breadth) that appeared not to be well developed. (Green & Murris (2014:127) (*cf*. 2.7.2.3). In addition, reasoning questions, inquiry questions, creative questions and evaluative questions could have benefited the development of the specific skills on which the study focused, namely analysis, synthesis and evaluation. The latter questions would have provided additional opportunities for the participants to probe information, connecting different pieces of information, exploring implications of decisions and summarising information, that could have benefited the development of their critical thinking skills and the development of the universal intellectual standards of reasoning (*cf.* Table 2.10).

- The researcher argues that the effectiveness of Thinking Maps for enhancing the application of critical thinking in problem-based content and content related to the scientific method, could be enhanced by including **teamwork**, communication and sharing of ideas, and discussions about subject content during the construction of Thinking Maps (Snyder & Snyder, 2008:96; Spence, 2001:4-5) (*cf.* 2.2.3, 2.7.2.3). The researcher is of the opinion that a lack of dynamic relationships between the lecturer (researcher) and students during the Thinking Maps intervention to engage in discussions about the learning content to promote the development of important critical thinking dispositions such as, open-mindedness, to evaluate different possible options to solve a problem or answer a question, possibly hampered the effective development of critical thinking skills (Brown & Brown, 2015:136); McGonigal, 2005:1) (*cf.* 2.7.1.4).
- The use of Thinking Maps alone as an independent teaching strategy, lacked focus on **inquiry, formulating questions**, **investigating, looking for alternatives** and **exploring** possible anwers, which are regarded as important activities for developing critical thinking (Qing *et al.,* 2010:4598) (*cf.* 2.7.2.3).
- As students have different **learning style preferences**, auditory, kinaesthetic and reflective learning combined with visual learning, might be more effective in enhancing the development of critical thinking skills (Gilakjani, 2012:1105; Gilakjani & Ahmadi, 2011:469) (*cf.* 3.3).

- Universities and other Higher Education institutions need to introduce Thinking Maps into their curricula to expose pre-service teachers to a valuable strategy that could enhance the development of critical thinking.

Given the aforementioned recommendations that were based on the researcher's evaluation of the Thinking Maps intervention, the researcher formulates his view on a classroom conducive to the development of critical thinking in Life Sciences.

7.7.3 Researcher's view of classrooms conducive to the development of critical thinking

After the twelve week Thinking Maps intervention, the researcher envisages to adapt the intervention by including some of the strategies and activities mentioned in the previous section.

On completion of the intervention and considering the findings that were obtained with the research, the researcher formulates the following view on teaching Life Sciences to enhance the development of critical thinking. Figure 7.1 indicates the different stages through which the teaching and learning in Life Scieces should progress.

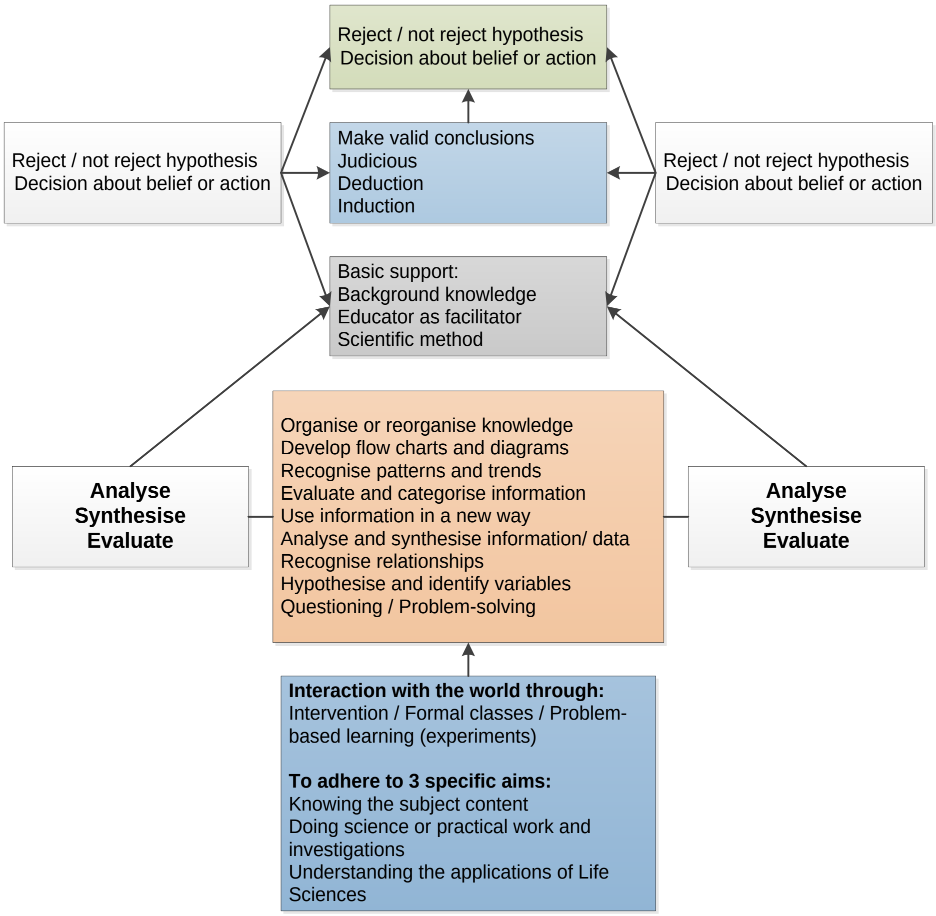


Figure 7.1: A visual representation of the development of critical thinking in Life Sciences as conceptualised by the researcher

The cognitive and metacognitive processes, as well as intellectual dispositions/traits and universal intellectual standards of reasoning that are important for critical thinking (cf. 2.2.2 – 2.2.6), are embedded in the learning outcomes. According to the CAPS Life Sciences, Grades 10-12, there are three broad subject-specific aims which relate to the purpose of learning science, namely knowing the subject content, doing science or practical work and investigations and understanding the applications of Life Sciences. To achieve the aforementioned aims, learners must possess well developed dispositons/behavioural traits and intellectual traits to be able to apply cognitive and metacognitive critical thinking skills and strategies effectively. It is clear from the aforementioned that the critical thinking skills to analyse, synthesize and evaluate, as conceptualised by the researcher, are particularly important to achieve the objectives of the curriculum.

- Many students are still exposed to teachers who lecture using the “old school” teaching strategies; students are passive and teachers use lectures and textbooks only to convey knowledge and information (Duron *et al*., 2006:161). However, this teacher-centered approach does not encourage or provide opportunities to enhance the development of critical thinking skills (Duron *et al.,* 2006:161).
- Based on the preceding discussions in Chapter 2 of the direct, indirect, independent and interactive teaching methods, the researcher is of the opinion that the following 5-step model, Figure 2.7, proposed by Duron *et al.* (2006:161), could be implemented in conjunction with the Thinking Maps as an approach to enhance the development of critical thinking.

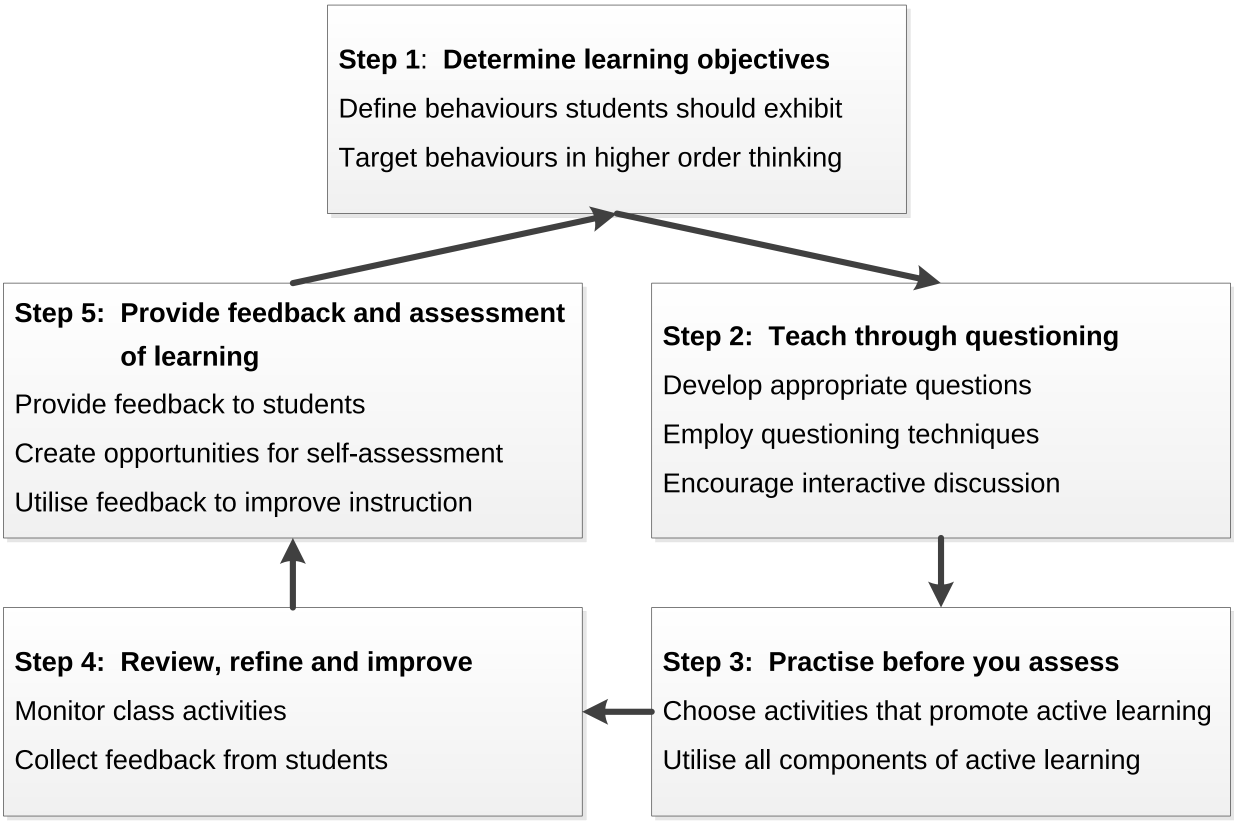


Figure 7.2: Five-step model to move students towards critical thinking (Duron *et al*., 2006:161)

- Step 1: **Determine learning objectives:** The learning objectives, activities and assessments must include the development of thinking at appropriate levels of Bloom's taxonomy, namely remember, understand, apply, analyse, evaluate and create (Anderson & Krathwohl, 2001:13).
- Step 2: **Teach through questioning:** Questions should be asked to stimulate interaction between teacher and students; to challenge the students to defend their ideas and understandings and engage students in collaborative work, whilst constructing Thinking Maps.
- Step 3: **Practise before you assess:** Choose activities which involve the students in thinking about what they are doing (self-reflection). Activities should include experiential and inquiry-based learning as well as opportunities to reflect. For this purpose, the Frame of Reference drawn around each Thinking Map could be utilized effectively (*cf.* 3.5.3.9).
- Step 4: **Review, refine and improve:** Teachers should use teaching strategies that will develop critical thinking skills, such as Thinking Maps.
- Step 5: **Provide feedback and assessment of learning:** Feedback will enhance the quality of student learning and allow teacher and students to engage in dialogue to discuss criteria and standards (Duron *et al*., 2006:161-163).

Linked to the 5-Step Model above, the researcher suggests the following to create classrooms conducive to the development of critical thinking:

- Teachers should be well trained and informed about what good critical thinking skills are and acquire skills to develop critical thinking skills, strategies, dispositions/traits and universal intellectual standards of reasoning within students. An teacher is an agent of change. Teachers therefore need to be guided on how to infuse critical thinking into their daily lessons; be able to model good critical thinking practices and create activities that promote the use of critical thinking among their learners (Uksw, 2014:161).
- Creating a learning environment where students should feel comfortable and are allowed time to think through an answer rather than simply having an answer. Teachers should make use of peer coaching strategies and participative learning (*cf*. Tables 2.9 & 2.10) to engage students in active learning and critical thinking opportunities (Browne & Freeman, 2000:302; Snyder & Snyder, 2008:96) (*cf.* 2.7.2.4).
- Using effective teaching methods, strategies (*cf*. Tables 2.6 - 2.11): The literature supports the notion that memorisation of subject content does not promote or support critical thinking (Snyder & Snyder, 2008:91). However, some content, such as definitions, morphological and physiological information, must be memorised to enable the student to develop a strong knowledge base which is regarded as a prerequisite for being effective at applying critical thinking skills. The subject Life Sciences lends itself to inquiry-based teaching which guides students through the critical thinking process by using the scientific method and problem-based learning (Arsal, 2015:241) (*cf.* 2.7.2.3). Combining the use of Thinking Maps with explicit emphasis on working according to a problem-based approach and according to the scientific method could advance the application of critical thinking skills through engaging students in inquiry, explaining and reasoning (Hmelo-Silver *et al.,* 2007:100; Hofstein *et al.,* 2001:193; Snyder & Snyder, 2008:93) (*cf.* 2.7.2.3).
- Teachers should ask good questions to stimulate students' critical thinking (Green & Murris, 2014:127) (*cf.* 2.7.2.3). According to Saavedra and Opfer (2012:19), questioning strategies should be integrated in class discussions to engage students actively in the learning process. Duron *et al.* (2006:162) and Paul and Elder (2006:4) argue that good questions will accelerate a student's movement into critical thinking.
  - The use of critical questioning (why, what and how), during instruction or in assessment tasks, requires students to evaluate the clarity and accuracy as well as the depth and breadth of their thinking (intellectual standards). By questioning their thought processes, students begin thinking about their thinking (metacognitive) skills (Snyder & Snyder, 2008:91).
  - Wait for student responses; critical thinking requires time and patience.

- Use review questions (tests and assignments) to enhance students' processing skills and explanations of correct answers by modelling the critical thinking process (Saavedra & Opfer, 2012:19).
- Assessment should emphasise critical thinking rather than facts (Snyder & Snyder, 2008:95).

- Using dialogue in education: Involvement in dialogue requires the application of a number of critical thinking skills and strategies, dispositions/behavioural traits such as humility, empathy, integrity, perseverance, open-mindedness, and the universal intellectual standards of reasononing such as being logical and analytical (*cf*. 2.2). Green (2014:147) states that being involved in dialogue is not simply a discussion about issues, but also involves making sense of different perspectives and producing new insights.
- Exploiting technology to support learning: Technology provides students with new ways to develop their problem-solving, critical thinking and communication skills. In the process they address misunderstandings, reflect on their thinking and collaborate with their peers (Saavedra & Opfer, 2012:16).
- Fostering students' creativity: Teachers can enhance students' creativity, the cognitive ability to produce new and valuable ideas (Saavedra & Opfer, 2012:17).
- Teachers must be reflective practitioners: Being reflective indicates teachers' abilities to adjust to change, to overcome barriers of learning and teaching in the classroom and to reflect on quality of learning and teaching in the classroom (Saavedra & Opfer, 2012:21).

Classrooms that are alive with critical thinking will encourage commitment to think critically and frequent self-reflection to gain new knowledge and encounter new perspectives (Browne & Freeman, 2000:307).

7.8 LIMITATIONS OF THE STUDY

A number of limitations were identified while conducting the research, which can be identified as the following:

- The study was not a true experiment, rather a quasi-experiment with a limited number of participants, and could not link all possible variables to cause and effect.
- The researcher focused only on the critical thinking abilities of first year pre-service Life Science teachers. This limits the study because deeper insights could have been gained from studying the entire Life Science group.

- Participants from only one university, who were conveniently sampled due to time and logistical constraints were used, and therefore the findings cannot be generalised to pre-service teachers of other universities.
- Focus was placed on only one subject, namely Life Sciences. This limits the generalisability of the findings with regard to other subjects when it comes to the enhancement of critical thinking skills.
- The researcher primarily focused only on a selection of three core critical thinking skills, namely analysis, synthesis and evaluation. This limits the study because deeper insights could have been gained by studying all the elements of critical thinking skills, namely the cognitive and metacognitive critical thinking skills, dispositions/intellectual traits and the universal intellectual standards of reasoning in their interrelatedness in depth.
- As the researcher aimed to promote indirect and independent learning with the use of the Thinking Maps, opportunities for social learning and emotional engagement during learning were probably underscored that could have enhanced the development and retainment of critical thinking skills (Browne & Freeman, 2000:304; Powell & Kalina, 2009:241) (cf. 2.7.1.3; 2.7.1.5).
- Finer trends in the data could have been disovered with cross comparisons between all the different tests and the various test items that addressed analysis, synthesis and evaluation respectively, and to establish the effect of the intervention over time, by using an Analysis of Variance test.
- Including a qualitative dimension in the study, for example interviews with the participants after the Thinking Maps intervention, could have provided richer data to explain the participants experiences with the Thinking Maps.
- The two Thinking Maps interventions were not exactly the same in terms of the subject topics on which they focused, and the researcher acknowledges that this could have influenced the research findings.

7.9 SUGGESTIONS FOR FURTHER RESEARCH

The following suggestions are made for further research studies in the field of enhancing critical thinking skills.

- A true experimental study with larger groups that combine quantitative and qualitative research could be attempted to obtain conclusive evidence about the effect of Thinking Maps as teaching strategy to enhance critical thinking.

- A similar study can be done using the entire Life Science group (year 1 to 4) at the same university to investigate any differences picked up in the different year-groups in relation to the development of critical thinking. Such a study could focus on addressing deficient or fragile critical thinking skills at first year level throughout the four years of study, and the development of the skills could then be continuously assessed to determine the retention and transferability of the critical thinking skills.
- Conducting experiments that discover finer trends in the data by doing cross comparisons between all the different tests as well as between the various test items that addressed analysis, synthesis and evaluation respectively, to establish the effect of the intervention over time, and to establish which of the critical thinking skills probably benefitted the most or the least form involvement in a Thinking Maps intervention, by using an Analysis of Variance test.
- The same study can be done using participants from other universities to employ comparative studies in relation to the development of critical thinking skills with pre-service teachers in different contexts.
- The same study can be carried out in different subjects as well, in order to understand the status quo and the development of critical thinking skills across a range of subjects.
- The same study can be carried out to explore the status quo in relation to all the interrelated elements of critical thinking and how the multi-dimensional nature of critical thinking can be enhanced.
- Standardised, subject-related tests in Life Sciences can be designed to establish the development of critical thinking in various school phases and grades.
- The effectiveness of Thinking Maps for different types of subject content needs to be explored in greater depth.
- The extent to which normal lecturing and Thinking Maps contribute to the development of critical thinking also needs to be explored in greater depth.

7.10 CONTRIBUTIONS OF THE STUDY

Many international and national studies have been done regarding the nurturing of critical thinking skills in several subjects, except Life Sciences. This exploratory pilot study highlights possible problem areas in relation to enhancing critical thinking skills in first year pre-service Life Science teachers, and therefore paves the way for further research in this field, with the aim of developing a programme that could lead to the enhancing of critical thinking skills in Life Sciences.

The present research contributes to theory regarding the nurturing of critical thinking at pre-service teacher level, and revealed the latent benefits and pitfalls when using Thinking Maps as a teaching strategy for enhancing the development of critical thinking. A lack of dynamic relationships between lecturer (researcher) and students during the Thinking Maps interventions to engage in discussions about the learning content that promote open-mindedness to evaluate different possible options to solve a problem or answer a question, possibly hampered the effective development of critical thinking skills (Brown & Brown, 2015:136); McGonigal, 2005:1) (*cf.* 2.7.1.4) by exclusively emphasising the independent nature of the learning process.

The findings of the present study extends the findings of research studies that focused on the merits of Thinking Maps to pre-service teachers. Previous research mainly emphasises with young learners, that reported the ineffectiveness of Thinking Maps to enhace achievement among young learners (Hudson, 2013; Sunseri, 2011; Russell, 2010) (*cf.* 1.1).

The participants in this research possibly benefitted as they might have acquired critical thinking skills with Thinking Maps, to enable them to start analysing, synthesising and evaluating information more effectively, which could improve their academic performance. Furthermore, the findings could be utilised to make recommendations regarding the improvement of the teaching practices of Life Science teachers in order to enhance critical thinking skills in school classrooms.

7.11 CONCLUSIONS

Critical thinking is of the utmost importance in education as it has been identified as an important objective in the CAPS. In addition, critical thinking is not only an academic skills but a survival skill needed in the 21st century to make one's way through life and cope with challenges.

Life Science teaching needs to emphasise the importance of critical thinking to help learners acquire cognitive and metacognitive skills and strategies, dispositions/intellectual traits and the standards of reasoning to cope in a changing 21st century environment. Therefore, the teaching of Life Sciences should implement teaching strategies, like Thinking Maps, to promote critical thinking that could benefit academic performance and equip students with life skills.

This research creates an awareness of possible limitations embedded in the teacher-training programmes that need to be addressed. What the findings revealed is that the most important challenge facing education at all levels of teaching appears to be an intellectual and practical one. Firstly, strategies have to be identified to improve the quality of pre-service teachers' critical thinking. Secondly, pre-service teachers have to be supplied with a repertoire of strategies to advance the development of the minds of learners whom they will teach. Placing a stronger focus on enhancing critical thinking at pre-service teacher level could assist pre-service teachers themselves to become effective critical thinkers who are empowered to promote skilled reasoning and intellectual self-discipline as well as self-reflective, self-directed, self-monitored and self-corrective thinking among school learners.

BIBLIOGRAPHY[4]

Akyüz, H.I., & Samsa, S. 2009. Critical thinking skills of pre-service teachers in the blended learning environment. *International journal of human sciences*, 6(2):538-550.

Allamnakhrah, A. 2013. Learning critical thinking in Saudi Arabia: Student perceptions of secondary pre-service teacher education programme. *Journal of education and learning*, 2(1):97-210.

Anderson, J. 2010. Succeeding with habits of mind: Developing infusing and sustaining the Habits of Mind for a more thoughtful classroom. Australia: Hawker Brownlow Education.

Anderson, L.W. & Krathwohl, D.R. 2001. A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives. New York: Longmans.

Arencibia, D.E. 2013. The effects of merging technology and thinking skills in the classroom. Minneapolis, Minnesota: Walden University. (Dissertation – PhD).

Arends, R.I. 2004. Learning to teach. 8th ed. Boston: McGraw-Hill.

Arsal, Z. 2015. The effects of microteaching on the critical thinking dispositions of pre-service Teachers. *Australian journal of teacher education,* 40(3):140-150.

Ausubel, D. 1978. In defence of advanced organizers: A reply to the critics. *Review of educational research*, 48:151-257.

Avia, N. 2010. Grade 10 Life Science teachers understanding the development of critical thinking skills in selected schools in Namibia. Grahamstown: Rhodes University. (Dissertation – MEd).

Beyer, B.K. 1983. Common sense about teaching thinking skills. *Educational leadership,* 41(3):44-49.

Beyer, B.K. 1995. Critical thinking. Bloomington, Indiana: Phi Delta Kappa Educational Foundation.

[4] The researcher reflects all the sources utilised during the completion of the study, and not only the quoted sources. For this purpose he compiled a bibliography and not a reference list.

Borich, G.D. 2003. Observation skills for effective teaching. 4th ed. New York: Merrill Prentice Hall.

Borich, G.D. 2007. Effective teaching methods: research-based practices. 6th ed. Upper Saddle River, N.J.: Pearson/Merrill Prentice Hall.

Botha, J. 2004. A design for the development of critical and creative thinking skills during the presentation of a web-based course. Johannesburg: University of Johannesburg. (Thesis – DEd).

Boucher, M.J. 2010. Maps: Developing critical thinking skills for deaf students in a social studies. San Diego: University of California. (Thesis – master of Arts).

Brace, I. 2008. Questionnaire design: How to plan, structure and write survey material for effective market research. 2nd ed. London: Kogan Page.

Brookfield, S.D. 2012. Teaching for critical thinking: tools and techniques to help students question their assumptions. San Francisco: Jossey-Bass.

Brookhart, S.M. 2010. How to assess higher-order thinking skills in your classroom. Alexandria, Virginia: ASCD

Brown, P.P., & Brown, C.S. 2015. Transformative learning theory in Gerontology: Nontraditional students. *Educational gerontology*, 41:136-148.

Brown, S. 2008. Measures of shape. Skewness and kurtosis.

http://www/tcs.edu/instruct/sbrown/stat/shape.htm Date of access: 12 July 2016.

Browne, M.N., & Freeman, K. 2000. Distinguishing features of critical thinking classrooms. *Teaching in higher education,* 5(3):301-309.

Burbach, M.E., Matkin, G.S., & Fritz, S.M. 2010. Teaching critical thinking in an introductory leadership course utilizing active learning strategies: a confirmatory study. http://findarticles.com/p/articles/mi_m0FCR/is_3_38/ai_n6245168 Date of access: 13 February 2014.

Burden, P.R., & Byrd, D.M. 2010. Methods for effective teaching: Meeting the needs of all learners. 5th edition. Boston: Pearson Education.

Buzan, T. 2014. The ultimate book of mind maps. https://archive.org/details/pdfy-MEuyCwZKGT3fqH56 Date of access: 27 July 2015.

Cheung, C-K., Rudowicz, E., Kwan, A.S.F., & Yue, X.D. 2002. Assessing university student's general and specific critical thinking. *College student journal,* 36(4):504-522.

Cohen, L., Manion, L., & Morrison, K. 2007. Research methods in education. 6th ed. New York: Routledge.

Costa, A.L. 2009. Describing the habits of mind. (*In* Costa, A.L. & Kallick, B., *eds.* Learning and leading with habits of mind: 16 essential characteristics for success. Victoria, Australia: Hawker Brownlow Education. p. 15-41).

Costa, A.L., & Kallick, B. 2014. Habits of mind. (*In* Green, L., *ed*   Schools as thinking communities.

Craighead, W.E. & Nemeroff, C.B., eds. 2002. The Corsini's Encylopedia of psychology and behaviourism science. 3rd ed.   New York: John Wiley and Sons.

Creswell, J.W. 2009. Research design: qualitative, quantitative, and mixed methods approaches. 3rd ed. Los Angeles, Calif.: Sage.

Creswell, J.W. 2012. Educational research. Planning, conducting and evaluating quantitative and qualitative research. 4th ed. Boston: Pearson.

Crockett, R. 2015. The critical 21st century skills every student needs and why. http://globaldigitalcitizen.org/critical21stcenturyskillseverystudentneeds Date of access: 23 June 2015.

Daniel, M. F. 2001. Philosophical dialogue among peers: A study of manifestations of critical thinking in preservice teachers. *Advances in health sciences education*, 6:49-67.

De Corte, E. 2011. Constructive, self-regulated, situated and collaborative learning: An Approach for the acquisition of adaptive competence. *Journal of education*, 192(2/3):33-47.

Delport, C.S.L., & Roestenburg, W.J.H. 2011. Quantitative data collection methods: Questionnaires, checklists, structured observations, and structured interview schedules. (*In* De Vos, A.S., Strydom, H., Fouché, C.B., & Delport, C.S.L., *eds.*   Research at grass roots. For the social sciences and human service professions. 4th ed. Pretoria: Van Schaik. p.171-205).

Department of Basic Education ***see*** South Africa. Department of Basic Education.

De Vos, A.S., & Strydom, H. 2011. Intervention research. (*In* De Vos, A.S., Strydom, H., Fouché, C.B., & Delport, C.S.L., *eds.* Research at grass roots. For the social sciences and human service professions. 4th ed. Pretoria: Van Schaik. p.473-490).

Dewey, J. 1933. How we think. New York: Prometheus Books.

Dewey, J., & Bento, J. 2009. Activating children's thinking skills (ACTS): The effects of an infusion approach to teaching thinking in primary schools. *British journal of educational psychology,* 79(2):329-351.

Dostál, J. 2015. Theory of Problem Solving. *Procedia - Social and Behavioral Science,s* 174: 2798–2805. doi:10.1016/j.sbspro.2015.01.970.

Duminy, P.A., Dreyer, H.J., & Steyn, P.D.G. 1990. Education for the student teacher. Cape Town: Maskew Miller. Longman, (Pty) Ltd, SA.

Du Plessis, E. 2013. Introduction to Caps: Curriculum & Assessment Policy Statement. Pretoria: Unisa.

Du Preez, L., & Van Wyk, A. 2006. Bios: An integrated approach to Life Sciences teaching and learning. Pretoria: Mediakor.

Duron, R., Limbach, B., & Waugh, W. 2006. Critical thinking framework for any discipline. *International journal of teaching and learning in higher education,* 17(2):160-166.

Elder, L. 2005. Critical thinking as the key to the Learning College: A professional development model. *New directions for community colleges,* 130:39-48.

Ennis, R.H. 1993. Critical thinking assessment. *Theory and practice,* 32(3):179-186.

Ennis, R.H. 1985. A logical basis for measuring critical thinking skills. *Educational leadership,* 43(2):44-48.

Ennis, R.H. 2001. Goals for a critical thinking curriculum and assessment. (*In* Costa, A., *ed.* Developing minds. 3rd ed. Alexandria, VA: ASCA publications. p. 44-66).

Ennis, R.H. 2002. A logical basis for measuring critical thinking skills. *Educational leadership:* 43(2):44-48.

Ertmer, P.A., & Newby, T.J. 2013. Behaviorism, Cognitivism, Constructivism: Comparing critical features from an instructional design perspective. *Performance improvement quarterly,* 26(2):43-71.

Epstein, R.L., & Kernberger, C. 2006. The pocket guide to critical thinking. 3rd ed. Belmont: Thomson and Wadsworth.

Facione, P. A. 2000. The disposition toward critical thinking: Its character, measurement, and relationship to critical thinking skill. *Informal logic,* 20(1):61-84.

Facione, P. A. 2009. Critical thinking: What it is and why it counts. *2009 Update.* 1-24.

Facione, P.A. 2011. Think critically. Boston, MA: Prentice Hall.

Facione, P.A., Facione, N.C., & Giancarlo, C.A. 2000. The disposition toward critical thinking: Its character, measurement, and relationship to critical thinking skill. *Informal logic*, 20(1):61-84.

Figueras, A.R. 2013. Graphical/advance organizers. http://www.slideshare.net/arfigueras/graphic-organizers-26697966?related=2 Date of access: 27 July 2015.

Fouché, C.B., Delport, C.S.L., & De Vos, A.S. 2011. (*In* De Vos, A.S., Strydom, H., Fouché, C.B., & Delport, C.S.L., *eds.* Research at grass roots. For the social sciences and human service professions. 4th ed. Pretoria: Van Schaik. p. 142-158).

Fradkin, L., Zernov, V., Crisan, C., & Lerman, S. 2010. First year engineering mathematics: The London South Bank University experience. *MSOR Connections*, 10(1):35-39. http://www.mathstore.ac.uk/?q=node/1319 Date of access: 27 July 2015.

Fraser, M.W., Rishman, J.M., Galinsky, M.J., & Day, S.H. 2009. Intervention research. New York: Oxford University Press.

Fraser, M.W., & Galinsky, M.J. 2010. Steps in intervention research: Designing and developing social programs. *Research on social work practice,* 20(5):459-466.

Frenton, N. 2015. Using the 'Top 20 Principles'. Psychology teacher network. http://www.apa.org.ed/precollege/ptn/2015/09/top-20-principles.aspx Date of access: 4 February 2017.

Galyam, N. 2004. Teaching thinking skills in science to learners with special needs: an evaluation study. Stellenbosch: Stellenbosch University. (Dissertation – PhD).

Gardner, H. 2010. Five Minds for the future (*In* Bellanca, J., & Brandt, R., *eds.* 21st century skills: Rethinking how students learn. Bloomington, IN: Solution Tree Press. p. 9-31).

Gawe, N. 2008. Cooperative learning. (*In* Jacobs, M., Vakalisa, N & Gawe, N., *eds.* Teaching-learning dynamics. A participative approach for OBE. 3rd ed. Sandton: Heinemann (Pty) Ltd. p. 208-227).

Gebhart, A., Preethlall, P., Pillay, S., & Farham, B. 2012. Grade 11: Study and master Life Sciences. Cape Town: Cambridge University Press.

Gilakjani, A.P. 2012. Visual, auditory, kinaesthetic styles and their impacts on English language teaching. *Journal of studies in education*, 2(1):104-113.

Gilakjani, A.P., & Ahmadi, S.M. 2011. The effect of visual, auditory, and kinaesthetic learning styles on language teaching: International conference on social science and humanity, Singapore: IACSIT Press.

Gilmartin, K., & Rex, K. 1999. Working with charts, graphs and tables. Margate, Kent: Thanet Press Ltd.

Good, T.L., & Brophy, J.E. 1994. Looking in classrooms. 6th ed. New York: Harper & Row.

Google images for mind maps, concept maps, brain maps. https://www.google.co.za/search?q=mind+maps,+concept+maps,+brain+maps,+graphical+organizers,+charts+and+diagrams&espv=2&biw=1846&bih=1019&tbm=isch&tbo=u&source=univ&sa=X&ved=0CB0QsARqFQoTCOCd_e78- Date of access: 27 July 2015.

Google images for charts and diagrams. https://www.google.co.za/search?q=Charts+and+diagrams&es_sm=93&biw=1846&bih=1019&tbm=isch&tbo=u&source=univ&sa=X&ved=0CBsQsARqFQoTCLHnm8C6_cYCFWZB2wodUI4DjA Date of access: 28 July 2015.

Goyak, A.M. 2009. The effects of cooperative learning techniques on perceived classroom environment and critical thinking skills. Liberty University. (Dissertation – PhD).

Green, L. 2014. Enquiry based teaching and learning. Short learning programme in cognitive education. Vanderbijlpark: North West University, Vaal Triangle Campus.

Green, L., & Murris, K. 2014. Philosophy for children. (*In* Green, L., *ed.* Schools as thinking communities. Pretoria: Van Schaik. p. 121-140).

Greeno, J.G., Collins, A.M., & Resnick, L.B. 1993. Cognition and learning. https://www.google.co.za/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=cognitive%20learning%20theory%20pdf. Date of access: 26 May 2015.

Grosser, M.M. 1999. Die rol van koöperatiewe leer in die ondersteuning van 'n denkontwikkelingsbenadering. Vanderbijlpark: Vista Universiteit. (Proefskrif – PhD).

Grosser, M.M. 2007. Effective teaching: Linking teaching to learning functions. *South African journal of education,* 27(1):37-52.

Grosser, M.M. 2009. Teaching and learning styles. Vanderbiljpark: NWU, Vaal Triangle Campus. (Study guide EDCC 312).

Grosser, M.M. 2014. Cooperative learning. (*In* Green, L., *ed.* Schools as thinking communities. Pretoria: Van Schaik. p. 225-244).

Grosser, M.M. 2016a. Development of the critical thinker (*In* Du Toit, E.R., Louw, L.P. & Jacobs,L., *eds.* Help I'm a student teacher. Skills development for teaching practice. 2nd. edition. Pretoria: Van Schaik. p. 67-90).

Grosser, M.M., *ed.* 2016b. (in press). Developing critical thinking: A multi-dimensional approach for the context of South Africa. New York: Nova Science Publishers.

Grosser, M.M., & Lombard, B.J.J. 2008. The relationship between culture and the development of critical thinking abilities of prospective teachers. *Teaching and teacher education*, 24:1363-1375.

GSI Teaching & Resource Center. 2015a. http://gsi.berkeley.edu/gsi-guide-contents/learning-theory-research/social-constructivism/ Date of access: 29 June 2015.

GSI Teaching & Resource Center. 2015b. http://gsi.berkeley.edu/gsi-guide-contents/learning-theory-research/cognitive-constructivism/ Date of access: 29 June 2015.

Gunter, M.A., Estes, T.H., & Mintz, S.L. 2010. Instruction: a models approach. Boston, Mass.: Pearson Education.

Gunter, M.A., Estes, T.H., & Schwab, J. 2003. Instruction: A models approach. 4th ed. Boston: Pearson.

Hager, P., & Kaye, M. 1992. Critical thinking in teacher education: A process-oriented research agenda. *Australian journal of teacher education*, 17(2):26-33.

Halpern, D.F. 2007. The nature and nurture of critical thinking (*In* Sternberg, R., Roediger, H.L. & Halpern, D.F., *eds*. Critical thinking psychology. Cambridge University Press. p. 1-12).

Hashim, O. R. 2010. Investigation of the teaching of critical and creative thinking in Malaysia. *Jurnal pendidikan Islam*, 1:39-56.

Hmelo-Silver, C.E. 2004. Problem-Based Learning: What and How Do Learners Learn? *Educational psychology review,* 16(3):235. doi:10.1023/B:EDPR.0000034022.16470.f3.

Hmelo-Silver, C.E., Duncan, R.G., & Chinn, C.A. 2007. Scaffolding and achievement in problem-based and inquiry learning: A response to Kiscchner, Sweller and Clark (2006). *Educational psychologist,* 42(2):99-107.

Hofstein, A., Nahum, T.L., & Shore, R. 2001. Assessment of the learning environment of inquiry-type laboratories in high school chemistry. *Learning environment research,* 4:193-207.

Howie, P., & Bagnall, R. 2015. A critical comparison of transformation and deep approach theories of learning. *International journal of lifelong education,* 34(3):348-365.

Hudson, D. 2013. The effect of thinking maps on fifth grade science achievement. Minneapolis, Minnesota: Walden University. (Dissertation – PhD).

Hyerle, D. 2009. Thinking maps: Visual tools for activating habits of mind. (*In* Costa, A.L., & Kallick, B., *eds.* Learning and leading with habits of mind: 16 essential characteristics for success. Victoria, Australia: Hawker Brownlow Education. p. 149-176).

Hyerle, D. 2014. Thinking maps. (*In* Green, L., *ed.* Schools as thinking communities. Pretoria: Van Schaik. p. 161-178).

Hyerle, D. & Yeager, C. 2007. Thinking maps: A language for learning. North Carolina: Thinking Maps Incorporate.

Ijaiya, N.Y.S., Alabi, A.T., & Fasasi, Y.A. 2010. Teacher education in Africa and critical thinking skills: Need and strategies. *The social sciences,* 5(4):380-390.

Illeris, K. 2015. The development of a comprehensive and coherent theory of learning. *European journal of education,* 50(1):29-40.

Jacobs, M. 2008. Curriculum design. (*In* Jacobs, M., Vakalisa, N & Gawe, N., *eds.* Teaching-learning dynamics. A participative approach for OBE. 3rd ed. Sandton: Heinemann (Pty) Ltd. p. 34-87).

Jacobson, L. 2014. From Habits of Mind to critical thinking: A study of student learning behaviors in a university great books general education course. Philadelphia: Temple University. (Dissertation – PhD).

Jansen, J.D. 2010. The language of research (*In* Maree, K., *ed*. First steps in research. Pretoria: Van Schaik Publishers. p. 15-22).

Jarvis, P. 2015. Learning expertise in practise: Implications for learning theory. *Studies in the education of adults,* 47(1):81-94.

Jensen, W. 1997. Defining the critical theory. The application of the critical theory, http://www127.pair.com/critical/d-ct.htm Date of access: 14 September 2015.

Johanson, J. 2010. Cultivating critical thinking: An interview with Stephan Brookfield. *Journal of developmental education,* 33(3):27.

Jordaan, E.J. 1998. Design and development of a computer program for the development of critical thinking skills in high school pupils. Pretoria: UP. (Dissertation – MEd).

Kolb, D.A. 1983. Experiential learning: Experience as the source of learning and development. Englewood Cliffs, New York: Prentice-Hall.

Killen, R. 2007. Teaching strategies for outcomes-based education. 2nd ed. Cape Town: Juta.

Kramer, D. 2006. OBE Teaching Toolbox. OBE strategies, tools and techniques for implementing Curriculum 2005. Florida Hills: Vivlia Publishers & Booksellers (Pty) Ltd.

Kruger, D.J. 2003. Integrating quantitative and qualitative methods in community research. *The community psychologist,* 36:18-19.

Kruger, N. 2002. About the heart of the teacher. (*In* Kruger, N. & Adams, H. *eds*., Psychology for teaching and learning. What teachers need to know. Sandton: Heineman (Pty) Ltd. p. 107-124).

Leech, N.L., Barrett, K.C., & Morgan, G.A. 2005. SPSS for intermediate statistics: use and interpretation. 2 nd ed. London:Routledge.

Leedy, P.D., & Ormrod, J.E. 2013. Practical research: planning and design. 10th ed. Upper Saddle River, N.J.: Prentice Hall.

Lodico, M.G., Spaulding, D.T., & Voegtle, K.H. 2010. Methods in research. From theory to practice. 2nd ed. San Francisco: Jossey Bass.

Lombard, B.J.J., & Grosser, M.M. 2004. Critical thinking abilities among prospective teachers: ideals versus realities. *South African journal of education*, 24(3):212-216.

Lombard, K., & Grosser, M. 2008. Are the ideals of OBE failing us, or are we failing the ideals of OBE? *South African journal of education*, 28:561-579.

Lun, V. M., Fischer, R., & Ward, C. 2010. Exploring cultural differences in critical thinking: is it about my thinking style of the language I speak? *Learning and individual differences,* 20:604-616.

MacFarlane, R. 2007. Romantic originality. Original copy: plagiarism and originality in nineteenth-century literature. Oxford: Oxford University Press.

Mahaye, T., & Jacobs, M. 2008. Teaching methods. (*In* Jacobs, M., Vakalisa, N & Gawe, N., *eds.* Teaching-learning dynamics. A participative approach for OBE. 3rd edition. Sandton: Heinemann (Pty) Ltd. p. 174-207).

Maree, K., & Pietersen, J. 2010a. The quantitative research process. (*In* Maree, K., *ed*. First steps in research. Pretoria: Van Schaik Publishers. p. 145-153).

Maree, K., & Pietersen, J. 2010b. Sampling. (2009:6-7) Marlow, L. & Inman, D. 1992. Higher order thinking skills: Teachers' perceptions. *Education,* 112(4):538-541.

McCollister, K., & Sayler, M.F. 2010. Lift the ceiling: Increase rigor with critical thinking skills. *Gifted child today,* 33(1):41-47.

McGonigal, K. 2005. Teaching for transformation: From learning theory to teaching strategies. *Newsletter on teaching*, 14(2). The center for teaching and learning, Stanford University.

McMillan, J.H., & Schumacher, S. 2006. Research in education: Evidence- based inquiry. 6th ed. Boston: Pearson.

McMillan, J.H., & Schumacher, S. 2008. Research in education: A conceptual introduction. Boston, Mass.: Allyn & Bacon.

McNeeley, R.S. 2007. Theories of learning: Learning theories in the early childhood classroom environment. http://web.utk.edu/-rmcneele/classroom Date of access: 28 May 2015.

McPeck, J.E. 1981. Critical thinking and education. Great Britain: Martin Robertson & Company Ltd.

Mezirow, J. 1991. Transformative dimensions of adult learning. San Francisco: Jossey Bass.

Miri, B., Ben-Chaim, D., & Zoller, U. 2007. Purposely teaching for the promotion of higher-order thinking skills: A case of critical thinking. *Research in science education*, 37(4):353-369.

Monteith, J. 2002. How to become an effective learner. (*In* Kruger, N. & Adams, H. *eds*., Psychology for teaching and learning. What teachers need to know. Sandton: Heineman (Pty) Ltd. p. 91-104).

Monyai, R.B. 2006. Teaching strategies. (*In* Nieman, M.M. & Monyai, R.B. 2006. The teacher as mediator of learning. Pretoria: Van Schaik. p. 104-135).

Moore, T. 2011. Critical thinking: Seven definitions in search of a concept. *Studies in higher education,* 38(4):506-522.

Mouton, J. 2009. Monitoring and evaluating educational interventions. Paper presentation at the national conference of the International Association for Cognitive Education in Southern Africa. 11-13 February 2008. Royal Cape Yacht Club, Cape Town, South Africa.

Naidoo, R.R. 2011. The teaching of high order thinking skills at grade 9 level in natural science in blacktownship schools in the Western Cape. Cape Town: Cape Peninsula University of Technology. (Dissertation – MEd).

Niehuis, A.E., Manstead, A.S.R., & Spears, R. 2001. Multiple motives and persuasive communication: creative elaboration as a result of impression motivation and accuracy motivation. *Personality and social psychology bulletin*, 27:118-132.

Nieman, M.M., & Pienaar, R.B. 2010. The role of the learning process, learning styles and learner differences in the mediation of learning (*In* Nieman, M.M. & Monyai, R.B., *eds.* The teacher as mediator of learning. 4th ed. Pretoria: Van Schaik Publishers. p.72-103).

Nieuwenhuis, J. 2010. Introduction qualitative research (*In* Maree, K., *ed*. First steps in research. Pretoria: Van Schaik Publishers. p. 46-68).

Nisbett, R.E., & Norenzayan, A. 2002. Culture and cognition. (*In* Medin, D.L., *ed*. 2002. Steven's handbook of experimental psychology. 3rd ed. New York: Wiley. p. 3-28).

Norris, S.P. 1985. Synthesis of research on critical thinking. *Educational leadership,* 42(8):40-45.

Norris, S.P., & Ennis, R.H. 1989. Evaluating critical thinking. Pacific Grove, CA: Critical Thinking Press Software.

Novak, J.D. 2006. The theory underlying Concept Maps and how to construct them. http://cmap.ihmc.us/docs/theory-of-concept-maps Date of access: 27 July 2015.

O'Neill, R. 2006. The advantages and disadvantages of qualitative and quantitative research methods. http://archive.learnhigher.ac.uk/analysethis/main/quantitative1.html Date of access: 6 August 2015.

Osana, H.P., & Seymour, J.R. 2004. Critical thinking in preservice teachers: a rubric for evaluating argumentation and statistical reasoning. *Educational research and evaluation: An international journal on theory and practice,* 10(4):473-498.

Paul, R.W. 1985. Bloom's taxonomy and critical thinking intervention. *Educational leadership,* 42(8):36-39.

Paul, R.W. 1988. Critical thinking in the classroom. *Teaching K-8,* 18:49-51.

Paul, R. W. 1993. Critical thinking: What every person needs to survive in a rapidly changing world. Santa Rosa, CA: Foundation for Critical Thinking.

Paul, R.W., & Elder, L. 2006. The miniature guide to critical thinking concepts and tools. California: The Foundation for Critical Thinking.

Paul, R.W., & Elder, L. 2007. Critical thinking competency standards: Standards, principles, performance indicators, and outcomes with a critical thinking master rubric. Foundations for critical thinking.

Perkins, D., Tishman, S., Ritchhart, R., Donis, K., & Andrade, A. 2000. Intelligence in the wild: A dispositional view if intellectual traits. *Educational psychology review,* 12(3):269-293.

Philpott, J. 2009. Captivating your class. Effective teaching skills. New York: Continuum International Publishing group.

Piaget, J. 1969. Psychology of intelligence. Totowa, New York: Littlefield, Adams and Company.

Pietersen, J., & Maree, K. 2010a. Statistical analysis I: Descriptive statistics. (*In* Maree, K., *ed*. 2010. First steps in research. Pretoria: Van Schaik Publishers. p. 183-196).

Pietersen, J., & Maree, K. 2010b. Statistical analysis II: Descriptive statistics. (*In* Maree, K., *ed*. 2010. First steps in research. Pretoria: Van Schaik Publishers. p. 198-213).

Pietersen, J., & Maree, K. 2010c. Standardisation of a questionnaire. (*In* Maree, K., *ed*. 2010. First steps in research. Pretoria: Van Schaik Publishers. p. 215-223).

Pietersen, J., & Maree, K. 2010d. Overview of statistical techniques. (*In* Maree, K., *ed*. 2010. First steps in research. Pretoria: Van Schaik Publishers. p. 225-254).

Pikulsky, J.J., & Chard, D.J. 2005. Fluency: bridge between decoding and reading comprehension. *Reading teacher*, 58(6):510-519.

Pink, D.H. 2006. A whole new mind: Why right-brainers will rule the future. New York:Riverhead Books.

Pintrich, P.R., & Schunk, D.H. 2002. Motivation in education. Theory, research and applications. 2nd ed. Upper Saddle River, NJ: Merrill Prentice Hall.

Pithers, R. T., & Soden, R. 2000. Critical thinking in education: A review. *Educational research*, 42(3):237-249.

Potterton, M. 2008. A curriculum that failed. *The teacher:* 15.

Powell, K.C., & Kalina, C.J. 2009. Cognitive and social constructivism: Developing tools for an effective classroom. *Education.* https://www.questia.com/library/journal/1G1-216181184/cognitive-and-social-constructivism-developing-tools Date of access: 30 June 2015.

Pritchard, A. 2014. Ways of learning. Learning theories and learning styles in the classroom. 3rd ed. London: David Fulton Publishers.

Profetto-McGrath, J. 2003. The relationship of critical thinking skills and critical thinking dispositions of baccalaureate nursing students. *Journal of advanced nursing,* 43(6):569-577.

Qing, Z., Jing, G., & Yan, W. 2010. Promoting preservice teachers' critical thinking skills by inquiry-based chemical experiment. *Procedia – social and behavioural sciences*, 2(2):4597-4603.

Ricketts, J.C., Irani, T., & Jones, L. 2003. The effect of instructional delivery methods on the critical thinking disposition of distance students and traditional on-campus students. *Journal of Southern agricultural education research,* 53(1):59-71.

Rubin, A., & Babbie, E.R. 2009. Essential research methods for social work. Belmont, CA: Brooks/Cole Cengage Learning.

Russell, L. 2010. The impact of thinking maps on the reading comprehension of elementary school for students. Texas: A & M University-Commerce. (Dissertation – PhD).

Rüütmann, T., & Kipper, H. 2011. Teaching strategies for direct and indirect instruction in teaching Engineering. Paper presented at the 14th International Conference on interactive collaborative learning, Piešťany, Slovakia, 21-23 September 2001. www.icl-conference.org/ dl/proceedings/2011/.../contribution122_a.pdf Date of access: 15 July 2015.

Saavedra, A.R., & Opfer, V.D. 2012. Teaching and learning 21st century skills: Lessons from the Learning Sciences. Asia society, Partnership for global learning: Rand corporation. p. 2-35.

Schmidt, H.G., Rotgans, J.I. & Yew, E.H.J. 2011. The process of problem-based learning: What works and why. *Medical rducation,* 45(8):792–806. doi:10.1111/j.1365-2923.2011.04035.x. PMID 21752076

Scholtz, Z., Braund, M., Hodgen, M., Koopman, R., & Lubben, F. 2008. South African teachers' ability to argue: the emergence of inclusive argumentation. *International journal of inclusive argumentation,* 28(1):21-34.

Schunk, D.H. 2000. Coming to terms with motivation constructs: *Contemporary educational psychology*, 25:116–119. http://www.idealibrary.com Date of access: 29 June 2015.

Şeker, H., & Kömür, S. 2008. The relationship between critical thinking skills and in-class questioning behaviours of English language teaching students. *European journal of teacher education,* 31(4):389-402.

Sessoms, D. 2008. Interactive instruction: creating interactive learning environments through tomorrow's teachers. *International journal of technology in teaching and learning*, 4(2):86-96.

Slater, P. 1995. A critical analysis of mathematics learning by identifying learning and thinking skills implicit in standard 8 algebra. Cape Town: UWC. (Dissertation - M Ed).

Slavin, R.E. 2003. Educational psychology. Theory and practise. 7th ed. NY: Pearson Education. p.254-289.

Snyder, L.G., & Snyder, M.J. 2008. Teaching critical thinking and problem solving skills. *The Delta Pi Epsilon journal,* L(2):90-99.

South Africa. Department of Basic Education. 2011. National Curriculum Statement. Curriculum and Assessment Policy Statement: Further Education and Training Phase, Life Sciences, Grades 10-12. Pretoria: Department of Basic Education.

South African Institute for Distance Education (SAIDE). 2013. Getting Practical. A guide to teaching and learning. 3rd edition. Cape Town: Oxford University Press. p. 313-348.

Spence, L.D. 2001. Problem-based learning: Lead to learn, learn to lead. https://www.studygs.net/pblhandbook.pdf Date of access:15 July 2015.

Stedman, N.L.P., & Adams, B.L. 2012. Identifying faculty's knowledge of critical thinking concepts and perceptions of critical thinking instruction in higher education. *NACTA jounal,* p.9-14.

Steffens, K. 2015. Competences, learning theories and MOOC's: Recent developments in lifelong learning. *European journal of education,* 50(1):41-59.

Sternberg, R.J. 1987. Teaching critical thinking: Eight ways to fail before you begin. *Phi Delta Kappa International,* 68:456-459.

Sterrenberg, L. 2009. Life Sciences Grade 10: The answer series. 1st edition. Cape Town: The Answer.

Sterrenberg, L. & Fouché, H. 2013. Life Sciences Grade 11: The answer series. Cape Town: The Answer.

Sterrenberg, L., Fouché, H., & Elliot, G. 2014. Life Sciences Grade 12: The answer series. Cape Town: The Answer.

Strydom, H. 2011a. Ethical aspects of research in the social sciences and human professions. (*In* De Vos, A.S., Strydom, H., Fouché, C.B., & Delport, C.S.L., *eds.* Research at grass roots. For the social sciences and human service professions. 4th ed. Pretoria: Van Schaik. p.113-130).

Strydom, H. 2011b. Sampling in the quantitative paradigm. (*In* De Vos, A.S., Strydom, H., Fouché, C.B., & Delport, C.S.L., *eds.* Research at grass roots. For the social sciences and human service professions. 4th ed. Pretoria: Van Schaik. p.222-235).

Strydom, H. 2011c. The pilot study in the quantitative paradigm. (*In* De Vos, A.S., Strydom, H., Fouché, C.B., & Delport, C.S.L., *eds.* Research at grass roots. For the social sciences and human service professions. 4th ed. Pretoria: Van Schaik. p.236-247).

Sunseri, A. 2011. The impact of thinking maps on elementary students expository texts. San Francisco: San Francisco State University. (Dissertation – PhD).

Thyer, B.A. 2012. Quasi-experimental research designs. New York: Oxford University Press.

Tsui, L. 2002. Fostering critical thinking through effective pedagogy: Evidence from four institutional case studies. *The journal of higher education,* 73(6):740-763.

Uksw, S. 2014. Developing critical thinking skills through school teacher training 'Training and development personnel' model and their determinants of success. *International journal of information and education technology,* 4(2):161-166.

Umar, I.N., & Ahmad, N.H. 2010. Trainee teachers' critical thinking in an online discussion forum: A content analysis. *Malaysian journal of learning and instruction*, 7: 75-91.

UNESCO. 2004. The office of learning and teaching. http://www.unesco.org/new/en/education/themes/strengthening-education-systems/quality-framework/technical-notes/influential-theories-of-learning/ Date of access: 27 May 2015.

VanGundy, A.B. 2005. 101 Activities for teaching creativity and problem solving. San Francisco: Pfeiffer.

Vieira, R.M, Tenreiro-Vieira, C., & Martins, I.P. 2011. Critical thinking: Conceptual clarification and its importance in science education. *Science education international,* 22(1):43-54.

Vygotsky, L. 1978. Mind in society: The development of higher psychological processes. Cambridge: Harvard University Press.

Vygotsky, L. 1986. Concrete human psychology. *Psikhologiya,* 14(1):51-64.

Wagner, T. 2008. The global achievement gap: Why even our best schools don't teach the new survival skills our children need, and what we can do about it. New York: Basic Books.

Wallace, B., Ross, A., Davies, J.B., & Anderson, T., *eds*. 2007. The mind, the body and the world: psychology after cognitivism. London: Imprint Academic.

Walsh, D., & Paul, R. 1986. The goal of critical thinking: From educational ideal to educational reality. Washington, DC: American Federation of Teachers.

Warburton, E. C. 2008. Changes in dance teachers' beliefs about critical thinking activities. *Journal of education and human development*, 2(1):1-13.

Watkins, C. 2002. Effective learning. *National school improvement network,* 17:1-20.

Yang, Y-TC. 2012. Cultivating critical thinkers: Exploring transfer of learning from pre-service teacher training to classroom practice. *Teaching and teacher education,* 28:1116-1130.

Zascavage, V. 2010. Critical thinking skills and the intervention specialist. *Journal of border education research,* 8:71-80.

.

APPENDIX A

ETHICAL CLEARANCE

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Private Bag X6001, Potchefstroom
South Africa 2520

Tel: (018) 299-4900
Faks: (018) 299-4910
Web: http://www.nwu.ac.za

Institutional Research Ethics Regulatory Committee
Tel +27 18 299 4849
Email Ethics@nwu.ac.za

ETHICS APPROVAL CERTIFICATE OF PROJECT

Based on approval by **Humanities and Health Research Ethics Committee (HHREC)**, the North-West University Institutional Research Ethics Regulatory Committee (NWU-IRERC) hereby approves your project as indicated below. This implies that the NWU-IRERC grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: The impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers.

Project Leader: **Prof MM Grosser**
Student: **Mr FG Minnie**

Ethics number:

N	W	U	-	HS	-	2	0	1	5	-	0	1	9	4
Institution						Project Number					Year			Status

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Approval date: 2015-11-23 **Expiry date**: 2018-11-23 **Category** N/A

Special conditions of the approval (if any): None

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- *The project leader (principle investigator) must report in the prescribed format to the NWU-IRERC:*
  - *annually (or as otherwise requested) on the progress of the project,*
  - *without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.*
- *The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-RERC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.*
- *The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-IRERC and new approval received before or on the expiry date.*
- *In the interest of ethical responsibility the NWU-IRERC retains the right to:*
  - *request access to any information or data at any time during the course or after completion of the project;*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the project are revealed or suspected,*
    - *it becomes apparent that any relevant information was withheld from the NWU-IRERC or that information has been false or misrepresented,*
    - *the required annual report and reporting of adverse events was not done timely and accurately,*
    - *new institutional rules, national legislation or international conventions deem it necessary.*

The IRERC would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the IRERC for any further enquiries or requests for assistance.

Yours sincerely

Linda du Plessis

Digitally signed by Linda du Plessis
DN: cn=Linda du Plessis, o=NWU, ou=Vaal Triangle Campus, email=linda.duplessis@nwu.ac.za, c=ZA
Date: 2015.11.24 18:59:15 +02'00'

Prof Linda du Plessis
Chair NWU Institutional Research Ethics Regulatory Committee (IRERC)

APPENDIX B

LETTERS OF CONSENT

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAALDRIEHOEKKAMPUS

PO Box 1174, Vanderbijlpark
South Africa, 1900

Tel: (016) 910-3111
Fax: (016) 910-3116
Web: http://www.nwu.ac.za

Tel: (016) 016 910 3063
Fax (016) 016 901 3078
EMail mary.grosser@nwu.ac.za

2 November 2015

Mr. Francois Minnie
Lecturer: Life Science
School of Educational Sciences
North-West University, Vaal Triangle Campus
Vanderbijlpark
1900

REQUEST FOR REGISTER PERIOD DURING 2016

In response to your request to schedule a register period for LIFE 111 students on the time table during 2016 to assist you with administrative issues related to your research project for your Masters Degree, I wish to inform you that I grant you permission to make the necessary arrangements with Mrs Lecretia Redelinghuys who is responsible for the time table arrangements of the BEd-students.

Yours sincerely

Dr. E. Küng

BEd Programme Manager

LEARNERS (ENGLISH)

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

1.

HHREC Stamp

PO Box 1174, Vanderbijlpark
South Africa, 1900
Web: http://www.nwu.ac.za

DATE: 3 September 2015

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR FIRST YEAR LIFE SCIENCE B.ED. STUDENTS

TITLE OF THE RESEARCH PROJECT: The impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers

REFERENCE NUMBERS:

PRINCIPAL INVESTIGATOR/RESEARCHER: Mr Francois Minnie

ADDRESS: SCHOOL OF EDUCATION SCIENCES, NORTH-WEST UNIVERSITY, HENDRICK VAN ECK BOULEVARD 100, VANDERBIJLPARK

CONTACT NUMBER: 016 910 3074/084 549 2583

You are invited to take part in a research project that forms part of my (the researcher's) study for a Master's degree in Education. Please take some time to read the information presented here, which will explain the details of this project. Please ask the independent person, Ms. Daphne Strauss, who will explain the research to you, any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied and that you clearly understand what this research is about and how you could be involved. In addition, your participation is **entirely voluntary** and you are free to decline participation. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part. You may also ask me to delete information/data about you that I collected. If you are younger than 18 , your parents/guardians will also give consent that you may take part in the study. You need to know that even if your parents/guardians give consent for you to take part, you still have the choice to decide if you want to take part in the research or not.

This study has been approved by the **Humanities and Health Research Ethics Committee (HHREC) of the Faculty of Humanities of the North-West University (NWU............)** and will be conducted according to the ethical guidelines and principles of the international

Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. It might be necessary for the research ethics committee or relevant authorities to inspect the research records to make sure that we (the researchers) are conducting research in an ethical manner.

What is this research study all about?

I am Mr Francois Minnie, the researcher and your Life Science lecturer, who would like to involve you in my research project, which I am completing for a Master's Degree. My research project will be conducted at the North-West University, Vaal Triangle Campus in Vanderbijlpark.

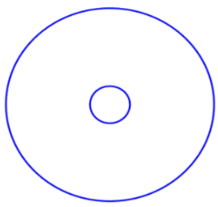
This research links well with the present teaching and learning situation in South African schools, where it is expected of teachers to teach learners the skills to identify and solve problems by means of critical and creative thinking. My study will specifically focus on critical thinking. In my study, critical thinking will mean that the research participants must be able to analyze, synthesize and evaluate information. Analysis means to break up information into smaller parts. Synthesis means to combine different ideas/information into a new idea. Evaluation means to judge the truth or value of something and motivate your answer.

The main objectives of the study are:

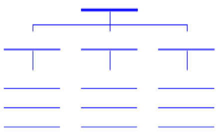
(i) To find out how well the critical thinking skills (analysis, synthesis, evaluation) of first year Life Science student teachers were developed during their school years.

(ii) To find out if the use of Thinking Maps as teaching strategy could help to develop critical thinking skills that might be in need of further development or improvement. Thinking Maps is a visual learning strategy where a student learns to process and summarize information in a map. The researcher will apply three Thinking Maps during the research, namely:

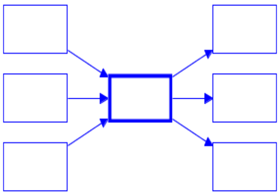
- ✓ A Circle Map to develop the skill of synthesis



- ✓ A Tree Map to develop the skill of analysis



✓ A Multi-Flow Map to develop the skill of evaluation



Although many international studies have found the Thinking Maps strategy to be successful for developing thinking skills, no studies have been conducted to test the effectiveness of Thinking Maps as teaching strategy to develop critical thinking skills among Life Science student teachers in the South African context; especially skills like analysis, synthesis and evaluation. These skills are important for mastering the subject content of Life Science at first year B.Ed.-level.

The researcher would like to include all the 2016 first year B.Ed.-students with Life Science as major subject in the research. The researcher will recruit the research participants by obtaining permission from the Director of the School of Education Sciences, Prof. J.E. Fourie, who will act as a gatekeeper to gain entry to the participants. Based on the numbers of students who enrolled for Life Science during the past two years, about 60-70 students will take Life Science as major subject in 2016. This group of students will be a new group of students who have not yet been exposed to, or overburdened by research at the university.

Why have you been invited to participate?

It will be important to do the research with you, as the researcher is your Life Science lecturer and want to use a new teaching strategy to firstly improve the quality of my own teaching practice. Secondly, the researcher was a Life Science teacher for many years, and know that teachers do not know about teaching strategies that they could use to develop the critical thinking skills of learners in Life Science. Doing the research with first year Life Science student teachers will give the researcher the chance to teach a strategy to a group of Life Science teachers which they could use to possibly nurture critical thinking more effectively at school-level, when they start teaching. The focus is on first year students, as the researcher wants to teach them how to use the strategy in their first year of study and encourage them to apply it throughout their four years of training, so that when they start teaching they might be good at guiding the learners whom they will teach to use the strategy too. The researcher has been trained by an accredited Thinking Maps facilitator to apply the Thinking Maps strategy.

In summary, you have been selected to take part in the research because:

(i) You are a first year, male or female B.Ed.-student from any ethnic and language group at the North-West University, Vaal Triangle Campus in Vanderbijlpark, who passed Life Science at matric level.

(ii) You are a first year BEd-student with Life Science as one of your major subjects.

Exclusion criteria: Participants will not be involved in the study if they are a second, third or fourth year B.Ed.Life Science student at the North-West University, Vaal Triangle Campus in Vanderbijlpark or any other university.

What will your responsibilities be?

The researcher will make use of an independent person, Ms. Daphne Strauss, who will recruit the participants for the research project. The researcher will train her for this purpose. Ms. Strauss is a qualified and experienced secondary school teacher. An independent observer, Ms. Aldine Oosthuyzen, who knows the study well, as she will be the independent statistician who will capture the data and assist with the analysis of data, will assist her. Moreover, Ms. Oosthuyzen is a member of the Ethics Committee of the School of Economic Sciences and IT at the NWU, Vaal Triangle Campus, with a good understanding of ethical research principles, who will be able to oversee that the work of Ms. Strauss is in line with good ethical practice. Neither Ms. Strauss nor Ms. Oosthuyzen will have any relationship with the LIFE 111 students.

The recruitment will involve a short one-hour and 20 minutes presentation about the study in the Life Science lecture venue at the university, to all the B.Ed. 2016 first year Life Science students, after which the independent person will hand the informed consent forms to the participants. The independent person will explain the information to the participants and request them to take the forms home where they have privacy to complete the form at their own time. The recruitment will take place at the beginning of the year during an hour register period on the timetable before classes commence. If you are absent during the recruitment session and you are interested to take part in the research, the independent person will be requested to conduct a follow-up session with all the participants who missed the first recruitment session, at a time convenient to the independent person and the participants.

In advance, the researcher will request the B.Ed. Programme Manager, Dr. Elize Küng, to accommodate a register period on the timetable for first year students during 2016, preferably on the same day as the LIFE 111 lectures. The researcher could then utilize this period for other administrative issues related to the research, such as receiving the informed consent, the writing of pretests and posttests, giving participants the opportunity to share their views about the research and to receive feedback about the research. The researcher will allow one week to pass between the recruitment and the obtaining of informed consent, to give participants time to think about the study and whether they want to take part or not. After one week, the independent person will meet with the participants during a register period in the Life Science lecture venue and collect the informed consent forms. The participants who decide to take part in the research will then be divided into an experimental and control group by the independent person. Participants will receive a number, which they will use when writing the different tests. If you decide to withdraw from the research, you do not need to complete the pretests and posttests and do not have to attend the discussion and feedback sessions. As the research involves the teaching of the Life Science content, you will however still need to attend class in one of the groups, A or B.

If you take part in the research, you will be part of an experimental and control group on a rotation basis during two experiments, experiment 1 and 2, that will run for six weeks each during the first semester (February to May 2016). These groups will be referred to as Group_A and B, with no specific indication to the students of which group will constitute the experimental group and which group will constitute the control group. The experimental group and control group will consist of approximately 30 participants each. The participants of the experimental and control groups will be determined by the independent person, who will divide the participants into the groups by keeping a balanced and equal division in terms of gender, language, ethnic group, type of school attended and matric result for Life Science.

The experimental group will be the group of participants where the researcher will use the new Thinking Maps strategy for a period of six weeks to see if the strategy will help the participants to improve in using critical thinking skills. The control group will be the group of participants who will not receive teaching with the new Thinking Maps strategy. The researcher will do normal lecturing with them for a period of six weeks. In both groups, the researcher will deal with the same subject content. If you are part of the experimental group during experiment 1, you will then be part of the control group during experiment 2, and vice versa. All the participants will therefore get a chance to receive instruction with the Thinking Maps strategy.

As the first year Life Science content is the same as the content dealt with at Grade 12-level, the researcher will use pretests to measure how well you have developed the critical thinking skills to analyse, synthesise and evaluate information in Life Science content at school. A pretest, pretest 1, will be written at the beginning of experiment 1, based on the learning content that will be dealt with in the first six weeks of semester 1. In the same way, pretest 2 will be written at the beginning of experiment 2, based on the learning content that will be dealt with in the last six weeks of semester 1. The pretests are mainly used to find out how well you developed critical thinking skills at school, before the researcher teaches you to use the Thinking Maps strategy. In total, you will write 2 pretests of approximately 30 minutes each.

Based on the pretest results, the researcher will develop the Thinking Maps teaching programme to address the problems with critical thinking that the researcher noted in the pretest results at the beginning of the first six weeks and second six weeks of the first semester during 2016. If the pretests should indicate that the participants do not experience problems with the critical thinking skills, the researcher will still apply the strategy to determine if it could improve on their present application of the critical thinking skills.

The Life Science students have 2 periods per week of 1 hour and 20 minutes each on the university timetable. One of the periods is a practical period, and the researcher will not apply the Thinking Maps teaching programme during the practical period, but continue with normal lectures. The remaining period that involves the teaching of theoretical subject content, will be used for the Thinking Maps teaching programme. The teaching in the experimental and control groups will take place at separate times on the timetable and in separate venues. The control group will receive normal lectures during a class period (1 hour and 20 minutes) as allocated by the university once a week. The experimental group will also receive the Thinking Maps intervention once a week, during another period (1 hour and 20 minutes).

On conclusion of the Thinking Maps teaching programme with each group, a posttest 1 (after the first six weeks of semester 1) and posttest 2 (after the last six weeks of semester 2), will be written to see if the Thinking Maps teaching programme assisted you to develop or improve the critical thinking skills of analysis, synthesis and evaluation in the context of the subject content dealt with in each experiment respectively. In total, you will write 2 posttests of 30 minutes each.

The table below summarizes the implementation of the research experiment.

Weeks 1-6: Semester 1- Experiment 1: February – Mid March 2016			
Pretest 1	Experimental group Thinking Maps Intervention: 6 weeks	Control group Normal class teaching (lecturing): 6 weeks	Posttest 1
Groups rotate Weeks 7-12: Semester 1 – Experiment 2: April – Mid May 2016			
Prestest 2	Experimental group Normal class teaching (lecturing): 6 weeks	Control group Thinking Maps Intervention: 6 weeks	Posttest 2

The pre- and posttests will contain 15 multiple-choice items each with one correct answer, and a follow-up open question for each multiple-choice answer where you need to motivate an answer. You need to motivate answers to avoid guessing answers. The motivation will also indicate to me how well you can reason/argue. The multiple-choice questions will have an equal number of questions to test the skills to analyze (5 questions), synthesize (5 questions) and evaluate (5 questions). The questions in the pre- and posttests will not be the same, as they will be based on the subject content of the first and second six weeks of the semester, respectively. However, the difficulty of the test and the skills tested, namely analysis, synthesis and evaluation, will remain the same. To make sure that the difficulty level of all the tests will be the same, the researcher will involve four experienced Life Science university lecturers to verify the difficulty level of all the tests independently. The researcher will adhere to their comments and adapt tests if necessary.

An example of how the questions will be asked follows below.

Choose the correct answer by drawing a circle around the correct answer (1-4). Motivate in writing why you chose the answer.

Proteins are made from amino acids by the process of:

1. hydrolysis
2. pinocytosis
3. active transport
4. dehydration synthesis

Correct Answer Number: 4

Motivation: Proteins are large chains of amino acids combined by dehydration synthesis, where by molecules join by removing water. Hydrolysis breaks down proteins into amino acids. Pinocytosis is a method of ingesting large insoluble molecules, and is a form of active transport.

At the end of the research, the researcher will compare the pretest and posttest results of all the participants to see which strategy assisted the participants the best to develop their critical thinking skills, the Thinking Maps strategy or normal lecturing. As suggested by the independent statistician who will assist the researcher with the data analysis, comparisons of the test results of individual students will also be done, as it could be that individual participants benefit more from the new strategy than the group of participants. For this purpose, each participant will receive a number that they will use throughout the research on their pretests and posttests so that it will be possible for the researcher to do comparisons with the different numbers. No comparison will, however, be linked to a participant's name.

Opportunities for participants to share their opinions about the research, as well as opportunities for feedback about the research will be scheduled.

In summary, your involvement will entail the following: (Exact dates and times to be provided when the 2016 time table has been finalized)

1. Invitation and explanation of informed consent (1 hour and 20 minutes during)
2. Completing informed consent (At home, 1 week)
3. Submit informed consent.
4. Selection to an experimental and a control group.
5. Writing pretests (30 minutes) before taking part in Experiment 1 during the LIFE 111 lectures: The implementation of the Thinking Maps strategy for six weeks, 1 hour and 20 minutes per week as part of the experimental group, or as part of the control group who will receive normal lecturing for six weeks, 1 hour and 20 minutes per week.
6. Writing posttests (30 minutes) after the implementation of the Thinking Maps strategy and normal lecturing for six weeks as part of Experiment 1 (1 hour and 20 minutes respectively).
7. Taking part in a reversed experiment, Experiment 2, during the LIFE 111 lectures where the experimental group becomes the control group who will receive normal lecturing for six weeks (1 hour and 20 minutes per week), and the control group becomes the experimental group who will receive teaching with the Thinking Maps strategy for six weeks, 1 hour and 20 minutes per week. The writing of pretests (30 minutes) and posttests (minutes) will apply before and after the six weeks.
8. One discussion session to obtain feedback from students after the implementation of the Thinking Maps strategy during Experiment 2 (1 hour and 20 minutes during a register period).
9. Feedback about the research: Feedback 1: 3 weeks after the implementation of Experiment 1 (1 hour and 20 minutes during a register period). Feedback 2: 3 weeks after the implementation of Experiment 2 (1 hour and 20 minutes during a register period).
10. Final feedback about the research findings (1 hour and 20 minutes during a register period).

11. Will you benefit from taking part in this research?

The direct benefits for you as participant will probably be the following:

(i) You might acquire critical thinking skills with the Thinking Maps teaching strategy to enable you to analyze, synthesize and evaluate information more effectively.

(ii) The Thinking Maps strategy is also a learning strategy that could assist you to learn and study better and possibly improve your academic performance in any subject.

(iii) Another benefit would be that you would probably possess an effective strategy that you could use when you start teaching.

The indirect benefit will probably be that:

(i) Researchers at other universities could be informed about the possible benefits of Thinking Maps as teaching strategy to develop critical thinking skills and conduct further studies in other contexts to prove the benefits of the strategy for developing critical thinking skills on a larger scale.

(ii) The research findings could be used to make recommendations to the Department of Education, regarding the possible improvement of the teaching practices of Life Science teachers.

(iii) The teaching practice of the greater population of Life Science teachers could benefit if the Thinking Maps strategy holds merits for developing critical thinking in Life Science, and the message be communicated to Schools of Education Sciences at Universities who could incorporate training in the use of the strategy into the teacher-training curriculum.

Are there risks involved in your taking part in this research and how will these be managed?

The possible risks in this study, and how the researcher will manage them, are summarised in the table below:

Probable/possible risks/discomforts	***Strategies to minimize risk/discomfort***
Conflict of interest and the power relationship due to the fact that the researcher will also be the participants' Life Science lecturer.	The researcher acknowledges that the group of participants will be a vulnerable group due to the conflict of interest and hierarchical lecturer-student relationship that will exist, because he is the lecturer of the participants. However, the use of an independent person to do the recruitment of the participants, obtain informed consent, select the participants to the experimental and control groups, administer tests for data collection purposes and verify the test results of the participants, could reduce vulnerability. Using an independent person will avoid participants feeling coerced to take part in the research, and avoid their being influenced by the student-lecturer relationship. The independent person will not know or have any contact with the participants and will not lecture to any first year participants. This will ensure that, the participants will not be forced to do something against their will, or be

	threatened, pressurized or persuaded with force to take part in the study to please their lecturer. The study cannot be done without including this group of participants, as the aim is to prepare them from their first year to apply a teaching strategy adequately that could enhance critical thinking during teaching.
The researcher cannot guarantee complete anonymity.	The independent person will make the participants aware of the fact that although those who agreed to take part in the pre- and posttest writing will remain anonymous to the researcher (their lecturer), absolute anonymity cannot be guaranteed during the writing of the pretests and posttests. Those who agree to write the tests will not be anonymous to their peers who will write the tests together with them. However, no results will be linked to individual participants, as numbers will be used to identify participants. The independent person who will collect the various test results of the participants for comparison purposes will know which name is linked to a specific number. She will keep the information confidential and will only report numbers and results to the researcher and independent statistician. Participants will also be made aware of the fact that although they might not consent to take part in the research and write the tests, they will still have to take part in the intervention, as the intervention will be linked to the compulsory subject content of the module (LIFE 111 - Life Science) which they have to pass. Exposure to the new teaching strategy could also be beneficial to them. The Thinking Maps intervention will not interfere with normal teaching time, but will form part of it.
Writing tests might cause anxiety and stress.	The independent person who will do the recruitment and obtain informed consent will explain the following to you: (i) You do not need to prepare or study for the tests. (ii) The tests will be written at times convenient to the participants, preferably

	during a free period on the timetable to avoid additional traveling to write the tests. For this purpose, the researcher will arrange for a fixed register period on the timetable for the first year students of 2016. (iii) The tests will not influence the participants' passing or failing the Life Science module, LIFE 111. (iv) The test results will only be used for research purposes to find out if the Thinking Maps strategy is effective for developing critical thinking skills or not. (v) The content on which the tests will be based will also be known to the participants as they would have done the content in Grade 12. This might reduce anxiety. (vi) For the purpose of making individual comparisons between test results, participants will be identified by means of numbers to the researcher. The researcher will not know who took part in writing the tests (he will not be involved in administering the tests). The independent person will assist the statistician with selecting the individual tests for comparison purposes. The researcher will only receive the numbers of the participants with the various test results. (vii) The tests will not focus on passing or failing but how good participants can apply critical thinking skills.

The researcher has planned for appropriate measures to minimize research-related risks, so that the participants could experience the benefits that the research could hold, as noted above. The risks appear to be reasonable in relation to the importance of knowledge to be gained that can possibly improve the teaching and learning of Life Science.

Who will have access to the data?

Your test results will not be linked to your name. You will not write your name on the test, but will be identified by a number (1, 2 etc.). All results that will be reported will be linked to a number. You will remain anonymous to the researcher, and your name will not be mentioned in the findings that will emanate from the research. The researcher assures you that we will protect the information we have about you. All information regarding the research will be stored on a password-protected computer and the completed tests will be locked up in a cupboard in the researcher's office. The researcher is the only person who has a key to unlock the cupboard.

It is important to inform you that confidentiality will be limited. Apart from the independent person, only two other people will have access to the data, namely the independent statistician who will assist me with the capturing of the data, and my supervisor who will check and verify that my research findings are correct. The independent statistician is Ms. Aldine Oosthuyzen who is a qualified and experienced statistician. The researcher will store the data for a minimum of five years. The independent person, study leader and the independent statistician will sign a written agreement at the beginning of the study that they will keep all information about the study and the findings of the study confidential, and not talk about it.

What will happen to the data?

The researcher assures you that the information obtained via the research will be used for research purposes only, and no information about you will be made known in reporting about the study (for example your name, your address or your parents'/guardians' name or an address). The data from this study will be reported in the following ways: (i) The researcher will report the findings in the form of a dissertation that will be submitted to examiners at other universities for examination purposes, (ii) The researcher also intends to write about the research in articles and book chapters, and speak about the research at conferences.

This is a once-off study, so the data will not be re-used in any other studies, which the researcher may do in future.

Will you be paid/compensated to take part in this study and are there any costs involved?

You will not be paid/compensated to take part in the study, but refreshments will be given to you after the completion of each test. This will serve as a token of appreciation that you were willing to become part of the research. The writing of the tests and the intervention programme will take place during periods on the normal timetable. You do not have to arrange for additional traveling to participate. No costs will be involved in taking part in the study.

How will you know about the findings?

The general findings of the research will be shared with you via email or post (please include your address below) by the researcher who will compile a short report about the findings that will be provided to all the research participants during a register period. All questions about the report can be directed to the researcher at the contact details below. Alternatively, you are welcome to schedule an appointment with the researcher to discuss your questions. If you wish to receive individual feedback, please indicate this in the

Is there anything else that you should know or do?

You can contact Mr Francois Minnie at 084 549 2583 or 23512326@nwu.ac.za or his study leader, Prof. Mary Grosser at 083 490 0501 or mary.grosser@nwu.ac.za, if you have any further queries or encounter any problems.

You can contact the c
hair of the Humanities and Health Research Ethics Committee (Prof Linda Theron) at 016 910 3076 or Linda.theron@nwu.ac.za if you have any concerns or complaints that have not been adequately addressed by the researcher. You can also contact, the co-chair, Prof Tumi Khumalo (016 910 3397 or Tumi.khumalo@nwu.ac.za). You can leave a message for either Linda or Tumi with Ms. Daleen Claasens (016 910 30441).

If you have difficulty in following and understanding the explanation of the research, please contact the researcher or the independent person at the details below, and they will arrange a time with you to meet with the researcher to explain what is problematic to you.

You will receive a copy of this information and consent form for your own records.

If you are younger than 18, and the researcher discovers any harm done towards you, he must tell someone who can help you.

Declaration by participants

By signing below, I …………………………………..………, agree that I will take part in a research study entitled: **The impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers**

I declare that:

- I have read and understood this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions to both the person obtaining consent, as well as the researcher (if this is a different person), and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to give consent that my son/daughter may take part.
- I understand that my test results could be reproduced publically and/or quoted, but without reference to me or my parents'/guardians' personal identity.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…........…………….. on (*date*) …………...……….. 20....

....	....
Signature of participant	**Signature of witness**

- You may contact me again ☐ **Yes** ☐ **No**
- I would like a summary of the findings of this research ☐ **Yes** ☐ **No**
- **I would like to receive individual feedback of the findings of this research** ☐ **Yes** ☐ **No**

The best way to reach me is:
Name & Surname: ____
Postal Address: ____
Email: ____
Phone Number: ______________________
Cell Phone Number: _______________________

In case the above details change, please contact the following person who knows me well and who does not live with me and who will help you to contact me:
Name & Surname:

____

Phone/ Cell Phone Number /Email:

____

Declaration by person obtaining consent

I *(name)* ……………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did not use an interpreter.

The best way to reach me is:
Name & Surname: ____
Postal Address: ____
Email: ____
Phone Number: ______________________
Cell Phone Number: _______________________

Signed at (*place*) ....…........…………….. on (*date*) …………...……….. 20....

....

Signature of person obtaining consent **Signature of witness**

Declaration by researcher

I *(name)* …………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use a interpreter.

Signed at (*place*) ....…........…………….. on (*date*) …………...……….. 20....

....	....
Signature of independent person	**Signature of witness**

LEARNERS (AFRIKAANS)

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAALDRIEHOEKKAMPUS

2.

HHREC Stempel

Posbus 1174, Vanderbijlpark
Suid Afrika, 1900
Web: http://www.nwu.ac.za

DATUM: 3 September 2015

DEELNEMER SE INLIGTINGSBROSJURE EN INGELIGTE TOESTEMMINGSVORM VIR B.ED. EERSTEJAAR STUDENTE IN LEWENSWETENSKAP

Titel van navorsingsprojek: Die impak van Denkkaarte om die ontwikkeling van kritiese denkvaardighede by eerstejaar voordiens Lewenswetenskap-onderwysers te koester

VERWYSINGSNOMMER :

HOOF-NAVORSER: Mnr Francois Minnie

ADRES: SKOOL VIR OPVOEDKUNDIGE WETENSKAPPE, NOORDWES-UNIVERSITEIT, HENDRICK VAN ECK BOULEVARD 100, VANDERBIJLPARK

KONTAKNOMMER: 016 3074/08 454 92583

U word uitgenooi om deel te neem aan 'n navorsingsprojek wat deel vorm van my, die navorser, se studie vir die verwerwing van 'n Meestersgraad in Opvoedkunde. Gebruik asseblief tyd om deur die inligting wat hier aangebied word om die navorsingsprojek te verduidelik, te lees. Vra asseblief vrae aan die navorser oor enige deel van die projek wat u nie ten volle verstaan nie. Dit is baie belangrik dat u heeltemal tevrede voel en duidelik verstaan waaroor die navorsing gaan en hoe u betrek kan word. U deelname is heeltemal vrywillig en u mag te enige tyd deelname aan die navorsing van die hand wys. As u nie toestemming gee dat u aan die navorsing gaan deelneem nie, sal dit u geensins negatief beïnvloed nie. U mag u ook enige tyd aan die studie onttrek, al sou u toestem dat u aan die navorsing gaan deelneem. U mag my ook versoek om enige inligting/data wat ek oor u ingesamel het te vernietig. U moet ook weet dat indien u jonger as 18 jaar is, u ouers ook toestemming moet gee dat u aan die navorsing mag deelneem. U het egter nog steeds die keuse om self te besluit of u wil deelneem of nie.

Hierdie studie is goedgekeur deur die **Humanities and Health Research Ethics Committee (HHREC) van die Fakulteit Geesteswetenskappe aan die Noord-Wes Universiteit, Vaal Driehoekkampus, Vanderbijlpark.** Die navorsing sal uitgevoer word in ooreenstemming met die etiese riglyne en beginsels van die internasionale Deklarasie van Helsinki en die National Health Research Ethics Council. Dit mag nodig wees dat lede van die etiekkomitee of relevante gesaghebbendes die navorsing ondersoek om seker te maak dat die navorser die navorsing op 'n etiese manier uitvoer.

Waaroor gaan die navorsing?

Ek, die navorser is mnr. Francois Minnie, u dosent in Lewenswetenskap, wat graag wil dat u aan my navorsingsprojek, wat ek vir my Meestersgraad in Opvoedkunde wil voltooi, deelneem. My navorsingsprojek sal by die Noordwes-Universiteit se Vaal Driehoekkampus in Vanderbijlpark uitgevoer word.

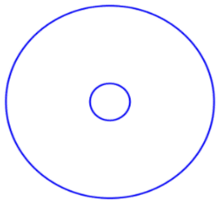
Die navorsing skakel goed met die huidige onderrig en leersituasie in Suid-Afrikaans skole, waar dit van onderwysers verwag word om leerders vaardighede te leer om probleme op te los deur middel van kritiese en kreatiewe denke. My studie gaan spesifiek op kritiese denke fokus. In my studie gaan kritiese denke soos volg verstaan word. Die deelnemers aan die navorsing moet in staat wees om inligting te analiseer, sintetiseer en evalueer. Om inligting te analiseer beteken om inligting in kleiner dele op te breek. Sintese beteken om verskillende idees of inligting te kombineer om 'n nuwe idee te vorm. Om te evalueer beteken om die waarheid of waarde van iets te beoordeel en 'n antwoord te motiveer.

Die belangrikste doelstellings van my studie is:

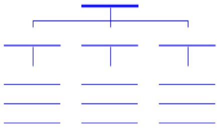
(i) Om vas te stel hoe goed die kritiese denkvaardighede (analise, sintese en evaluering) by eerstejaar Lewenswetenskap-studentonderwysers ontwikkel is gedurende hulle skoolloopbane.

(ii) Om vas te stel of die gebruik van Denkkaarte as onderrigstrategie die ontwikkeling van kritiese denkvaardighede wat moontlik verdere ontwikkeling nodig het, of verbeter kan word, bevorder. Denkkaarte is 'n visuele leerstrategie waar 'n student leer om inligting hulle eie te maak deur dit op te som met behulp van 'n kaart. Ek gaan van drie strategieë tydens die navorsing gebruik maak, naamlik:

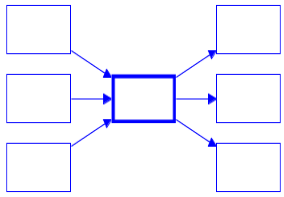
- ✓ 'n Sirkelkaart om sintese as vaardigheid te ontwikkel



- ✓ 'n Boomkaart om analise as vaardigheid te ontwikkel



✓ ‘n Multi-vloeikaart om evaluasie as vaardigheid te ontwikkel



Alhoewel baie internasionale studies bevind het dat Denkkaarte suksesvol is vir die ontwikkeling van denkvaardighede, is nog geen studies gedoen om die effektiwiteit van Denkkaarte as onderrigstrategie vir die ontwikkeling van kritiese denkvaardighede by Lewenswetenskap-studentonderwysers in die Suid-Afrikaanse konteks vas te stel nie, veral nie die vaardighede soos analise, sintese en evaluasie nie. Hierdie vaardighede is belangrik vir die bemeestering van die Lewenswetenskap-vakinhoud op eerstejaar B.Ed.-vlak.

Die navorser wil graag alle 2016 eerstejaar B.Ed.-studente met Lewenswetenskap as hoofvak by die navorsing betrek. Ek sal die deelnemers aan die navorsing werf deur toestemming te verkry by die Direkteur van die Skool vir Opvoedkundige Wetenskappe, Prof. J.E. Fourie, wat as hekwagter sal optree om vir hom toegang tot die studente te gee.

Gebaseer op die getalle van studente wat die afgelope twee jaar ingeskryf het met Lewenswetenskap as hoofvak, sal ongeveer 60-70 studente in 2016 Lewenswetenskap as hoofvak neem. Die navorser wil graag met hierdie nuwe groep studente werk aangesien hulle nog nie blootgestel was aan of oorlaai is met navorsing wat by die universiteit onderneem word nie.

Hoekom is u genooi om deel te neem?

Dit sal belangrik wees om navorsing met u te doen, aangesien ek u Lewenswetenskapdosent is wat self die nuwe onderrigstrategie wil gebruik om die kwaliteit van my eie onderrigpraktyk te verbeter. Tweedens was die navorser baie jare lank ‘n Lewenswetenskap- onderwyser, en weet dat onderwysers nie kennis het van onderrigstrategieë wat hulle kan gebruik om kritiese denkvaardighede in Lewenswetenskap te verbeter nie. Om navorsing met die eerstejaar Lewenswetenskap-studentonderwysers te doen sal my ‘n kans gee om ‘n strategie vir ‘n groep Lewenswetenskap-studentonderwysers aan te leer wat hulle sou kon gebruik om kritiese denke moontlik meer effektief te koester op skoolvlak as hulle begin skoolhou. Die fokus is op eerstejaar studente omdat ek hulle reeds in hul eerste jaar wil leer hoe om die strategie te gebruik, en hulle dan aan te moedig om die strategie toe te pas gedurende hulle vier jaar van opleiding, sodat hulle, wanneer hulle begin skool hou, moontlik goeie leiding aan leerders sal kan gee om ook die strategie te gebruik. Die navorser is opgelei deur ‘n geakkrediteerde opleier om Denkkaarte te gebruik.

Opsommenderwys is u gekies om deel te neem aan die studie omdat:

(i) U ‘n manlike of vroulike eerstejaar B.Ed.-student aan die Noordwes-Universiteit se Vaaldriehoekkampus in Vanderbijlpark is, afkomstig is van enige etniese en taalgroep, en Lewenswetenskap op matriekvlak geslaag het.

(ii) U ‘n eerstejaar B.Ed.-student is wat Lewenswetenskap as een van sy/haar hoofvakke neem.

Uitsluitingskriteria: Deelnemers sal nie by die studie betrek word as hulle ‘n tweedejaar, derdejaar of vierdejaar B.Ed.-student aan die Noordwes-Universiteit se Vaaldriehoekkampus in Vanderbijlpark of enige ander universiteit is nie.

Wat sal u verantwoordelikhede wees?

Die navorser gaan gebruik maak van ‘n onafhanklike persoon, Mev. Daphne Strauss, ‘n ervare sekondêre skoolonderwyseres, wat gaan help met die werwing van die deelnemers vir die navorsingsprojek. Die navorser sal haar oplei vir hierdie doel. Sy sal bygestaan word deur ‘n onafhanklike waarnemer, Mev. Aldine Oosthuyzen. Mev. Oosthuyzen ken die studie goed omdat sy as onafhanklike statistikus die vaslegging van data gaan doen en behulpsaam gaan wees met die analise van die data. Mev. Oosthuyzen is ook ‘n lid van die Etiese Komitee van die Skool vir Ekonomiese Wetenskappe en IT aan die NWU, Vaal Driehoekkampus, en het ‘n goeie begrip van etiese beginsels tydens navorsing. Sy sou dus tydens haar waarneming kon verseker dat die werk van Mev. Strauss voldoen aan goeie etiese praktyk. Mev. Strauss en Mev. Oosthuyzen sal geen verbintenis met die LIFE 111 studente hê nie.

Die werwing gaan ‘n kort een-uur en 20 minute aanbieding deur Mev. Strauss aan al die 2016 Lewenswetenskap eerstejaar B.Ed.-studente in die Lewenswetenskap lesinglokaal by die universiteit behels. Daarna sal sy die ingeligte toestemmingsvorms aan die deelnemers uitdeel, die inligting verduidelik en aan die deelnemers noem dat hulle self ook deur die inligting moet werk, die vorms huis-toe moet neem en op hulle eie tyd en in privaatheid die vorm moet voltooi en aandui of hulle wil deelneem aan die navorsing of nie. Die werwing sal aan die begin van die jaar, voordat die klasse begin plaasvind tydens ‘n registerperiode op die rooster. Indien u afwesig is tydens die werwingsessie en u stel belang om aan die navorsing deel te neem, sal die onafhanklike persoon versoek word om ‘n opvolgsessie met al die deelnemers wat afwesig was te reël op ‘n tyd wat die onafhanklike persoon en die deelnemers sal pas.

Die navorser sal vroegtydig aan die B.Ed. Programbestuurder, Dr Elize Küng, ‘n versoek rig dat daar voorsiening gemaak moet word vir ‘n registerperiode op die rooster vir die 2016 eerstejaar B.Ed.-studente, verkieslik op dieselfde dag as die LIFE 111 lesings. Die navorser sou dan hierdie periode kon gebruik vir administatiewe sake rondom die navorsing, soos vir die ontvang van die ingeligte toestemmingsvorms, die skryf van voortoetse en posttoeste, geleentheid om die deelnemers kans te gee om hul sienings oor die navorsing te deel en om terugvoer oor die navorsing te gee. Die navorser sal sorg dat een week verloop tussen die werwing en die inneem van ingeligte toestemming, om deelnemers die kans te gee om na te dink oor die studie en of hulle wil deelneem of nie. Na een week, sal die onafhanklike persoon weer die deelnemers ontmoet en die ingeligte toestemmingsvorms inneem. Die deelnemers wat besluit om deel te neem aan die navorsing sal dan deur die onafhanlike persoon in eksperimentele en kontrole groepe verdeel word. Deelnemers sal ‘n nommer ontvang wat hulle tydens die skryf van die toetse gaan gebruik. Indien u besluit om aan die navorsing te onttrek, hoef u nie die voortoetse en natoetse te skryf nie, en ook nie die besprekings en terugvoer sessies by te woon nie. Omdat die navorsing egter die onderrig van die Lewenswetenskap vakinhoud behels, moet u nog steeds die klasse in een van die groepe, A of B, bywoon.

Indien u aan die navorsing gaan deelneem, sal u deel wees van ‘n eksperimentele en kontrole groep wat op rotasiebasis tydens die navorsing aan twee eksperimente, eksperimente 1 en 2, wat elk ses weke lank gedurende die eerste semester (Februarie tot Mei 2016) sal plaasvind, sal deelneem. Daar sal na die groepe as Groep A en B verwys word, sonder om aan die studente ‘n aanduiding te gee watter groep die eksperimentele groep, en watter groep die kontrole groep is. Die eksperimentele groep en kontrole groep sal elk uit ongeveer 30 deelnemers bestaan. Die deelnemers vir die eksperimentele en kontrole groepe sal deur die onafhanlike persoon bepaal word, deur deelnemers min of meer gebalanseerd en gelykop ten opsigte van geslag, taal, etniese groep, tipe skool bygewoon en matriekpunt vir Lewenswetenskap in die eksperimentele en kontrole groepe in te deel.

Die eksperimentele groep sal die groep deelnemers wees waar ek die nuwe onderrigstrategie, Denkkaarte, vir ‘n tydperk van ses weke sal gebruik om vas te stel of die nuwe strategie die deelnemers sal help om hul kritiese denkvaardighede te verbeter of verder te ontwikkel. Die kontrole groep sal die groep deelnemers wees wat nie onderrig met die nuwe onderrigstrategie, Denkkaarte, sal ontvang nie. Die navorser sal slegs gewone lesings vir ‘n tydperk van ses weke aan hulle aanbied. In beide groepe sal ek dieselfde vakinhoud aanbied. As u deel is van die eksperimentele groep tydens eksperiment 1, sal u dan deel wees van die kontrole groep tydens eksperiment 2, en andersom. Al die deelnemers gaan dus ‘n kans kry om onderrig deur middel van Denkkaarte te ontvang.

Aangesien die vakinhoud van Lewenswetenskap op eerstejaarsvlak dieselfde is as die vakinhoud wat op Graad 12 vlak hanteer word, gaan die navorser van voortoetse gebruik maak om vas te stel hoe goed u die kritiese denkvaardighede om te analiseer, sintetiseer en te evalueer in Lewenswetenskap op skool aangeleer het. ‘n Voortoets, voortoets 1, sal aan die begin van eksperiment 1 geskryf word en sal gebaseer wees op die vakinhoud wat ons tydens die eerste ses weke van semester 1 gaan behandel. Op dieselfde manier sal voortoets 2 aan die begin van eksperiment 2 geskryf word, wat op die vakinhoud wat ons in die laaste 6 weke van semester 1 gaan behandel, gebaseer sal wees. Met die voortoetse wil die navorser hoofsaaklik vasstel hoe goed u kritiese denkvaardighede op skool ontwikkel is, voordat hy Denkkaarte as onderrigstrategie gebruik. In totaal, gaan u 2 voortoetse van ongeveer 30 minute elk skryf.

Gebaseer op die voortoets resultate, sal die navorser die onderrigprogram waar hy Denkkaarte gaan gebruik, ontwikkel, om die probleme met kritiese denke wat hy tydens die voortoetse aan die begin van die eerste ses weke en die tweede ses weke van die eerste semester gedurende 2016 opgemerk het, aan te spreek. Indien die voortoetse sou uitwys dat die deelnemers nie probleme met die kritiese denkvaardighede ervaar nie, sal die navorser steeds die strategie toepas om te kyk of die navorser die toepassing van die kritiese denkvaardighede nog beter kan ontwikkel.

Die Lewenswetenskap deelnemers het twee Lewenswetenskap periodes per week van 1 uur en 20 minute elk op die universiteitsrooster. Een van die periodes is ‘n praktiese periode en die navorser sal nie tydens hierdie periode met Denkkaarte onderrig gee nie, maar slegs gewone lesings aanbied. Die oorblywende periode wat fokus op teoretiese vakinhoud sal gebruik word om Denkkaarte as onderrigstrategie toe te pas. Die onderrig in die eksperimentele en kontrole groepe sal op aparte tye en in aparte lokale plaasvind. Die kontrole groep sal normale lesings tydens hulle klasperiode van 1 uur en 20 minute een keer per week, soos deur die universiteit toegeken is, ontvang. Die eksperimentele groep sal onderrig met behulp van Denkkaarte een keer per week tydens hulle periode van 1 uur en 20 minute ontvang.

Wanneer die implementering van die Denkkaart-onderrigprogam voltooi is, sal natoets 1 na afloop van die eerste ses weke van semester 1 geskryf word en natoets 2 na afloop van die laaste ses weke van semester 2. Die natoetse word geskryf om te sien of Denkkaarte u gehelp het om die kritiese denkvaardighede van analise, sintese en evaluasie in die konteks van die vakinhoud wat tydens elke eksperiment hanteer is, te ontwikkel of te verbeter. In totaal sal u twee natoetse van 30 minute elk skryf.

In die tabel hier onder word die implementering van die navorsingseksperiment opgesom.

Weke1-6: Semester 1- Eksperiment 1: Februarie – middel Maart 2016			
Voortoets 1	Eksperimentele groep Denkkaarte 6 weke	Kontrole groep Normale klasonderrig (lesings) 6 weke	Natoets 1
Groepe roteer Weke 7-12: Semester 1 – Eksperiment 2: April – middel Mei 2016			
Voortoets 2	Eksperimentele groep Normale klasonderrig (lesings) 6 weke	Kontrole groep Denkkaarte 6 weke	Natoets 2

Die voortoetse en natoetse sal uit 15 multi-keuse vrae bestaan, waar elke vraag een korrekte antwoord sal hê. Elke vraag het ook ‘n opvolgvraag waar u ‘n antwoord moet motiveer. U moet u antwoord motiveer om raaiwerk te ontmoedig en sodat die navorser kan vasstel hoe goed u kan redeneer/argumenteer. Die multi-keuse vrae sal ‘n gelyke aantal vrae bevat vir die verskillende vaardighede, naamlik analise (5 vrae), sintese (5 vrae) en evaluasie (5 vrae). Die vrae in die voortoetse en natoetse sal nie dieselfde wees nie, omdat die toetse elk op verskillende vakinhoud van die eerste ses en tweede ses weke van semester 1 onderskeidelik, gebaseer sal wees.

Die moeilikheidsgraad van die toetse en die vaardighede wat getoets word, naamlik analise, sintese en evaluasie, sal dieselfde wees. Om seker te maak dat die moeilikheidsgraad van al die toetse dieselfde is, sal die navorser vier ervare kollegas wat universiteitsdosente in Lewenswetenskap is, inskakel om die moeilikheidsgraad van al die toetse onafhanklik te evalueer. Die navorser sal aandag gee aan hulle kommentaar en indien nodig, die toetse aanpas.

‘n Voorbeeld van hoe die vrae gestel gaan word verskyn hier onder.

Kies die korrekte antwoord deur ‘n sirkel om die korrekte antwoord (1-4) te maak. Motiveer skirftelik hoekom u die antwoord gekies het.

Proteïne word gemaak van aminosure deur die proses van:

1.hidrolis

2.pinositosis

3.aktiewe vervoer

4.dehidrasie-sintese

Korrekte antwoord: 4

Motivering: Proteïne is groot kettings van aminosure wat gekombineer word deur middel van dehidrasie-sintese, waar molekules saamgevoeg word deur water te verwyder. Hidrolise breek die proteïne af in aminosure. Pinositosis is ‘n metode waardeur groot onoplosbare molekules ingeneem word, en word beskou as ‘n vorm van aktiewe vervoer.

Aan die einde van die navorsing, sal die navorser die voortoets en natoets resultate van al die deelnemers vergelyk om vas te stel watter strategie die deelnemers se kritiese denkvaardighede die beste ontwikkel het: Denkkaarte of normale lesings. Op aanbeveling van die onafhanklike statistiese konsultant wat die navorser gaan help met die analise van die data, gaan vergelykings ook ten opsigte van individuele deelnemers se toetsresultate gedoen word, aangesien dit moontlik is dat die nuwe strategie individuele deelnemers beter mag baat as die groep. Die deelnemers sal elkeen vir hierdie doel ‘n nommer ontvang wat hulle deurgaans op hulle voortoetse en natoetse gaan aanbring sodat dit vir die navorser moontlik sal wees om vergelykings ten opsigte van die verskillende toetse gekoppel aan ‘n nommer ook uit te voer. Geen vergelyking sal egter aan ‘n deelnemer se naam gekopppel word nie.

Geleentheid vir die deelnemers om hulle menings oor die navorsing te gee, asook geleentheid vir terugvoer deur die navorser oor die navorsingsbevindinge, sal geskeduleer word.

Opsommenderwys gaan u deelname die volgende behels: (Presiese datums en tye sal verskaf word sodra die klasrooster vir 2016 gefinaliseer is)

1. Uitnodinging en verduideliking van ingeligte toestemming (1 uur en 20 minute).
2.Die voltooiing van ingeligte toestemming (Tuis, 1 week).
3.Inhandiging van ingeligte toestemming.
4.Selektering tot ‘n eksperimentele en kontrole groep.
5.Die skryf van voortoetse (30 minute) voordat u deelneem aan Eksperiment 1: Die implementering van die Denkkaarte onderrigstrategie tydens die LIFE 111 lesings vir ses weke (1 uur en 20 minute per week) as deel van die eksperimentele groep, of as deel van die kontrole groep wat slegs normale lesings vir ses weke (1 uur en 20 minute per week) sal ontvang.
6.Die skryf van natoetse (30 minute) na die implementering van Denkkkaarte en normale lesings vir ses weke onderskeidelik tydens Eksperiment 1.
7.Deelname aan ‘n omgekeerde eksperiment, Eksperiment 2, tydens die LIFE 111 lesings waar die eksperimentele groep die kontrole groep word, en die kontrole groep die eksperimentel groep word. Die eksperimentele groep sal weer vir ses weke onderrig met Denkkaarte ontvang (1 uur en 20 minute per week) en die kontrole groep vir ses weke onderrig met behulp van normale lesings sal ontvang (1 uur en 20 minute per week). Die skryf van voortoetse (30 minute) en natoese (30 minute) voor en na die ses weke sal ook van toepassing wees.
8.Een bespreking waar deelnemers hulle menings oor die navorsing kan gee aan die einde van Eksperiment 2 (1 uur en 20 minute tydens ‘n register periode) na afloop van die intervensie met die Denkkaarte.
9.Terugvoer oor die navorsing: Sessie 1: Aan die einde van Eksperiment 1 (1 uur en 20 minute tydens ‘n registerperiode). Sessie 2: Aan die einde van Eksperiment 2 (1 uur en 20 minute tydens ‘n registerperiode).
10.‘n Finale terugvoersessie oor die navorsingsbevindinge (1 uur en 20 minute tydens ‘n registerperiode)

Sal u baat vind deur aan die navorsing deel te neem?

Die onmiddellike voordele vir u as deelnemer sal waarskynlik die volgende wees:

(i) U mag moontlik die kritiese denkvaardighede deur middel van Denkkaarte aanleer wat u in kan staat stel om inligting meer effektief te analiseer, sintetiseer en evalueer.
(ii) Denkkaarte is ook ‘n effektiewe leerstrategie wat jou sou kon help om beter te studeer en moontlik u akademiese prestasie in enige vak te verbeter.
(iii) ‘n Ander voordeel sou wees dat u moontlik oor ‘n effektiewe strategie sou kon beskik wanneer u begin skoolhou.

Die indirekte voordele sal waarskynlik wees dat:

(iv) Navorsers by ander universiteite sou moontlik kon kennis neem van die voordele van Denkkaarte as onderrigstrategie om kritiese denkvaardighede te verbeter, en verdere studies in ander kontekste sou kon onderneem om die voordele van die strategie vir die ontwikkeling van kritiese denkvaardighede op groter skaal te bewys.
(v) Die navorsingsbevindinge sou gebruik kon word om aanbevelings aan die Departement van Onderwys te maak met betrekking tot die moontlike verbetering van die onderrigpraktyk in Lewenswetenskap op skool, om te verseker dat kritiese denke wel in klaskamers op skool ontwikkel word.
(vi) Die groter populasie van Lewenswetenskap-onderwysers se onderrigpraktyk sou kon baat as Denkkaarte as onderrigstrategie meriete inhou vir die ontwikkeling van kritiese denke in Lewenswetenskap en hierdie bevinding aan Skole vir Opvoedkundige Wetenskappe aan Universiteite gekommunikeer kan word en opleiding in die gebruik van die strategie deel gemaak kan word van die kurrikulum vir onderwysersopleiding.

Is daar enige risiko’s betrokke by u deelname aan die navorsing en hoe gaan die risiko’s bestuur word?

Die volgende risiko’s is betrokke by die studie, en in die tabel hieronder verduidelik die navorser hoe hy die risiko’s gaan bestuur.

Moontlike/waarskynlike risko’s /ongemak	***Strategieë om risiko’s en ongemak te verminder***
Botsende belange en die magsverhouding wat bestaan omdat die navorser ook die deelnemers se Lewenswetenskapdosent is.	Die navorser erken dat die groep deelnemers kwesbaar is as gevolg van botsende belange en die hiërargiese dosent-student verhouding wat bestaan omdat hy die deelnemers se dosent is. Deur gebruik te maak van ‘n onafhanklike persoon vir die werwing van deelnemers, die verkryging van ingeligte toestemming, die selektering van deelnemers tot die eksperimentele en kontrole groepe en die afneem van toetse vir data insameling, is die navorser van mening dat hy kwesbaarheid sal verminder. Die onafhanklike peroon sal verhoed dat die deelnemers voel dat hulle

	gedwing word om aan die navorsing deel te neem of voel dat hulle beïnvloed word om deel te neem as gevolg van die student-dosent verhouding. Die onafhanklike persoon sal die deelnemers nie ken nie en ook nie kontak met hulle hê nie, omdat sy nie klas gee vir eerstejaar-studente nie. Dit sal verseker dat die deelnemers nie verplig voel om iets teen hulle wil te doen nie, of voel dat hulle bedreig word, onder druk geplaas word of oorreed word om deel te neem aan die navorsing omdat die navorser hulle dosent is nie. Die studie kan nie gedoen word sonder die insluiting van die groep deelnemers nie. ‘n Belangrike doel met die studie is om die deelnemers reeds van hulle eerstejaar af behoorlik toe te rus om 'n onderrigstrategie te gebruik om kritiese denke moontlik tydens onderrig te ontwikkel.
Die navorser kan nie algehele anonimiteit waarborg nie.	Die onafhanklike persoon/navorser sal die deelnemers bewus maak van die feit dat, hoewel dié wat aan die navorsing gaan deelneem, anoniem sal bly vir die navorser (hulle dosent) wanneer hulle die voortoetse en natoetse skryf, algehele anonimiteit nie gewaarborg kan word nie. Die deelnemers wat die toetse skryf sal nie anoniem vir die res van hulle maats wees wat saam met hulle die toetse skryf nie. Geen resultate sal egter direk aan ‘n deelnemer se naam gekoppel word nie, maar aan die nommer wat gebruik sal word om die deelnemers te identifiseer. Die onafhanklike persoon wat die verskillende toetsuitslae sal versamel om vergelykings te maak, sal weet watter naam aan watter nommer gekoppel is. Sy sal die inligting vertroulik hanteer, en slegs die nommer en die toetsuitlslae aan die navorser en die onafhanklike statistikus rapporteer. Deelnemers sal ook bewus gemaak word van die feit dat hoewel hulle mag besluit om nie aan die navorsing deel te neem nie, en nie die toetse skryf nie, hulle steeds onderrig deur middel van Denkkaarte gaan ontvang. Die gebruik van Denkkaarte is gekoppel aan die vakinhoud van die module, LIFE 111 – Lewenswetenskap, wat hulle moet slaag.

	Blootstelling aan die nuwe onderrigstrategie kan egter vir hulle ook voordelig wees. Die gebruik van Denkkaarte as onderrigstrategie gaan dus nie inmeng met normale klastyd nie, maar deel daarvan vorm.
Die skryf van toetse mag angs en stres veroorsaak.	Die onafhanklike persoon wat die werwing sal hanteer en die ingeligte toestemming van u sal verky, sal die volgende aan u verduidelik: (i) U hoef nie vir die toetse voor te berei of te studeer nie. (ii) Die toetse sal geskryf word in tye wat vir die deelnemers gerieflik sal wees, verkieslik gedurende 'n oop periode op die rooster sodat addisionele ryery om die toetse te skryf, nie sal plaasvind nie. Die navorser gaan reël vir 'n vaste registerperiode op die rooster vir eerstejaar studente van 2016 vir hierdie doel. (iii) Die toetse sal nie invloed uitoefen op die deelnemer se slaag of druip van die Lewenswetenskap module, LIFE 111 nie. (iv) Die toetsresultate gaan slegs vir navorsingsdoeleindes gebruik word om vas te stel of die gebruik van Denkkaarte effektief is vir die ontwikkeling of verbetering van kritiese denkvaardighede of nie. (v) Die inoud waarop die toetse gebaseer gaan wees, gaan vir die deelnemers bekend wees, aangesien die inhoud reeds in Graad 12 behandel is. Dit mag angs verlig. (vi) Vir die maak van individuele vergelykings, sal die deelnemers met behulp van nommers aan die navorser uitgeken word. Die navorser sal nie weet wie 'n toets gekryf het of nie (die navorser gaan nie betrokke wees by die afneem van die toetse nie). Die onafhanklike persoon sal die statistikus help om die individuele toetspunte te selekteer vir die vergelykings wat gemaak gaan word. Die navorser sal slegs die

		nommers van die deelnemers met hulle punte vir die verskillende toetsgeleenthede ontvang.
	(vii)	Die fokus van die toetse gaan nie op slaag of druip wees nie, maar of die deelnemers kritiese denkvaardighede kan toepas of nie.

Die navorser het gepaste maatreëls in plek gestel om die navorsingsverwante risiko's te verminder, sodat die deelnemers die voordele wat die navorsing mag inhou, soos hierbo vermeld, kan ervaar. Die risiko's blyk redelik te wees in verhouding tot die belangrikheid van die kennis wat verwerf kan word wat die moontlike verbetering van onderrig in Lewenswetenskap tot gevolg kan hê.

Wie sal toegang tot die data hê?

U toetsresultate sal nie aan u naam gekoppel word nie. U sal nie 'n naam op 'n toets skryf nie, maar met 'n nommer uitgeken word (1, 2 ens.). Alle resultate sal bekend gemaak word deur dit aan 'n nommer te koppel. U sal anoniem bly vir die navorser. Geen name sal vermeld word in bevindinge wat uit die navorsing voortspruit nie. Die navorser verseker u dat ons die inligting wat ons oor u seun/dogter het, sal beskerm. Alle inligting rakende die navorsing sal gestoor word op 'n rekenaar wat met 'n wagwoord beskerm is en die voltooide toetse sal in 'n kas in die navorser se kantoor toegesluit word. Die navorser is die enigste persoon wat 'n sleultel het om die kas oop te sluit.

Dit is belangrik om te weet dat vertroulikheid in die studie beperk sal wees. Buiten die onafhanklike persoon, sal slegs twee ander mense ook toegang tot die data hê, naamlik die onafhanklike statistikus wat my sal help met die vaslegging van die data, en die studieleier wat kontrole gaan uitoefen om te verseker dat die navorsingsbevindinge korrek is. Die onafhanklike statistikus is Me Aldine Oosthuyzen, 'n ervare en gekwalifiseerde statistikus aan die Noordwes-Universiteit se Vaaldriehoekkampus. Die navorser sal die data vir 'n minimum van vyf jaar stoor. Die onafhanklike persoon, die studieleier en die onafhanklike statistikus sal 'n geskrewe ooreenkoms teken aan die begin van die navorsing dat hulle onderneem om alle inligting met betrekking tot die navorsing en die data vertroulik te hanteer, en nie daaroor te praat nie.

Wat gaan met die data gebeur?

Die navorser verseker u dat die inligting wat via die navorsing verkry word, slegs vir navorsingsdoeleindes gebruik gaan word. Geen inligting oor u sal bekend gemaak word in verslae oor die studie nie (byvoorbeeld u ouers/voog se naam, u naam of adres).

Die data van die studie gaan as volg grerapporteer word: (i) die navorser sal die navorsingbevindinge in die vorm van 'n proefskrif rapporteer wat vir eksamineringsdoeleindes aan eksaminatore by ander universiteite voorgehou sal word, (ii) die navorser beoog ook om oor die navorsing te skryf in artikels en boek-hoofstukke, en om aanbiedings oor die navorsing by konferensies te doen.

Hierdie studie is eenmalig en die data sal nie hergebruik word in ander toekomstige studies nie.

Gaan u betaal of vergoed word om aan die studie deel te neem/ is daar enige kostes betrokke?

U gaan nie betaal of vergoed word om aan die studie deel te neem nie. Verversings sal aan u na afloop van die toetse verskaf word. Die verversings sal 'n blyk van waardering wees vir die tyd wat u opgeoffer het om aan die navorsing deel te neem. Die skryf van die toetse en die onderrig met behulp van Denkkaarte sal plaasvind gedurende periodes wat op die klasrooster geskeduleer is. U hoef dus nie vir addisionele vervoer te reël om op ander tye aan die navorsing deel te neem nie. Geen kostes is dus betrokke by deelname aan die navorsing nie.

Hoe gaan ek weet wat die bevindinge is?

Die algemene bevindinge van die navorsing sal die navorser met u deel via epos of gewone pos (verskaf asseblief u adres hieronder) deur 'n kort verslag saam te stel wat aan al die deelnemers beskikbaar gestel sal word. Alle vrae oor die verslag kan direk aan die navorser gerig word by die kontakbesonderhede hieronder. U is ook welkom om met die navorser 'n afspraak te maak om u vrae te bespreek.

Is daar iets anders wat ek behoort te weet?

U kan mnr. Francois Minnie by 084 549 2583 of 23512326@nwu.ac.za of sy studieleier, Prof. Mary Grosser by 083 490 0501 of mary.grosser@nwu.ac.za, kontak as u enige verdere navrae het of probleme teekom.

U kan die voorsitter van die Humanities and Health Research Ethics Committee (Prof Linda Theron) by 016 910 3076 of Linda.theron@nwu.ac.za kontak as u enige bekommernis of klagte het wat nie voldoende deur die navorser aangespreek is nie. U kan ook die mede-voorsitter, Prof. Tumi Khumalo (016 910 3397 of Tumi.khumalo@nwu.ac.za) kontak, of 'n boodskap vir Linda of Tumi los by Me Daleen Claasens (016 910 30441).

As u dit moeilik vind om die verduideliking van die navorsing te volg, kontak asseblief die navorser of die onafhanklike persoon by die kontakbesonderhede hier onder. Hulle sal met u 'n tyd reël om die navorser te ontmoet om aan u te verduidelik wat vir u problematies is.

U sal 'n kopie van die inligting en toestemming ontvang wat u vir u eie rekords kan hou.

Indien u jonger as 18 jaar is, en die navorser kom tydens die navorsing agter dat daar leed aan jou gedoen word, moet hy iemand daarvan vertel sodat jy hulp kan ontvang.

Verklaring deur student

Deur hier onder te teken, verklaar ek…………………………..dat ek dit goedkeur dat ek aan die volgende navorsingstudie gaan deelneem: **Die impak van Denkkaarte om die ontwikkeling van kritiese denkvaardighede by eerstejaar voordiens Lewenswetenskap- onderwysers te koester**

Ek verklaar die volgende:

- Ek het die inligting gelees en verstaan die inligting in die ingeligte toestemmingsvorm, en dat dit in ‘n taal geskryf is wat ek gemaklik mee is en vlot praat.
- Ek het ‘n kans gehad om vrae te stel aan die persoon wat die ingeligte toestemming verkry het sowel as aan die navorser (as hierdie ‘n ander persoon is), en al my vrae is voldoende beantwoord.
- Ek verstaan dat deelname aan die studie **vrywillig** is, en ek is nie onder druk geplaas om toestemming te gee dat ek moet deelneem nie.
- Ek verstaan dat my toetsresultate in die openbaar bekend gemaak en/of aangehaal kan word, sonder enige verwysing na my of my ouers se persoonlike identiteit.
- Ek mag kies om my enige tyd aan die studie te onttrek, en dit sal vir my geen penalisering of bevooroordeeldheid inhou nie.
- Ek mag gevra word om die studie te verlaat voordat dit voltooi is, as die navorser voel dat dit in my beste belang is, of as ek nie hou by die navorsingsplan waarop ooreengekom is nie.

Geteken te (*plek*) ....….......…………….. op (*datum*) …………...……….. 20....

....

Handtekening van deelnemer **Handtekening van getuie**

- U mag my weer kontak ☐ **Ja** ☐ **Nee**
- Ek wil graag ‘n opsomming van die navorsingsbevindinge hê ☐ **Ja** ☐ **Nee**
- Ek wil graag individuele terugvoer oor die navorsingsbevindinge hê ☐ **Ja** ☐ **Nee**

Die beste manier om my te bereik is:

Naam en Van: ____
Posadres: ____
Epos: ____
Telefoonnommer: ______________________
Selfoonnommer: _______________________

Indien die bogenoemde besonderhede verander, kontak asseblief die volgende persoon wat my goed ken, nie saam met my bly nie en sal help om my te kontak.

Naam en Van:
____
Telefoonommer/ Selfoonnommer /Epos:
____

Verklaring deur persoon wat toestemming verkry

Ek *(naam)* ………………………………………………..……… verklaar dat:

- Ek die inligting in die dokument verduidelik het aan……………………………

- Ek hom/haar aangemoedig het om vrae te stel en genoeg tyd toegelaat het om hom/haar te antwoord.
- Ek tevrede is dat hy/sy alle aspekte van die studie soos hierbo bespreek word, genoegsaam verstaan.
- Ek het/het nie ‘n vertaler gebruik het nie.

Die beste manier om my te bereik is:

Naam en Van: ____
Posadres: ____
Epos: ____
Telefoonnommer: ____________________
Selfoonnommer: _____________________

Geteken te (*plek*) ....…........…………….. op (*datum*) …………....……….. 20....

....
Handtekening van onafhanklike persoon **Handtekening van getuie**

Verklaring deur navorser

Ek *(naam)* …………………………………………...……… verklaar dat:

- Ek die inligting in die dokument verduidelik het aan……………………………
- Ek hom/haar aangemoedig het om vrae te stel en genoeg tyd toegelaat het om hom/haar te antwoord.
- Ek tevrede is dat hy/sy alle aspekte van die studie soos hierbo bespreek word, genoegsaam verstaan.
- Ek het/het nie ‘n vertaler gebruik het nie.

Geteken te (*plek*) ....…........…………….. op (*daum*) …………....……….. 20....

....
Handtekening van navorser **Handtekening van getuie**

PARENTS (ENGLISH)

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

3.

HHREC Stamp

PO Box 1174, Vanderbijlpark
South Africa, 1900
Web: http://www.nwu.ac.za

DATE: 3 September 2015

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR PARENTS/GUARDIANS OF FIRST YEAR B.ED. LIFE SCIENCE STUDENTS

TITLE OF THE RESEARCH PROJECT: The impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers

REFERENCE NUMBERS:

PRINCIPAL INVESTIGATOR/RESEARCHER: Mr Francois Minnie

ADDRESS: SCHOOL OF EDUCATION SCIENCES, NORTH-WEST UNIVERSITY, HENDRICK VAN ECK BOULEVARD 100, VANDERBIJLPARK

CONTACT NUMBER: 016 910 3074/084 549 2583

You son/daughter is invited to take part in a research project that forms part of my (the researcher's) study for a Master's degree in Education. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied and that you clearly understand what this research is about and how your son/daughter could be involved. Also, their participation is **entirely voluntary** and he/she is free to decline participation. If you say no, this will not affect your son/daughter negatively in any way whatsoever. You son/daughter is also free to withdraw from the study at any point, even if you do agree that they take part. You may also ask me to delete information/data about your son/daughter that I collected. Your son/daughter will also give consent on his/her own to take part in the study. You need to know that even if you give consent that your son/daughter may take part, they have the choice to decide if they want to take part in the research or not.

This study has been approved by the **Humanities and Health Research Ethics Committee (HHREC) of the Faculty of Humanities of the North-West University (NWU.............)** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. It might be necessary for the research ethics committee members or relevant authorities to inspect the research records to make sure that we (the researchers) are conducting research in an ethical manner.

What is this research study all about?

I am Mr Francois Minnie, the researcher and the Life Science lecturer of your son/daughter, who would like to involve your son/daughter in my research project, which I am completing for a Master's Degree. My research project will be conducted at the North-West University, Vaal Triangle Campus in Vanderbijlpark.

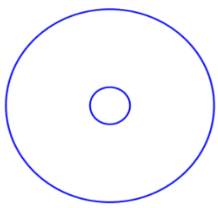
This research links well with the present teaching and learning situation in South African schools, where it is expected of teachers to teach learners the skills to identify and solve problems by means of critical and creative thinking. My study will specifically focus on critical thinking. In my study, critical thinking will mean that the research participants must be able to analyze, synthesize and evaluate information. Analysis means to break up information into smaller parts. Synthesis means to combine different ideas/information into a new idea. Evaluation means to judge the truth or value of something and motivate your answer.

The main objectives of the study are:

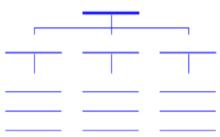
(i) To find out how well the critical thinking skills (analysis, synthesis, evaluation) of first year Life Science teachers were developed during their school years.

(ii) To find out if the use of Thinking Maps as teaching strategy could enhance the development of critical thinking skills that might need further development or improvement. Thinking Maps is a visual learning strategy where a student learns to process and summarize information in a map. The researcher will apply three Thinking Maps during the research, namely:

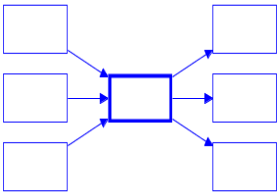
✓ A Circle Map to develop the skill of synthesis



✓ A Tree Map to develop the skill of analysis



✓ A Multi-Flow Map to develop the skill of evaluation



Although many international studies have found the Thinking Maps strategy to be successful for developing thinking skills, no studies have been conducted to test the effectiveness of Thinking Maps as teaching strategy to develop critical thinking skills among Life Science student teachers in the South African context; especially skills like analysis, synthesis and evaluation. These skills are important for mastering the subject content of Life Science at first year B.Ed.-level.

The researcher would like to include all the 2016 first year B.Ed.-students with Life Science as major subject in the research. The researcher will recruit the research participants by obtaining permission from the Director of the School of Education Sciences, Prof. J.E. Fourie, who will act as a gatekeeper to gain entry to the students. Based on the numbers of students who enrolled for Life Science during the past two years, about 60-70 students will take Life Science as major subject in 2016. This group of students will be a new group of students who have not yet been exposed to, or overburdened by research at the university.

Why has your son/daughter been invited to participate?

It will be important to do the research with your son/daughter, as the researcher is their Life Science lecturer and firstly want to use a new teaching strategy to improve the quality of my own teaching practice. Secondly, the researcher was a Life Science teacher for many years, and know that teachers do not know about teaching strategies that they could use to develop the critical thinking skills of learners in Life Science. Doing the research with first year Life Science student teachers will give him the chance to teach a strategy to a group of Life Science teachers which they could use to possibly nurture critical thinking more effectively at school-level, when they start teaching. The focus is on first year participants, as the researcher wants to teach them how to use the strategy in their first year of study and then encourage them to apply it throughout their four years of training, so that when they start teaching, they might be good at guiding the learners whom they will teach to use the strategy too. The researcher has been trained by an accredited Thinking Maps trainer to apply the strategy.

In summary, your son/daughter has been selected to take part in the research because:

(i) He/she is a first year, male or female BEd-student from any ethnic and language group at the North-West University, Vaal Triangle Campus in Vanderbijlpark, who passed Life Science at matric level.

(ii) He/she is a first year BEd-student with Life Science as one of his/her major subjects.

Exclusion criteria: Participants will not be involved in the study if they are a second, third or fourth year B.Ed.-Life Science student at the North-West University, Vaal Triangle Campus in Vanderbijlpark or any other university.

What will your son's/daughter's responsibilities be?

The researcher will make use of an independent person, Ms. Daphne Strauss, an experienced, secondary school teacher, who will recruit the participants for the research project. The researcher will train her for this purpose. An independent observer, Ms. Aldine Oosthuyzen, who knows the study well, as she will be the independent statistician who will capture the data and assist with the analysis of data, will assist her. Moreover, Ms. Oosthuyzen is a member of the Ethics Committee of the School of Economic Sciences and IT at the NWU, Vaal Triangle Campus, with a good understanding of ethical research principles, who will be able to oversee that the work of Ms. Strauss is in line with good ethical practice. Neither Ms. Strauss nor Ms. Oosthuyzen will have any relationship with the LIFE 111 students.

The recruitment will involve a short one-hour and 20 minutes presentation about the study in the Life Science lecture room at the university, to all the 2016 B.Ed. first year Life Science students, after which the independent person will hand the informed consent forms to the participants and explain the information to the participants and request them to take home the forms where they have privacy to complete the form at their own time. The recruitment will take place at the beginning of the year during an hour register period on the timetable before classes commence. If your son/daughter is absent during the recruitment session and they are interested to take part in the research, the independent person will be requested to conduct a follow-up session with all the participants who missed the first recruitment session, at a time convenient to the independent person and the participants.

In advance, the researcher will request the B.Ed. Programme Manager, Dr. Elize Küng, to accommodate a register period on the timetable for first year students during 2016, preferably on the same day as the LIFE 111 lectures. The researcher could then utilize this period for other administrative issues related to the research, such as receiving the informed consent, the writing of pretests and posttests, giving participants opportunity to share their views about the research and to receive feedback about the research. The researcher will allow one week to pass between the recruitment and the obtaining of informed consent, to give participants time to think about the study and whether they want to take part or not. After one week, the independent person will meet with the research participants and collect the informed consent forms during a register period in the Life Science lecture venue. The participants who decide to take part in the research will then be divided into an experimental and control group by the independent person. Participants will receive a number, which they will use when writing the different tests. If a participant decides to withdraw from the research, they do not need to complete the pretests and posttests and do not have to attend the discussion and feedback sessions. As the research involves the teaching of the Life Science content, a participant will however still need to attend class in one of the groups, A or B.

If your son/daughter takes part in the research, he/she will be part of an experimental and control group on a rotation basis during two experiments, experiment 1 and 2, that will run for six weeks each during the first semester (February to May 2016). These groups will be referred to as Group A and B, with no specific indication to the participants of which group will constitute the experimental or control group. The experimental group and control group will consist of approximately 30 participants each. The participants of the experimental and control groups will be determined by die independent person, who will divide the participants into the groups by keeping a balanced and equal division in terms of gender, language, ethnic group, type of school attended and matric result for Life Science.

The experimental group will be the group of participants where the researcher will use the new Thinking Maps strategy for a period of six weeks to see if the strategy will help the participants to improve in using critical thinking skills. The control group will be the group of participants who will not receive teaching with the new Thinking Maps strategy. The researcher will do normal lecturing with them for a period of six weeks. In both groups, the researcher will deal with the same subject content. If your son/daughter is part of the experimental group during experiment 1, he/she will then be part of the control group during experiment 2, and vice versa. All the participants will therefore get a chance to receive instruction with the Thinking Maps strategy.

As the first year Life Science content is the same as the content dealt with at Grade 12-level, the researcher will use pretests to measure how well your son/daughter has developed the critical thinking skills to analyse, synthesise and evaluate information in Life Science content at school. A pretest, pretest 1, will be written at the beginning of experiment 1, based on the learning content that will be dealt with in the first six weeks of semester 1. In the same way, pretest 2 will be written at the beginning of experiment 2, based on the learning content that will be dealt with in the last six weeks of semester 1. The pretests are mainly used to find out how well your son/daughter developed critical thinking skills at school, before the researcher teaches them to use the Thinking Maps strategy. In total, your son/daughter will write 2 pretests of approximately 30 minutes each.

Based on the pretest results, the researcher will develop the Thinking Maps teaching programme to address the problems with critical thinking that the researcher noted in the pretest results at the beginning of the first six weeks and second six weeks of the first semester during 2016. If the pretests should indicate that the participants do not experience problems with the critical thinking skills, the researcher will still apply the strategy to determine if it could improve on their present application of the critical thinking skills.

The Life Science participants have 2 periods per week of 1 hour and 20 minutes each on the university timetable. One of the periods is a practical period, and the researcher will not apply the Thinking Maps strategy during the practical period, but continue with normal lectures. The remaining period that focuses on theoretical subject content will be used for applying the Thinking Maps strategy. The teaching in the experimental and control groups will take place at separate times on the timetable and in separate venues. The control group will receive normal lectures during a class period (1 hour and 20 minutes) as allocated by the university once a week. The experimental group will receive teaching with the Thinking Maps once a week, during another period (1 hour and 20 minutes).

On conclusion of the Thinking Maps teaching programme with each group, a posttest 1 (after the first six weeks of semester 1) and posttest 2 (after the last six weeks of semester 2), will be written to see if the Thinking Maps assisted your son/daughter to develop or improve the critical thinking skills of analysis, synthesis and evaluation in the context of the subject content dealt with in each experiment respectively. In total, your son/daughter will write 2 posttests of 30 minutes each.

The table below summarizes the implementation of the research experiment.

Weeks 1-6: Semester 1- Experiment 1: February – Mid-March 2016			
Pretest 1	Experimental group Thinking Maps 6 weeks	Control group Normal class teaching (lecturing): 6 weeks	Posttest 1
Groups rotate Weeks 7-12: Semester 1 – Experiment 2: April – Mid May 2016			
Prestest 2	Experimental group Normal class teaching (lecturing): 6 weeks	Control group Thinking Maps 6 weeks	Posttest 2

The pre- and posttests will contain 15 multiple-choice items each with one correct answer, and a follow-up open question for each multiple-choice answer where your son/daughter needs to motivate an answer. Your son/daughter needs to motivate his/her answers to avoid that he/she guesses answers in the multiple-choice test. The motivation will also indicate to me how well your son/daughter can reason/argue. The multiple-choice questions will have an equal number of questions to test the skills to analyze (5 questions), synthesize (5 questions) and evaluate (5 questions). The questions in the pre- and posttests will not be the same, as they will be based on the subject content of the first and second six weeks of the semester, respectively. However, the difficulty of the test and the skills tested, namely analysis, synthesis and evaluation, will remain the same. To make sure that the difficulty level of all the tests will be the same, the researcher will involve four experienced Life Science university lecturers to verify the difficulty level of all the tests independently. The researcher will adhere to their comments and adapt tests if necessary.

An example of how the questions will be asked follows below.

Choose the correct answer by drawing a circle around the correct answer (1-4). Motivate in writing why you chose the answer.

Proteins are made from amino acids by the process of:

1.hydrolysis

2.pinocytosis

3.active transport

4.dehydration synthesis

Correct Answer Number: 4

Motivation: Proteins are large chains of amino acids combined by dehydration synthesis, where by molecules join by removing water. Hydrolysis breaks down proteins into amino acids. Pinocytosis is a method of ingesting large insoluble molecules, and is a form of active transport.

At the end of the research, the researcher will compare the pretest and posttest results of all the participants to see which strategy assisted the participants the best to develop their critical thinking skills, the Thinking Maps strategy or normal lecturing. As suggested by the independent statistician who will assist the researcher with the data analysis, comparisons of the test results of individual students will also be done, as it could be that individual participants benefit more from the new strategy than the group of participants. For this purpose each participant will receive a number that they will use throughout the research on their pretests and posttests so that it will be possible for the researcher to do comparisons of the different tests by using the number of the participants.

Opportunities for participants to share their opinions about the research, as well as opportunities for feedback about the research will be scheduled.

In summary, your son's/daughter's involvement will entail the following: (Exact dates and times to be provided when the 2016 time table has been finalized)

1.Invitation and explanation of informed consent (1 hour and 20 minutes during)
2.Completing informed consent (At home, 1 week)
3.Submit informed consent.
4.Selection to an experimental and a control group.
5.Writing pretests (30 minutes) before taking part in Experiment 1 during the LIFE 111 lectures: The implementation of the Thinking Maps strategy for six weeks, 1 hour and 20 minutes per week as part of the experimental group, or as part of the control group who will receive normal lecturing for six weeks, 1 hour and 20 minutes per week.
6.Writing posttests (30 minutes) after the implementation of the Thinking Maps strategy and normal lecturing for six weeks (1 hour and 20 minutes respectively), as part of Experiment 1.
7.Taking part in a reversed experiment, Experiment 2, during the LIFE 111 lectures where the experimental group becomes the control group who will receive normal lecturing for six weeks (1 hour and 20 minutes per week), and the control group becomes the experimental group who will receive teaching with the Thinking Maps strategy for six weeks, 1 hour and 20 minutes per week. The writing of pretests (30 minutes) and posttests (minutes) will apply before and after the six weeks.
8.One discussion session to obtain feedback from students after the implementation of the Thinking Maps strategy during Experiment 2 (1 hour and 20 minutes during a register period).
9.Feedback about the research: Feedback 1: 3 weeks after the implementation of Experiment 1 (1 hour and 20 minutes during a register period). Feedback 2: 3 weeks after the implementation of Experiment 2 (1 hour and 20 minutes during a register period).
10. Final feedback about the research findings (1 hour and 20 minutes during a register period).

Will your son/daughter benefit from taking part in this research?

The direct benefits for your son/daughter as participant will probably be the following:

(i) He/she might acquire critical thinking skills with the Thinking Maps teaching strategy to enable him/her to analyze, synthesize and evaluate information more effectively.

(ii) The Thinking Maps strategy is also a learning strategy that could assist him/her to learn and study better and possibly improve his/her academic performance in any subject.

(iii) Another benefit would be that your son/daughter would probably possess an effective strategy that he/she could use when he/she starts teaching.

The indirect benefit will probably be that:

(i) Researchers at other universities could be informed about the benefits of Thinking Maps as teaching strategy to develop critical thinking skills and conduct further studies in other contexts to prove the benefits of the strategy for developing critical thinking skills on a larger scale.

(ii) The research findings could be used to make recommendations to the Department of Education, regarding the possible improvement of the teaching practices of Life Science teachers in order to ensure that critical thinking skills will be developed in classrooms at school.

(iii) The teaching practice of the greater population of Life Science teachers could benefit if the Thinking Maps strategy holds merits for developing critical thinking in Life Science, and the message be communicated to Schools of Education Sciences at Universities who could incorporate training in the use of the strategy into the teacher-training curriculum.

Are there risks involved in your son/daughter taking part in this research and how will these be managed?

The possible risks in this study, and how I will manage them, are summarised in the table below:

Probable/possible risks/discomforts	***Strategies to minimize risk/discomfort***
Conflict of interest and the power relationship due to the fact that the researcher will also be the participants' Life Science lecturer.	The researcher acknowledges that the group of participants will be a vulnerable group due to the conflict of interest and hierarchical lecturer-student relationship that will exist, because he is the lecturer of the participants. However, the use of an independent person to do the recruitment of the participants, obtain informed consent, do the selection of the participants to the experimental and control groups, and administer tests for data collection could reduce vulnerability. Using an independent person will avoid participants feeling coerced to take part in the research, and avoid their being influenced by the student-lecturer relationship, so that vulnerability could be reduced. The independent person will not know or have any contact with these participants and will not lecture to any first year participants. This will ensure that the participants will not be forced to do something against their will, or be threatened, pressurized or persuaded with

	force to take part in the study to please their lecturer. The study cannot be done without including this group of participants, as the aim is to prepare them from their first year to apply a teaching strategy adequately that could enhance critical thinking during teaching.
The researcher cannot guarantee complete anonymity.	The independent person will make the participants aware of the fact that although those who agreed to take part in the pre- and posttest writing will remain anonymous to the researcher (their lecturer), absolute anonymity cannot be guaranteed during the writing of the pretests and posttests. Those who agree to write the tests will not be anonymous to their peers who will write the tests together with them. However, no results will be linked to individual participants, as numbers will be used to identify participants. The independent person who will collect the various test results of the participants for comparison purposes will know which name is linked to a specific number. She will keep the information confidential and will only report numbers and results to the researcher and independent statistician. Participants will also be made aware of the fact that although they might not consent to write the tests, they will still have to receive teaching with the Thinking Maps strategy, as the strategy will be linked to the compulsory subject content of the module (LIFE 111 - Life Science) which they have to pass. Exposure to the new teaching strategy could also be beneficial to them. The Thinking Maps strategy will not interfere with normal teaching time, but will form part of it.
Writing tests might cause anxiety and stress.	The independent person who will do the recruitment and obtain informed consent will explain the following to your son/daughter : They do not need to prepare or study for the tests.

	The tests will be written at times convenient to the participants, preferably during a free period on the timetable, to avoid additional traveling to write the tests. For this purpose, the researcher will arrange for a fixed register period on the timetable for the first year students of 2016. The tests will not influence the participants' passing or failing the Life Science module, LIFE 111. The test results will only be used for research purposes to find out if the Thinking Maps strategy is effective for developing critical thinking skills or not. The content on which the tests will be based will also be known to the participants as they would have done the content in Grade 12. This might reduce anxiety. (i) For the purpose of making individual comparisons between the test results, participants will be identified by means of numbers to the researcher. The researcher will not know who took part in writing the tests (he will not be involved in the administering of the tests). The independent person will assist the statistician with selecting the individual tests for comparison purposes. The researcher will only receive the numbers of the participants with the various test results. (ii) The focus will not be on passing or failing the test, but how well participants can apply critical thinking.

The researcher has planned for appropriate measures to minimize research-related risks, so that the participants could experience the benefits that the research could hold, as noted above. The risks appear to be reasonable in relation to the importance of knowledge to be gained that can possibly improve the teaching and learning of Life Science.

Who will have access to the data?

Your son's/daughter's test results will not be linked to his/her name. He/she will not write his/her name on the test, but will be identified by a number (1, 2, etc.). All results that will be reported will be linked to a number. He/she will remain anonymous, and his/her name will not be mentioned in the findings that will emanate from the research. The researcher assures you that we will protect the information we have about your son/daughter. All information regarding the research will be stored on a password-protected computer and the completed tests will be locked up in a cupboard in my office. The researcher is the only person who has a key to unlock the cupboard.

It is important to inform you that confidentiality will be limited in the study. Apart from the independent person, only two other people will have access to the data, namely the independent statistician who will assist me with the capturing of the data, and my supervisor who will check and verify that my research findings are correct. The independent statistician is Ms. Aldine Oosthuyzen, who is an experienced and qualified statistician at the North-West University, Vaal Triangle Campus. I will store the data for a minimum of five years. The independent person, the study leader and independent statistician will sign a written agreement at the beginning of the study that they will keep all information about the study and the findings of the study confidential, and not talk about it.

What will happen to the data?

The researcher assures you that the information obtained via the research will be used for research purposes only, and no information about your son/daughter will be made known in reporting about the study (for example your name, his/her name or an address). The data from this study will be reported in the following ways: (i) The researcher will report the findings in the form of a dissertation that will be submitted to examiners at other universities for examination purposes, (ii) The researcher also intends to write about the research in articles and book chapters, and speak about the research at conferences.

This is a once-off study, so the data will not be re-used in any other studies, which I may do in future.

Will your son/daughter be paid/compensated to take part in this study and are there any costs involved?

Your son/daughter will not be paid/compensated to take part in the study, but refreshments will be given to him/her after the completion of each test. This will serve as a token of appreciation that he/she was willing to become part of the research. The writing of the tests and the application of the Thinking Maps strategy take place during periods on the normal timetable of the participants, and during normal lecturing time. Your son/daughter does not have to arrange for additional traveling to participate. No costs will be involved in taking part in the study.

How will you know about the findings?

The general findings of the research will be shared with you via email or post (please provide your address below) by the researcher who will compile the final findings in a short report that will be provided to all the parents/guardians of the research participants. All questions about the report can be directed to the researcher at the contact details below. Alternatively, you are welcome to schedule an appointment with the researcher to discuss your questions.

Is there anything else that you should know or do?

You can contact Mr Francois Minnie at 084 549 2583 or 23512326@nwu.ac.za or his studyleader, Prof. Mary Grosser at 083 490 0501 or mary.grosser@nwu.ac.za, if you have any further queries or encounter any problems.

You can contact the chair of the Humanities and Health Research Ethics Committee (Prof Linda Theron) at 016 910 3076 or Linda.theron@nwu.ac.za if you have any concerns or complaints that have not been adequately addressed by the researcher. You can also contact, the co-chair, Prof Tumi Khumalo (016 910 3397 or Tumi.khumalo@nwu.ac.za). You can leave a message for either Linda or Tumi with Ms. Daleen Claasens (016 910 30441).

If you have difficulty in following and understanding the explanation of the research, please contact the researcher or the independent person at the details below, and they will arrange a time with you to meet with the researcher to explain what is problematic to you.

You will receive a copy of this information and consent form for your own records.

Declaration by parent

By signing below, I ……………………………………..…………., agree that my son/daughter ………………………….. may take part in a research study entitled: **The impact of Thinking Maps to enhance the development of critical thinking skills among first year pre-service Life Science teachers**

I declare that:

- I have read and understood this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions to both the person obtaining consent, as well as the researcher (if this is a different person), and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to give consent that my son/daughter may take part.
- I understand that my son/daughter’s test results could be reproduced publically and/or quoted, but without reference to his/her or my personal identity.
- My son/daughter may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- My son/daughter may be asked to leave the study before it has finished, if the researcher feels it is in my son’s/daughter’s best interests, or if my son/daughter does not follow the study plan, as agreed to.

Signed at (*place*) ....…........…………….. on (*date*) …………...……….. 20....

....
Signature of participant **Signature of witness**

- You may contact me again ☐ **Yes** ☐ **No**
- I would like a summary of the findings of this research ☐ **Yes** ☐ **No**

The best way to reach me is:
Name & Surname: ____
Postal Address: ____
Email: ____
Phone Number: _____________________
Cell Phone Number: ______________________

In case the above details change, please contact the following person who knows me well and who does not live with me and who will help you to contact me:
Name & Surname:
____
Phone/ Cell Phone Number /Email:
____

Declaration by person obtaining consent

I *(name)* ……………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did not use an interpreter.

The best way to reach me is:
Name & Surname: ____
Postal Address: ____
Email: ____
Phone Number: _____________________
Cell Phone Number: ______________________

Signed at (*place*) ....…......……………….. on (*date*) …………...……….. 20....

....
Signature of independent person **Signature of witness**

Declaration by researcher

I *(name)* …………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (*place*) ....…......……………….. on (*date*) …………...……….. 20....

....	....
Signature of researcher	**Signature of witness**

PARENTS (AFRIKAANS)

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAALDRIEHOEKKAMPUS

4.

HHREC Stempel

Posbus 1174, Vanderbijlpark
Suid Afrika, 1900
Web: http://www.nwu.ac.za

DATUM: 3 September 2015

DEELENEMER SE INLIGTINGSBROSJURE EN INGELIGTE TOESTEMMINGSVORM VIR OUERS/VOOGDE VAN B.ED. EERSTEJAAR STUDENTE IN LEWENSWETENSKAP

Titel van navorsingsprojek: Die impak van Denkkaarte om die ontwikkeling van kritiese denkvaardighede by eerstejaar voordiens Lewenswetenskap-onderwysers te koester

VERWYSINGSNOMMER :

HOOF NAVORSER: Mnr Francois Minnie

ADRES: SKOOL VIR OPVOEDKUNDIGE WETENSKAPPE, NOORDWES-UNIVERSITEIT, HENDRICK VAN ECK BOULEVARD 100, VANDERBIJLPARK

KONTAKNOMMER: 016 910 3074/084 549 2583

U seun/dogter word uitgenooi om deel te neem aan 'n navorsingsprojek wat deel vorm van my studie vir die verwerwing van 'n Meestersgraad in Opvoedkunde. Gebruik asseblief tyd om deur die inligting wat hier aangebied word om die navorsingsprojek te verduidelik, te lees. Vra asseblief vrae aan die navorser oor enige deel van die projek wat u nie ten volle verstaan nie. Dit is baie belangrik dat u heeltemal tevrede voel en duidelik verstaan waaroor die navorsing gaan en hoe u seun/dogter betrek kan word. U seun of dogter se deelname is heeltemal vrywillig en hy/sy mag te enige tyd deelname aan die navorsing van die hand wys. As u nie toestemming gee dat u seun/dogter aan die navorsing mag deelneem nie, sal dit hom/haar geensins negatief beïnvloed nie. U seun/dogter mag ook enige tyd hom/haar aan die studie onttrek, al sou u toestem dat hy/sy aan die navorsing mag deelneem. U mag my ook versoek om enige inligting/data wat ek oor u seun/dogter ingesamel het te vernietig. U moet ook weet dat al gee u toestemming dat u seun/dogter aan die navorsing mag deelneem, hy/sy self mag besluit of hulle toestemming gaan gee om aan die studie deel te neem, Hierdie studie is goedgekeur deur die **Humanities and Health Research Ethics Committee (HHREC) van die Fakulteit Geesteswetenskappe aan die Noord-Wes Universiteit, Vaal Driehoekkampus, Vanderbijlpark.** Die navorsing sal uitgevoer word in ooreenstemming met die etiese riglyne en beginsels van die internasionale Deklarasie van Helsinki en die National Health Research Ethics Council. Dit mag nodig wees dat lede van die etiekkomitee of relevante gesaghebbendes die navorsing ondersoek om seker te maak dat die navorser die navorsing op 'n etiese manier uitvoer.

Waaroor gaan die navorsing?

Ek is mnr Francois Minnie, die navorser en u seun/dogter se dosent in Lewenswetenskap, wat graag wil dat u seun/dogter aan my navorsingsprojek, wat ek vir my Meestersgraad in Opvoedkunde wil voltooi, deelneem. My navorsingsprojek sal by die Noordwes-Universiteit se Vaal Driehoekkampus in Vanderbijlpark uitgevoer word.

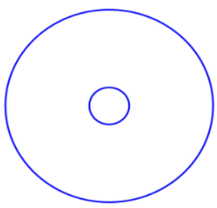
Die navorsing skakel goed met die huidige onderrig en leersituasie in Suid-Afrikaans skole, waar dit van onderwysers verwag word om leerders vaardighede te leer om probleme op te los deur middel van kritiese en kreatiewe denke. My studie gaan spesifiek op kritiese denke fokus. In my studie gaan kritiese denke soos volg verstaan word: Die deelnemers aan die navorsing moet in staat wees om inligting te analiseer, sintetiseer en evalueer. Om inligting te analiseer beteken om inligting in kleiner dele op te breek. Sintese beteken om verskillende idees of inligting te kombineer om 'n nuwe idee te vorm. Om te evalueer beteken om die waarheid of waarde van iets te beoordeel en 'n antwoord te motiveer.

Die belangrikste doelstellings van die studie is:

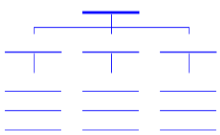
(i) Om vas te stel hoe goed die kritiese denkvaardighede (analise, sintese en evaluering) by eerstejaar Lewenswetenskap-studentonderwysers ontwikkel is gedurende hulle skoolloopbane.

(ii) Om vas te stel of die gebruik van Denkkaarte as onderrigstrategie die ontwikkeling van kritiese denkvaardighede wat moontlik verdere ontwikkeling nodig het, of verbeter kan word, kan bevorder. Denkkaarte is 'n visuele leerstrategie waar 'n student leer om inligting hulle eie te maak deur dit op te som met behulp van 'n kaart. Ek gaan van drie strategieë tydens die navorsing gebruik maak, naamlik:

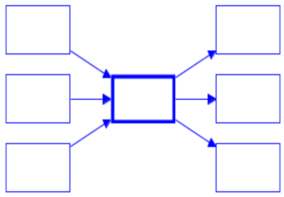
- ✓ 'n Sirkelkaart om sintese as vaardigheid te ontwikkel



- ✓ 'n Boomkaart om analise as vaardigheid te ontwikkel



✓ ‘n Multi-vloeikaart om evaluasie as vaardigheid te ontwikkel



Alhoewel baie internasionale studies bevind het dat Denkkaarte suksesvol is vir die ontwikkeling van denkvaardighede, is nog geen studies gedoen om die effektiwiteit van Denkkaarte as onderrigstrategie vir die ontwikkeling van kritiese denkvaardighede by Lewenswetenskap-studentonderwysers in die Suid-Afrikaanse konteks vas te stel nie, veral nie die vaardighede soos analise, sintese en evaluasie nie. Hierdie vaardighede is belangrik vir die bemeestering van die Lewenswetenskap-vakinhoud op eerstejaar B.Ed.-vlak.

Die navorser wil graag alle 2016 eerstejaar B.Ed.-studente met Lewenswetenskap as hoofvak by die navorsing betrek. Die navorser sal die deelnemers aan die navorsing werf deur toestemming te verkry by die Direkteur van die Skool vir Opvoedkundige Wetenskappe, Prof. J.E. Fourie, wat as hekwagter sal optree om vir hom toegang tot die studente te gee.

Gebaseer op die getalle van studente wat die afgelope twee jaar ingeskryf het met Lewenswetenskap as hoofvak, sal ongeveer 60-70 studente in 2016 Lewenswetenskap as hoofvak neem. Ek wil graag met hierdie nuwe groep studente werk aangesien hulle nog nie blootgestel was aan of oorlaai is met navorsing wat by die universiteit onderneem word nie.

Hoekom is u seun/dogter genooi om deel te neem?

Dit sal belangrik wees om navorsing met u seun/dogter te doen, aangesien ek hulle Lewenswetenskapdosent is wat self die nuwe onderrigstrategie wil gebruik om die kwaliteit van my eie onderrigpraktyk te verbeter. Tweedens was ek baie jare lank ‘n Lewenswetenskap-onderwyser, en weet dat onderwysers nie kennis het van onderrigstrategieë wat hulle kan gebruik om kritiese denkvaardighede in Lewenswetenskap te verbeter nie. Om navorsing met die eerstejaar Lewenswetenskap-studentonderwysers te doen sal my ‘n kans gee om ‘n strategie vir ‘n groep eerstejaar Lewenswetenskap-studentonderwysers aan te leer wat hulle sou kon gebruik om kritiese denke moontlik meer effektief te koester op skoolvlak as hulle begin skoolhou. Die fokus is op eerstejaar studente omdat ek hulle reeds in hul eerste jaar wil leer hoe om die strategie te gebruik, en hulle dan aan te moedig om die strategie toe te pas gedurende hulle vier jaar van opleiding, sodat hulle, wanneer hulle begin skool hou moontlik goeie leiding aan leerders sal kan gee om ook die strategie te gebruik. Ek is opgelei deur ‘n geakkrediteerde opleier om Denkkkaarte te gebruik.

Opsommenderwys, is u seun/dogter gekies om deel te neem aan die studie omdat:

(i) Hy/sy ‘n manlike of vroulike eerstejaar B.Ed.-student aan die Noordwes-Universiteit se Vaaldriehoekkampus in Vanderbijlpark is, en afkomstig is van enige etniese en taalgroep, en Lewenswetenskap op matriekvlak geslaag het .

(ii) Hy/sy is ‘n eerstejaar B.Ed.-student wat Lewenswetenskap as een van sy/haar hoofvakke neem.

Deelnemers sal nie by die studie betrek word as hulle ‘n tweedejaar, derdejaar of vierdejaar B.Ed.-student aan die Noordwes-Universiteit se Vaaldriehoekkampus in Vanderbijlpark of enige ander universiteit is nie.

Wat sal u seun/dogter se verantwoordelikhede wees?

Ek gaan gebruik maak van ‘n onafhanklike persoon, Me Daphne Strauss, ‘n ervare, sekondêre skool onderwyseres, wat gaan help met die werwing van die deelnemers vir die navorsingsprojek. Die navorser sal haar oplei vir hierdie doel. Sy sal bygestaan word deur ‘n onafhanklike waarnemer, Mev. Aldine Oosthuyzen. Mev. Oosthuyzen ken die studie goed omdat sy as onafhanklike statistikus die vaslegging van data gaan doen en behulpsaam gaan wees met die analise van die data. Mev. Oosthuyzen is ook ‘n lid van die Etiese Komitee van die Skool vir Ekonomiese Wetenskappe en IT aan die NWU, Vaal Driehoekkampus, en het ‘n goeie begrip van etiese beginsels tydens navorsing. Sy sou dus tydens haar waarneming kon verseker dat die werk van Mev. Strauss voldoen aan goeie etiese praktyk. Mev. Strauss en Mev. Oosthuyzen sal geen verbintenis met die LIFE 111 studente hê nie.

Die werwing gaan ‘n kort een-uur aanbieding aan al die 2016 Lewenswetenskap eerstejaar B.Ed.-studente in die Lewenswetenskap-lesinglokaal by die universiteit behels. Daarna sal die onafhanklike persoon die ingeligte toestemmingsvorms aan die deelnemers uitdeel, die inligting verduidelik en aan die deelnemers noem dat hulle self ook deur die inligting moet werk, die vorms huis-toe moet neem en op hulle eie tyd en in privaatheid die vorm moet voltooi en aandui of hulle wil deelneem aan die navorsing of nie. Die werwing sal aan die begin van die jaar, voordat die klasse begin, plaasvind tydens ‘n registerperiode op die rooster. Indien u seun/dogter afwesig is tydens die werwingsessie en hy/sy stel belang om aan die navorsing deel te neem, sal die onafhanklike persoon versoek word om ‘n opvolgsessie te skeduleer met al die deelnemers wat afwesig was op ‘n tyd wat gerieflik is vir die onafhanklike persoon en die deelnemers.

Die navorser sal vroegtydig aan die B.Ed.-programbestuurder, Dr Elize Küng, ‘n versoek rig dat daar voorsiening gemaak moet word vir ‘n registerperiode op die rooster vir die 2016 eerstejaar BEd-studente,verkieslik op dieselfde dag as die LIFE 111 lesings. Die navorser sou dan hierdie periode kon gebruik vir administatiewe sake rondom die navorsing, soos vir die ontvang van die ingeligte toestemmingsvorms, die skryf van voortoetse en natoeste, geleentheid om die deelnemers kans te gee om hul sienings oor die navorsing te deel en om terugvoer oor die navorsing te gee. Die navorser sal sorg dat een week verloop tussen die werwing en die inneem van ingeligte toestemming, om deelnemers die kans te gee om na te dink oor die studie en of hulle wil deelneem of nie. Na een week sal die onafhanklike persoon weer die deelnemers ontmoet, en die ingeligte toestemmingsvorms inneem. Die deelnemers wat besluit om deel te neem aan die navorsing sal dan deur die onafhanlike persoon in eksperimentele en kontrole groepe verdeel word. Deelnemers sal ‘n nommer ontvang wat hulle tydens die skryf van die toetse gaan gebruik. As u seun/dogter besluit om aan die navorsing te onttrek, hoef hy/sy nie die voortoetse en natoetse te skryf nie, en ook nie die bespreking en terugvoersessies by te woon nie. Aangesien die navorsing die onderrig van die Lewenswetenskap vakinhoud behels, sal u seun/dogter steeds die klas moet bywoon in een van die Groepe, A of B.
Indien u seun/dogter aan die navorsing gaan deelneem, sal hy/sy deel wees van ‘n eksperimentele en kontrole groep wat op rotasiebasis tydens die navorsing aan twee eksperimente, eksperimente 1 en 2, wat elk vir ses weke lank gedurende die eerste semester (Februarie tot Mei 2016) sal plaasvind, gaan deelneem. Hierdie groepe sal bekend staan as Groep A en B, sonder om enige aanduiding aan deelnemers te gee watter groep die eksperimentele groep en watter groep die kontrole groep is. Die eksperimentele groep en kontrole groep sal elk

uit ongeveer 30 deelnemers bestaan. Die deelnemers vir die eksperimentele en kontrole groepe sal deur die onafhanlike persoon/navorser bepaal word, deur deelnemers min of meer gebalanseerd en gelykop ten opsigte van geslag, taal, etniese groep, tipe skool bygewoon en matriekpunt vir Lewenswetenskap in die eksperimentele en kontrole groepe in te deel.

Die eksperimentele groep sal die groep deelnemers wees waar ek die nuwe onderrigstrategie, Denkkaarte, vir 'n tydperk van ses weke sal gebruik om vas te stel of die nuwe strategie die deelnemers sal help om hul kritiese denkvaardighede te verbeter. Die kontrole groep sal die groep deelnemers wees wat nie onderrig met die nuwe onderrigstrategie, Denkkaarte, sal ontvang nie. Ek sal slegs gewone lesings vir 'n tydperk van ses weke aan hulle aanbied. In beide groepe sal ek dieselfde vakinhoud aanbied. As u seun/dogter deel is van die eksperimentele groep tydens eksperiment 1, sal hy/sy dan deel wees van die kontrole groep tydens eksperiment 2, en andersom. Al die deelnemers gaan dus 'n kans kry om onderrig deur middel van Denkkaarte te ontvang.

Aangesien die vakinhoud van Lewenswetenskap op eerstejaarsvlak dieselfde is as die vakinhoud wat op Graad 12 vlak hanteer is, gaan die navorser van voortoetse gebruik maak om vas te stel hoe goed u seun/dogter die kritiese denkvaardighede om te analiseer, sintetiseer en te evalueer in Lewenswetenskap op skool aangeleer het. 'n Voortoets, voortoets 1, sal aan die begin van eksperiment 1 geskryf word en sal gebaseer wees op die vakinhoud wat ons tydens die eerste ses weke van semester 1 gaan behandel. Op dieselfde manier sal voortoets 2 aan die begin van eksperiment 2 geskryf word, wat op die vakinhoud wat ons in die laaste 6 weke van semester 1 gaan behandel, gebaseer sal wees. Met die voortoetse wil die navorser hoofsaaklik vasstel hoe goed u seun/dogter se kritiese denkvaardighede op skool ontwikkel is, voordat hy Denkkaarte as onderrigstrategie gebruik. In totaal, gaan u seun/dogter 2 voortoetse van ongeveer 30 minute elk skryf.

Gebaseer op die voortoets-resultate, sal die navorser die onderrigprogram waar ek Denkkaarte gaan gebruik, ontwikkel, om die probleme met kritiese denke wat hy tydens die voortoetse aan die begin van die eerste ses weke en die tweede ses weke van die eerste semester gedurende 2016 opgemerk het, aan te spreek. Indien die voortoetse sou uitwys dat die deelnemers nie probleme met die kritiese denkvaardighede ervaar nie, sal die navorser steeds die strategie toepas om te kyk of ek die toepassing van die kritiese denkvaardighede nog beter kan ontwikkel.

Die Lewenswetenskap-deelnemers het 2 Lewenswetenskap-periodes per week van 1 uur en 20 minute elk op die universiteitsrooster. Een van die periodes is 'n praktiese periode en die navorser sal nie tydens hierdie periode met Denkkaarte onderrig gee nie, maar slegs gewone lesings aanbied. Die oorblywende periode wat fokus op teoretiese vakinhoud sal gebruik word om Denkkaarte as onderrigstrategie toe te pas. Die onderrig in die eksperimentele en kontrole groepe sal op aparte tye en in aparte lokale plaasvind. Die kontrole groep sal normale lesings tydens hulle klasperiode van 1 uur en 20 minute een keer per week, soos deur die universiteit toegeken is, ontvang. Die eksperimentele groep sal onderrig met behulp van Denkkaarte een keer per week tydens hulle periode van 1 uur en 20 minute ontvang.

Wanneer die implementering van die Denkkaart-onderrigprogam voltooi is, sal natoets 1
na afloop van die eerste ses weke van semester 1 geskryf word en natoets 2 na afloop van die laaste ses weke van semester 2. Die natoetse word geskryf om te sien of Denkkaarte u seun/dogter gehelp het om die kritiese denkvaardighede van analise, sintese en evaluasie in die konteks van die vakinhoud wat tydens elke eksperiment hanteer is, te ontwikkel of te verbeter. In totaal sal u seun/dogter twee natoetse van 30 minute elk skryf.

In die tabel hier onder word die implementering van die navorsingseksperiment opgesom.

<table>
<tr><td colspan="4">Weke1-6: Semester 1- Eksperiment 1</td></tr>
<tr><td>Voortoets 1</td><td>Eksperimentele groep
Denkkaarte
6 weke</td><td>Kontrole groep
Normale klasonderrig
(lesings)
6 weke</td><td>Natoets 1</td></tr>
<tr><td colspan="4">Groepe roteer
Weke 7-12: Semester 1 – Eksperiment 2</td></tr>
<tr><td>Voortoets 2</td><td>Eksperimentele groep
Normale klasonderrig
(lesings)
6 weke</td><td>Kontrole groep
Denkkaarte
6 weke</td><td>Natoets 2</td></tr>
</table>

Die voortoetse en natoetse sal uit 15 multi-keuse vrae bestaan, waar elke vraag een korrekte antwoord sal hê. Elke vraag het ook ‘n opvolgvraag waar u seun/dogter ‘n antwoord moet motiveer. U seun/dogter moet sy/haar antwoord motiveer om raaiwerk te ontmoedig en sodat die navorser kan vasstel hoe goed u seun/dogter kan redeneer/argumenteer. Die multi-keuse vrae sal ‘n gelyke aantal vrae bevat vir die verskillende vaardighede, naamlik analise (5 vrae), sintese (5 vrae) en evaluasie (5 vrae). Die vrae in die voortoetse en natoetse sal nie dieselfde wees nie, omdat die toetse elk op verskillende vakinhoud van die eerste ses en tweede ses weke van semester 1 onderskeidelik, gebaseer sal wees.

Die moeilikheidsgraad van die toetse en die vaardighede wat getoets word, naamlik analise, sintese en evaluasie, sal dieselfde wees. Om seker te maak dat die moeilikheidsgraad van al die toetse dieselfde is, sal die navorser vier ervare kollegas wat universiteitsdosente in Lewenswetenskap is inskakel om die moeilikheidsgraad van al die toetse onafhanklik te evalueer. Die navorser sal aandag gee aan hulle kommentaar en indien nodig, die toetse aanpas.

‘n Voorbeeld van hoe die vrae gestel gaan word, verskyn hier onder.

Kies die korrekte antwoord deur ‘n sirkel om die korrekte antwoord (1-4) te maak. Motiveer skriftelik, hoekom u die antwoord gekies het.

Proteïne word gemaak van aminosure deur die proses van:

1.hidrolise

2.pinositosis

3.aktiewe vervoer

4.dehidrasie-sintese

Korrekte antwoord: 4

Motivering: Proteïne is groot kettings aminosure wat gekombineer word deur middel van dehidrasie-sintese, waar molekules saamgevoeg word deur water te verwyder. Hidrolise breek die proteïne af in aminosure. Pinositosis is ‘n metode waardeur groot onoplosbare molekules ingeneem word, en word beskou as ‘n vorm van aktiewe vervoer.

Aan die einde van die navorsing, sal die navorser die voortoets en natoets resultate van al die deelnemers vergelyk om vas te stel watter strategie die deelnemers se kritiese denkvaardighede die beste ontwikkel het: Denkkaarte of normale lesings. Op aanbeveling van die onafhanklike statistiese konsultant wat die navorser gaan help met die analise van die data, gaan vergelykings ook ten opsigte van individuele deelnemers se toetsresultate gedoen word, aangesien dit moontlik is dat die nuwe strategie individuele deelnemers beter mag baat as die groep. Die deelnemers sal elkeen vir hierdie doel ‘n nommer ontvang wat hulle deurgaans op hulle voortoetse en natoetse gaan aanbring sodat dit vir die navorser moontlik sal wees om vergelykings ten opsigte van die verskillende toetse gekoppel aan nommers ook uit te voer. Geen vergelyking sal egter aan ‘n deelnemer se naam gekopppel word nie.

Geleentheid vir die deelnemers om hulle menings oor die navorsing te gee, asook geleentheid vir terugvoer deur die navorser oor die navorsingsbevindinge, sal geskeduleer word.

Opsommenderwys gaan u deelname die volgende behels: (Presiese datums en tye sal verskaf word sodra die klasrooster vir 2016 gefinaliseer is)

1.Uitnodinging en verduideliking van ingeligte toestemming (1 uur en 20 minute). 2.Die voltooiing van ingeligte toestemming (Tuis, 1 week). 3.Inhandiging van ingeligte toestemming. 4.Selektering tot ‘n eksperimentele en kontrole groep. 5.Die skryf van voortoetse (30 minute) voordat u deelneem aan Eksperiment 1: Die implementering van die Denkkaarte onderrigstrategie tydens die LIFE 111 lesings vir ses weke (1 uur en 20 minute per week) as deel van die eksperimentele groep, of as deel van die kontrole groep wat slegs normale lesings vir ses weke (1 uur en 20 minute per week) sal ontvang. 6.Die skryf van natoetse (30 minute) na die implementering van Denkkkaarte en normale lesings vir ses weke onderskeidelik tydens Eksperiment 1. 7.Deelname aan ‘n omgekeerde eksperiment, Eksperiment 2, tydens die LIFE 111 lesings waar die eksperimentele groep die kontrole groep word, en die kontrole groep die eksperimentel groep word. Die eksperimentele groep sal weer vir ses weke onderrig met Denkkaarte ontvang (1 uur en 20 minute per week) en die kontrole groep vir ses weke onderrig met behulp van normale lesings sal ontvang (1 uur en 20 minute per week). Die skryf van voortoetse (30 minute) en natoese (30 minute) voor en na die ses weke sal ook van toepassing wees. 8.Een bespreking waar deelnemers hulle menings oor die navorsing kan gee na afloop van Eksperiment 2 (1 uur en 20 minute tydens ‘n register periode), na die implementering van die intervensie met Denkkaarte. 9.Terugvoer oor die navorsing: Sessie 1: Aan die einde van Eksperiment 1 (1 uur en 20 minute tydens ‘n registerperiode). Sessie 2: Aan die einde van Eksperiment 2 (1 uur en 20 minute tydens ‘n registerperiode). 10.‘n Finale terugvoersessie oor die navorsingsbevindinge (1 uur en 20 minute tydens ‘n registerperiode)

Sal u seun/dogter baat vind deur aan die navorsing deel te neem?

Die onmiddellike voordele vir u seun/dogter as deelnemer sal waarskynlik die volgende wees:

(i) Hy/sy mag moontlik die kritiese denkvaardighede deur middel van Denkkaarte aanleer wat hom/haar in staat kan stel om inligting meer effektief te analiseer, sintetiseer en evalueer.

(ii) Denkkaarte is ook ‘n effektiewe leerstrategie wat hom/haar sou kon help om beter te studeer en moontlik sy/haar akademiese prestasie in enige vak te verbeter.
(iii) ‘n Ander voordeel sou wees dat u seun/dogter moontlik oor ‘n effektiewe strategie sou kon beskik wanneer hy/sy begin skoolhou.

Die indirekte voordele sal waarskynlik wees dat:

(i) Navorsers by ander universiteite sou moontlik kon kennis neem van die voordele van Denkkaarte as onderrigstrategie om kritiese denkvaardighede te verbeter, en verdere studies in ander kontekste sou kon onderneem om die voordele van die strategie vir die ontwikkeling van kritiese denkvaardighede op groter skaal te bewys.
(ii) Die navorsingsbevindinge sou gebruik kon word om aanbevelings aan die Departement van Onderwys te maak met betrekking tot die moontlike verbetering van die onderrigpraktyk in Lewenswetenskap op skool, om te verseker dat kritiese denke wel in klaskamers op skool ontwikkel word.
(iii) Die groter populasie van Lewenswetenskap-onderwysers se onderrigpraktyk sou kon baat as Denkkaarte as onderrigstrategie meriete inhou vir die ontwikkeling van kritiese denke in Lewenswetenskap en hierdie bevinding aan Skole vir Opvoedkundige Wetenskappe aan Universiteite gekommunikeer kan word en opleiding in die gebruik van die strategie deel gemaak kan word van die kurrikulum vir onderwysersopleiding.

Is daar enige risiko’s betrokke by u seun/dogter se deelname aan die navorsing en hoe gaan die risiko’s bestuur word?

Die volgende risiko’s is betrokke by die studie, en in die tabel hieronder verduidelik die navorser hoe hy die risiko’s gaan bestuur.

Moontlike/waarskynlike risko’s /ongemak	***Strategieë om risiko’s en ongemak te verminder***
(i) Botsende belange en die magsverhouding wat bestaan omdat die navorser ook die deelnemers se Lewenswetenskapdosent is.	Die navorser erken dat die groep deelnemers kwesbaar is as gevolg van botsende belange en die hiërargiese dosent-student verhouding wat bestaan omdat hy die deelnemers se dosent is. Deur gebruik te maak van ‘n onafhanklike persoon, vir die werwing van deelnemers, die verkryging van ingeligte toestemming, die selektering van deelnemers tot die eksperimentele en kontrole groepe, en die afneem van toetse vir data insameling kan die kwesbaarheid van deelnemers verminder word. Die onafhanklike persoon sal verhoed dat die deelnemers voel dat hulle gedwing word om aan die navorsing deel te neem of voel dat hulle beïnvloed word om deel te neem as gevolg van die student-dosent verhouding. Die onafhanklike persoon sal die deelnemers nie ken nie en ook nie kontak met hulle hê nie,

	omdat sy nie klas gee vir eerstejaar-studente nie. Dit sal verseker dat die deelnemers nie verplig voel om iets teen hulle wil te doen nie, of voel dat hulle bedreig word, onder druk geplaas word of oorreed word om deel te neem aan die navorsing omdat die navorser hulle dosent is nie. Die studie kan nie gedoen word sonder die insluiting van die groep deelnemers nie. ‘n Belangrike doel met die studie is om die deelnemers reeds van hulle eerstejaar af behoorlik toe te rus om 'n onderrigstrategie te gebruik om kritiese denke moontlik tydens onderrig te ontwikkel.
(ii) Die navorser kan nie algehele anonimiteit waarborg nie.	Die onafhanklike persoon sal die deelnemers bewus maak van die feit dat alhoewel dié wat aan die navorsing gaan deelneem anoniem sal bly vir die navorser (hulle dosent) wanneer hulle die voortoetse en natoetse skryf, algehele anonimiteit nie gewaarborg kan word nie. Die deelnemers wat die toetse skryf sal nie anoniem vir die res van hulle maats wees wat saam met hulle die toetse skryf nie. Geen resultate sal egter direk aan ‘n deelnemer se naam gekoppel word nie, maar aan die nommer, wat gebruik sal word om die deelnemers te identifiseer. Die onafhanklike persoon wat die verskillende toetsuitslae sal versamel om vergelykings te maak, sal weet watter naam aan watter nommer gekoppel is. Sy sal die inligting vertroulik hanteer, en slegs die nommer en die toetsuitlslae aan die navorser en die onafhanklike statistikus rapporteer. Deelnemers sal bewus gemaak word van die feit dat alhoewel hulle mag besluit om nie aan die navorsing deel te neem nie, en nie die toetse skryf nie, hulle steeds onderrig deur middel van Denkkaarte gaan ontvang. Die gebruik van Denkkaarte is gekoppel aan die vakinhoud van die module, LIFE 111 – Lewenswetenskap, wat hulle moet slaag. Blootstelling aan die nuwe onderrigstrategie kan egter vir hulle ook voordelig wees. Die gebruik van Denkkaarte as onderrigstrategie gaan dus nie inmeng met normale klastyd nie, maar deel daarvan vorm.

(iii) Die skryf van toetse mag angs en stres veroorsaak.	Die onafhanklike persoon wat die werwing sal hanteer en die ingeligte toestemming van u seun/dogter sal verky, sal die volgende aan u seun/dogter verduidelik: (i) Hulle hoef nie vir die toetse voor te berei of te studeer nie. (ii) Die toetse sal geskryf word in tye wat vir die deelnemers gerieflik sal wees, verkieslik gedurende 'n oop periode op die rooster sodat addisionele ryery om die toetse te skryf, nie sal plaasvind nie. Die navorser gaan reël vir 'n vaste registerperiode op die rooster vir eerstejaar studente van 2016 vir hierdie doel. (iii) Die toetse sal nie invloed uitoefen op die student se slaag of druip van die Lewenswetenskap module, LIFE 111 nie. (iv) Die toetsresultate gaan slegs vir navorsingsdoeleindes gebruik word om vas te stel of die gebruik van Denkkaarte effektief is vir die ontwikkeling of verbetering van kritiese denkvaardighede of nie. (v) Die inoud waarop die toetse gebaseer gaan wees, gaan vir die deelnemers bekend wees, aangesien die inhoud reeds in Graad 12 behandel is. Dit mag angs verlig. (vi) Vir die maak van individuele vergelykings sal die deelnemers met behulp van nommers aan die navorser uitgeken word. Die navorser sal nie weet wie 'n toets gekryf het of nie (die navorser gaan nie betrokke wees by die afneem van die toetse nie). Die onafhanklike persoon sal die statistikus help om die individuele toetspunte te selekteer vir die vergelykings wat gemaak gaan word. Die navorser sal slegs die nommers van die deelnemers met hulle punte vir die verskillende toetsgeleenthede ontvang. (vii) Die fokus van die toetse gaan nie op slaag of druip wees nie, maar of die deelnemers kritiese

	denkvaardighede kan toepas of nie.

Die navorser het gepaste maatreëls in plek gestel om die navorsingsverwante risiko's te verminder, sodat die deelnemers die voordele wat die navorsing mag inhou, soos hierbo vermeld, kan ervaar. Die risiko's blyk redelik te wees in verhouding tot die belangrikheid van die kennis wat verwerf kan word wat die moontlike verbetering van onderrig in Lewenswetenskap tot gevolg kan hê.

Wie sal toegang tot die data hê?

U seun/dogter se toetsresultate sal nie aan sy/haar naam gekoppel word nie. Hy/sy sal nie 'n naam op 'n toets skryf nie, maar met 'n nommer uitgeken word (1, 2 ens.). Alle resultate sal bekend gemaak word deur dit aan 'n nommer te koppel. Hy/sy sal anoniem bly vir die navorser. Geen name sal vermeld word in bevindinge wat uit die navorsing voortspruit nie. Die navorser verseker u dat ons die inligting wat ons oor u seun/dogter het, sal beskerm. Alle inligting rakende die navorsing sal gestoor word op 'n rekenaar wat met 'n wagwoord beskerm is en die voltooide toetse sal in 'n kas in die navorser se kantoor toegesluit word. Die navorser is die enigste persoon wat 'n sleultel het om die kas oop te sluit.

Dit is belangrik om te weet dat vertroulikheid in die navorsing beperk gaan wees. Buiten die onafhanklike persoon, sal slegs twee ander mense ook toegang tot die data hê, naamlik die onafhanklike statistikus wat my sal help met die vaslegging van die data, en die studieleier wat kontrole gaan uitoefen om te verseker dat die navorsingsbevindinge korrek is. Die onafhanklike statistikus is Me Aldine Oosthuyzen, 'n ervare en gekwalifiseerde statistikus aan die Noordwes-Universiteit se Vaaldriehoekkampus. Die navorser sal die data vir 'n minimum van vyf jaar stoor. Die onafhanklike persoon, die navorser en die onafhanklike statistikus sal 'n geskrewe ooreenkoms teken aan die begin van die navorsing dat hulle onderneem om alle inligting met betrekking tot die navorsing en die data vertroulik te hanteer, en nie daaroor te praat nie.

Wat gaan met die data gebeur?

Ek verseker u dat die inligting wat via die navorsing verkry word, slegs vir navorsingsdoeleindes gebruik gaan word. Geen inligting oor u seun/dogter sal bekend gemaak word in verslae oor die studie nie (byvoorbeeld u naam, u seun/dogter se naam of adres).

Die data van my studie gaan as volg grerapporteer word: (i) Die navorser sal die navorsingbevindinge in die vorm van 'n proefskrif rapporteer wat vir eksamineringsdoeleindes aan eksaminatore by ander universiteite voorgehou sal word, (ii) Die navorser beoog ook om oor die navorsing te skryf in artikels en boek-hoofstukke, en om aanbiedings oor die navorsing by konferensies te doen.

Hierdie studie is eenmalig en die data sal nie hergebruik word in ander toekomstige studies nie.

Gaan u seun/dogter betaal of vergoed word om aan die studie deel te neem/ is daar enige kostes betrokke?

U seun/dogter gaan nie betaal of vergoed word om aan die studie deel te neem nie. Verversings sal aan hom/haar gegee word na afloop van elke toets. Die verversings sal 'n blyk van waardering wees vir die tyd wat u opgeoffer het om aan die navorsing deel te neem. Die skryf van daarvan en die onderrig met behulp van Denkkaarte sal plaasvind gedurende periodes wat op die klasrooster geskeduleer is. U seun/dogter hoef dus nie vir addisionele vervoer te reël om op ander tye aan die navorsing deel te neem nie. Geen kostes is dus betrokke by deelname aan die navorsing nie.

Hoe gaan ek weet wat die bevindinge is?

Die algemene bevindinge van die navorsing sal die navorser met u deel via epos of gewone pos (verskaf asseblief u adres hieronder) deur 'n kort verslag saam te stel wat aan al die ouers/voogde van die deelnemers beskikbaar gestel sal word. Alle vrae oor die verslag kan direk aan die navorser gerig word by die kontakbesonderhede hieronder. U is ook welkom om met die navorser 'n afspraak te maak om u vrae te bespreek.

Is daar iets anders wat ek behoort te weet?

U kan mnr Francois Minnie by 084 549 2583 of 23512326@nwu.ac.za of sy studieleier, Prof. Mary Grosser by 083 490 0501 of mary.grosser@nwu.ac.za, kontak as u enige verdere navrae het of probleme teekom.

U kan die voorsitter van die Humanities and Health Research Ethics Committee (Prof Linda Theron) by 016 910 3076 of Linda.theron@nwu.ac.za kontak as u enige bekommernis of klagte het wat nie voldoende deur die navorser aangespreek is nie. U kan ook die mede-voorsitter, Prof. Tumi Khumalo (016 910 3397 of Tumi.khumalo@nwu.ac.za) kontak, of 'n boodskap vir Linda of Tumi los by Me Daleen Claasens (016 910 30441).

As u dit moeilik vind om die verduideliking van die navorsing te volg, kontak asseblief die navorser of die onafhanklike persoon by die kontakbesonderhede hier onder. Hulle sal met u 'n tyd reël om die navorser te ontmoet om aan u te verduidelik wat problematies vir u is.

U sal 'n kopie van die inligting en toestemming ontvang wat u vir u eie rekords kan hou.

Verklaring deur ouer

Deur hier onder te teken, verklaar ek…………………………..dat ek dit goedkeur dat my seun/dogter ………………………………….. …………………………. aan die volgende navorsingstudie mag deelneem: **Die impak van Denkkaarte om die ontwikkeling van kritiese denkvaardighede by eerstejaar voordiens Lewenswetenskap-onderwysers te koester**

Ek verklaar die volgende:

- Ek het die inligting gelees en verstaan die inligting in die ingeligte toestemmingsvorm, wat in 'n taal geskryf is waarmee ek gemaklik is en vlot praat.
- Ek het 'n kans gehad om vrae te vra aan die persoon wat die ingeligte toestemming verkry het sowel as aan die navorser (as hierdie 'n ander persoon is), en al my vrae is voldoende beantwoord.
- Ek verstaan dat deelname aan die studie **vrywillig** is, en ek is nie onder druk geplaas om toestemming te gee dat my seun/dogter mag deelneem nie.

- Ek verstaan dat my seun/dogter se toetsresultate in die openbaar bekend gemaak en/of aangehaal kan word, sonder enige verwysing na sy/haar of my persoonlike identiteit.
- My seun/dogter mag kies om om/haar enige tyd aan die studie te onttrek, en dit sal vir hom /haar geen penalisering of bevooroordeeldheid inhou nie.
- My seun/dogter mag gevra word om die studie te verlaat voordat dit voltooi is, as die navorser voel dat dit in my seun/dogter se beste belang is, of as my seun/doger nie hou by die navorsingsplan waarop ooreengekom is nie.

Geteken te (*plek*) ....….......…………….. op (*datum*) …………...……….. 20....

....

Handtekening van deelnemer **Handtekening van getuie**

- U mag my weer kontak ☐ **Ja** ☐ **Nee**
- Ek wil graag 'n opsomming van die navorsingsbevindinge hê ☐ **Ja** ☐ **Nee**

Die beste manier om my te bereik is:

Naam en Van: ____
Posadres: ____
Epos: ____
Telefoonnommer: ____________________
Selfoonnommer: _____________________

Indien die bogenoemde besonderhede verander, kontak asseblief die volgende persoon wat my goed ken, nie saam met my bly nie en sal help om my te kontak.

Naam en van:
____
Telefoonommer/ Selfoonnommer /Epos:
____

Verklaring deur persoon wat toestemming verkry

Ek *(naam)* …………………………………………...……… verklaar dat:

- Ek die inligting in die dokument verduidelik het aan……………………………
- Ek hom/haar aangemoedig het om vrae te stel en genoeg tyd toegelaat het om hom/haar te antwoord.
- Ek tevrede is dat hy/sy alle aspekte van die studie soos hierbo bespreek word, genoegsaam verstaan.
- Ek het/het nie 'n vertaler gebruik het nie.

Die beste manier om my te bereik is:

Naam en Van: ____
Posadres: ____

Epos: ____
Telefoonnommer: _____________________
Selfoonnommer: ______________________

Geteken te (*plek*) ....….......…………….. op (*datum*) …………...……….. 20....

....
Handtekening van persoon wat toestemming verkry **Handtekening van getuie**

Verklaring deur navorser

Ek *(naam)* ……………………………………………..……… verklaar dat:

- Ek die inligting in die dokument verduidelik het aan……………………………
- Ek hom/haar aangemoedig het om vrae te stel en genoeg tyd toegelaat het om hom/haar te antwoord.
- Ek tevrede is dat hy/sy alle aspekte van die studie soos hierbo bespreek word, genoegsaam verstaan.
- Ek het/het nie 'n vertaler gebruik het nie.

Geteken te (*plek*) ....….......…………….. op (*daum*) …………...……….. 20....

....
Handtekening van navorser **Handtekening van getuie**

APPENDIX C

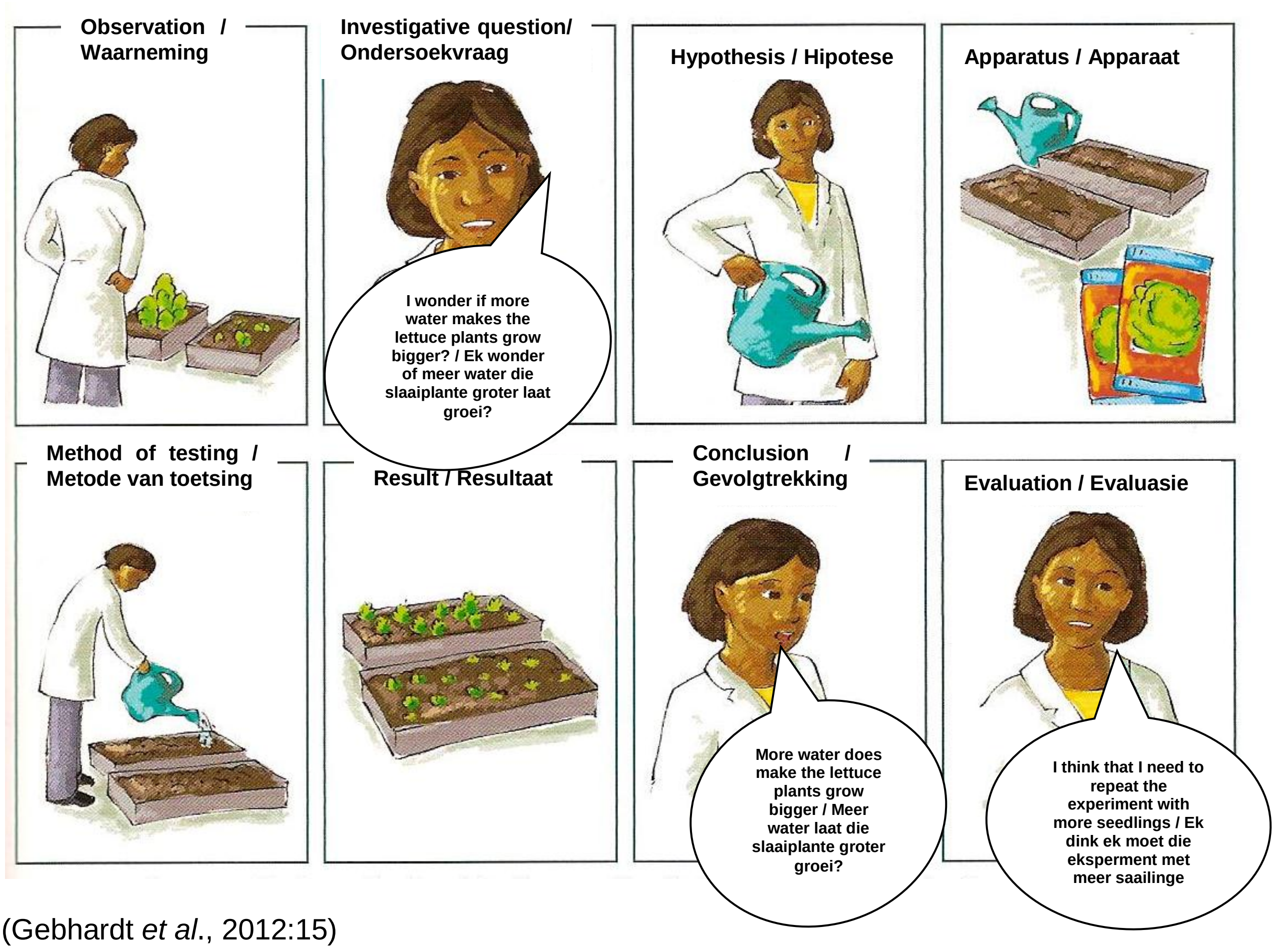
PRE- AND POST-TESTS

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

PRETEST 1 **LIFE 111**

Various possible options are provided as answers to the following questions. Choose the correct answer and cross only the letter (A - D) next to the question number on the answer sheet, for example 1. E. Each answer must be motivated.	Verskeie moontlike opsies word as antwoorde vir die volgende vrae verskaf. Kies die korrekte antwoord en deurkruis slegs die letter (A – D) langs die vraagnommer op die antwoordblad, byvoorbeeld 1. E. Elke antwoord moet gemotiveer word.

Study the following representation of the Scientific Method and answer questions 1 to 6 that follow: / *Bestudeer die volgende voorstelling van die Wetenskaplike metode en beantwoord vrae1 tot 6 wat volg:*



(Gebhardt *et al*., 2012:15)

1. This diagram represents the Scientific Method as it A consists of eight different steps. B shows results. C is the specific method used in any scientific investigation. D does include steps to design an experiment.	1. Hierdie diagram verteenwoordig die wetenskaplike metode omdat dit A uit agt verskillende stappe bestaan. B resultate toon. C die spesifieke metode is wat in enige wetenskaplike ondersoek gebruik word. D stappe insluit vir die ontwerp van 'n eksperiment.
2. According to the given investigative question, what is a possible observation? A Difference in height of plants between the two trays. B One tray receives more sunlight. C One tray has a sandy soil type. D One tray receives more water than the other one.	2. Na aanleiding van die gegewe ondersoek vraag, wat is 'n moontlike waarneming? A Verskil in planthoogte tussen die twee bakke. B Een bak ontvang meer sonlig. C Een bak het 'n sanderige grondtipe. D Een bak het meer water as die ander een ontvang.
3. Which ONE of the following is the most appropriate independent variable for this experiment? A Sunlight B More water C Bigger plants D Sandy soil	3. Watter EEN van die volgende is die mees geskikte onafhanklike veranderlike vir die eksperiment? A Sonlig B Meer water C Groter plante D Sanderige grond
4. Which ONE of the following is the most	4. Watter EEN van die volgende is die

appropriate hypothesis for this experiment? A Less water makes the lettuce plants grow bigger. B Does more water makes the lettuce plants grow bigger? C Water makes the lettuce plants grow bigger. D Does sunlight makes the lettuce plants grow bigger?	mees geskikte hipotese vir die eksperiment? A Minder water laat die blaarslaai groter groei. B Sal meer water die blaarslaai groter laat groei? C Water laat die blaarslaai groter groei. D Sal sonlig die blaarslaai groter laat groei?
5. Which ONE of the following is the most appropriate dependent variable for this experiment? A Sunlight B More water C Bigger plants D Sandy soil	5. Watter EEN van die volgende is die mees geskikte afhanklike veranderlike vir die eksperiment? A Sonlig B Meer water C Groter plante D Sanderige grond
6. Which ONE of the following indicates the correct order of the steps to design an experiment? A Aim → apparatus → determine variables → method B Aim → determine variables → apparatus → method C Determine variables → aim → apparatus → method D Aim → apparatus → method → determine variables	6. Watter EEN van die volgende dui die korrekte volgorde van stappe tydens die ontwerp van ‘n eksperiment? A Doel → apparaat → bepaal veranderlikes → metode B Doel → bepaal veranderlikes → apparaat → metode C Bepaal veranderlikes → doel → apparaat → metode D Doel → apparaat → metode → bepaal veranderlikes
Study the following question and answer	Bestudeer die volgende vraag en

questions 7 to 10 that follow: Does heating a cup of water allow more sugar in a cup to be dissolved? 7. Which ONE of the following is the most appropriate hypothesis for this question? A Does heating allow more sugar to dissolve? B Does heating a cup of water allow it to dissolve more sugar? C Water allows more sugar to dissolve. D Heating a cup of water allows more sugar to dissolve. 8. Which ONE of the following is the most appropriate dependent variable for this experiment? A Heat B Cup of water C Sugar D More sugar dissolves 9. Which ONE of the following is the most appropriate independent variable for this experiment? A Heat B Cup of water C Sugar D More sugar dissolves 10. Which ONE of the following is the most	beantwoord vrae 7 tot 10 wat volg: Sal meer suiker in 'n koppie oplos wanneer water in die koppie verhit word? 7. Watter EEN van die volgende is die mees geskikte hipotese vir die vraag? A Sal hitte meer suiker laat oplos? B Sal die verhitting van 'n koppie water meer suiker laat oplos? C Water laat toe dat meer suiker oplos. D Die verhitting van 'n koppie water sal meer suiker laat oplos. 8. Watter EEN van die volgende is die mees geskikte afhanklike veranderlike vir die eksperiment? A Hitte B Koppie water C Suiker D Meer suiker los op 9. Watter EEN van die volgende is die mees geskikte onafhanklike veranderlike vir die eksperiment? A Hitte B Koppie water C Suiker D Meer suiker los op 10. Watter EEN van die volgende is die

appropriate fixed(constant) variable for this experiment?

A Heat

B Cup of water

C Less sugar dissolves

D More sugar dissolves

mees geskikte vaste(konstante) veranderlike vir die eksperiment?

A Hitte

B Koppie water

C Minder suiker los op/

D Meer suiker los op

Study the following and answer questions 11 to 15 that follow:

A scientist designed an experiment to investigate the water-carrying capacity of sand, loam and clay soil. A soil sample of each soil type was placed in funnels lined with filter paper. 100 cm^3 of water was added to all three soil samples at exactly the same time. The filtrates were collected in measuring cylinders. The results are shown in the following table:

Time (in minutes)	Volume of filtrate (in cm^3)		
	Sand	Loam	Clay
2	10	5	0
4	20	10	0
6	35	20	0
8	50	35	5
10	65	45	10
20	75	55	12
40	75	60	14
60	75	65	16

Bestudeer die volgende en beantwoord vrae 11 tot 15 wat volg:

‘n Wetenskaplike het ‘n eksperiment ontwerp om die waterhouvermoë van sand, leem en kleigrond te ondersoek. ‘n Grondmonster van elke grondtipe is in tregters met filtreerpapier geplaas en 100 cm^3 water is op dieselfde tydstip by elke grondmonster gevoeg. Die filtraat is in maatsilinders opgevang. Die resultate word in onderstaande tabel weergegee:

Tyd (in minute)	Volume van filtraat (in cm^3)		
	Sand	Leem	Klei
2	10	5	0
4	20	10	0
6	35	20	0
8	50	35	5
10	65	45	10
20	75	55	12
40	75	60	14
60	75	65	16

11. Which ONE of the following is the most appropriate question for this experiment? A Does time influence the volume of filtrate? B Does more water filter through sand? C Which soil type has the best water-carrying capacity? D Does the filter paper influence the volume of the filtrate?	11. Watter EEN van die volgende is die mees geskikte vraag vir die eksperiment? A Beïnvloed tyd die volume van die filtraat? B Filtreer meer water deur sand? C Watter grondtipe het die beste water-houvermoë? D Beïnvloed die filtreerpapier die volume van die filtraat?
12. Which ONE of the following is the most appropriate independent variable for this experiment? A Filter paper B Time in minutes C Volume of filtrate in cm^3 D Soil sample	12. Watter EEN van die volgende is die mees geskikte onafhanklike veranderlike vir die eksperiment? A Filtreerpapier B Tyd in minute C Volume van filtraat in cm^3 D Grondmonster
13. Which ONE of the following is the most appropriate dependent variable for this experiment? A Filter paper B Time in minutes C Volume of filtrate in cm^3 D Soil sample	13. Watter EEN van die volgende is die mees geskikte afhanklike veranderlike vir die eksperiment? A Filtreerpapier B Tyd in minute C Volume van filtraat in cm^3 D Grondmonster
14. Identify three fixed variables for this experiment. A Same quantity of each soil type; 100 cm^3 of water; add water the same time. B Time in minutes; 100 cm^3 of water; add water the same time C Same quantity of each soil type; 100	14. Identifiseer drie vaste veranderlikes vir die eksperiment. A Ewe veel van elke tipe grond; 100 cm^3 of water; voeg water op dieselfde tydstip by. B Tyd in minute; 100 cm^3 of water; voeg water op dieselfde tydstip by. C Ewe veel van elke tipe grond; 100

cm^3 of water; volume of filtrate in cm^3 D Same quantity of each soil type; volume of filtrate in cm^3; time in minutes 15. A possible conclusion for this experiment? A Clay has the best water-carrying capacity. B Spaces between clay particles are very small. C Clay particles are smaller than sand particles. D Spaces between sand particles are large.	cm^3 of water; volume van filtraat in cm^3 D Ewe veel van elke tipe grond; volume van filtraat in cm^3; tyd in minute 15. ‘n Moontlike gevolgtrekking vir die eksperiment: A Kleigrond het die beste waterhou-vermoë. B Spasies tussen kleideeltjies is baie klein. C Kleideeltjies is kleiner as sanddeeltjies. D Spasies tussen sanddeeltjies is groot.

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

PRETEST 1 – ANSWER SHEET / ANTWOORDBLAD LIFE 111

1 ~~A~~ B C D

Motivation / Motivering: **Steps given in diagram**

2 ~~A~~ B C D

Motivation / Motivering: **Observation – what you see**

3 A ~~B~~ C D

Motivation / Motivering: **Cause**

4 A B ~~C~~ D

Motivation / Motivering: **Statement with cause and effect**

5 A B ~~C~~ D

Motivation / Motivering: **Effect**

6 A ~~B~~ C D

Motivation / Motivering: **According scientific method**

7 A B C ~~D~~

Motivation / Motivering: **Statement with cause and effect**

8 A B C ~~D~~

Motivation / Motivering: **Effect**

9 ~~A~~ B C D

Motivation / Motivering: **Cause**

10 A ~~B~~ C D

Motivation / Motivering: **Must be the same in cause and effect**

11 A B ~~C~~ D

Motivation / Motivering: **According to introduction**

12 A B C ~~D~~

Motivation / Motivering: **Cause**

13 A B ~~C~~ D

Motivation / Motivering: **Effect**

14 ~~A~~ B C D

Motivation / Motivering: **According to introduction all fixed variables**

15 ~~A~~ B C D

Motivation / Motivering: **Linked to question**

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

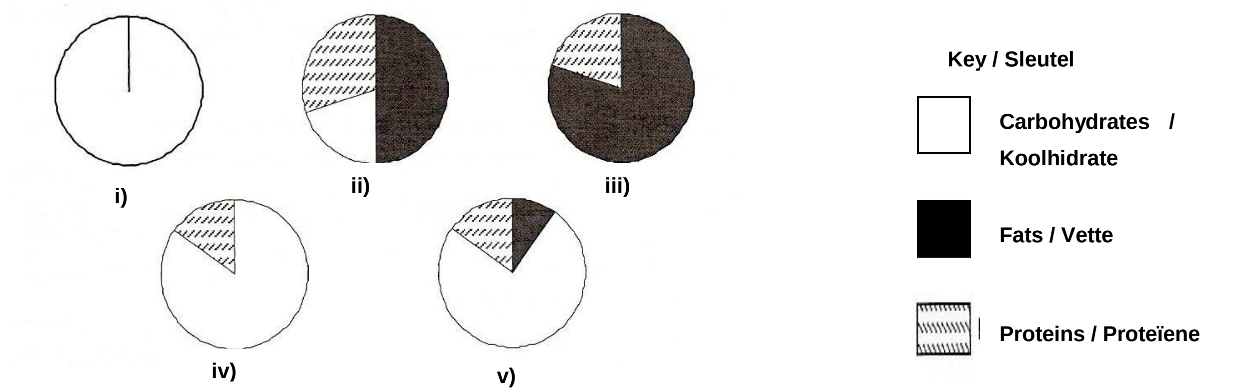
POSTTEST 1 **LIFE 111**

Various possible options are provided as answers to the following questions. Choose the correct answer and cross only the letter (A - D) next to the question number on the answer sheet, for example 1. E.
Each answer must be motivated.

Verskeie moontlike opsies word as antwoorde vir die volgende vrae verskaf. Kies die antwoord en deurkruis slegs die letter (A – D) langs die vraagnommer op die antwoordblad, byvoorbeeld 1. E.
Elke antwoord moet gemotiveer word.

Study the accompanying pie charts which show the carbohydrate, fat and protein content of five different food types marked i) to v). Answer then the questions 1 to 4.

Bestudeer die bygaande sirkeldiagramme wat koolhidraat-, vet- en proteïeninhoud van vyf verskillende voedselsoorte gemerk i) tot v) aantoon. Beantwoord dan die vrae 1 tot 4.



(Sterrenberg, 2009:3.31)

1. Which of the food types are the least suitable as a source of insulation?

   A i)

   B ii)

   C iii)

   D v)

1. Watter van die voedselsoorte sal die minste geskik wees as 'n bron van isolering?

   A i)

   B ii)

   C iii)

   D v)

2. Which of these food types will be the most suitable for structural growth in size?

   A ii)

   B iii)

   C iv)

   D v)

2. Watter van hierdie voedselsoorte sal die mees bevorderlike wees vir strukturele groei in grootte?

   A ii)

   B iii)

   C iv)

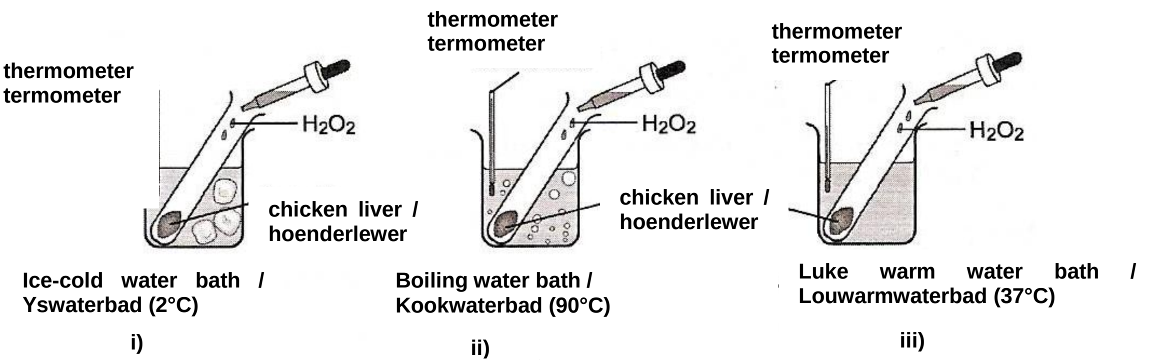
   D v)

3. Which of these food types is the richest source of energy? A i) B ii) C iii) D v)	3. Watter van hierdie voedselsoorte is die rykste bron van energie? A i) B ii) C iii) D v)
4. What percentage of food type ii) is fat? A 25% B 50% C 60% D 75%	4. Watter persentasie van voedselsoort ii) bestaan uit vet? A 25% B 50% C 60% D 75%
Sometimes during cell metabolism, chemical substances are formed that are poisonous to the body. However, the body cells are not destroyed due to the presence of enzymes that decompose these poisonous substances into harmless products. One such poisonous substance that is released as a by-product during normal cellular reactions is *hydrogen peroxide.* However, the enzyme, *catalase,* ensures that this poisonous substance is converted into two harmless products as quickly as possible.	Gedurende selmetabolisme ontstaan daar soms chemiese stowwe wat vir die liggaam giftig is. Die liggaamselle word egter nie vernietig nie, omdat daar ensieme teenwoordig is, wat hierdie giftige stowwe afbreek tot onskadelike produkte. Een so 'n giftige stof wat as neweproduk vrygestel word tydens normale selreaksies, is *waterstof-peroksied.* Die ensiem, *katalase*, verseker egter dat hierdie giftige stof so gou as moontlik in twee onskadelike produkte omgeskakel word.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

hydrogen peroxide / waterstofperoksied **water** **oxygen / suurstof**

An experiment is conducted to determine the effect of different temperatures on the action of the enzyme catalase, found in raw chicken livers. Study the accompanying setup apparatus for this experiment and answer questions 5 to 9 that follow:	'n Eksperiment word uitgevoer om vas te stel wat die effek van verskillende temperature op die werking van die ensiem katalase, wat in rou hoenderlewer aangetref word, is. Bestudeer die bygaande opstelling van die apparaat vir hierdie eksperiment en beantwoord vrae 5 tot 9 wat volg:



(Sterrenberg & Fouché, 2013:2.58)	
5. Suppose you had to conduct this investigation, which one of the following is a possible hypothesis for the experiment? A Catalase functions optimally at 2°C B Catalase functions optimally at 90°C C Catalase functions optimally at 37°C D Different temperatures have an effect on the action of catalase	5. Indien jy die ondersoek moes uitvoer, watter een van die volgende is ‘n moontlike hipotese vir die eksperiment? A Katalase funksioneer optimaal by 2°C B Katalase funksioneer optimaal by 90°C C Katalase funksioneer optimaal by 37°C D Verskillende temperature het ‘n effek op die werking van katalase
6. In which of the test tube/s would the reaction take place the fastest? A i) B ii) C iii) D i) en iii)	6. In watter proefbuis/e sou die reaksie die vinnigste plaasvind? A i) B ii) C iii) D i) en iii)
7. For this experiment, name the dependent variable. A The temperature of the water bath B The condition of the chicken liver C The amount of hydrogen peroxide D The amount of bubbles formed	7. Noem die afhanklike veranderlike vir die eksperiment. A Die temperatuur van die waterbad B Die toestand van die hoenderlewer C Die hoeveelheid waterstofperoksied D Die hoeveelheid borrels wat gevorm word
8. For this experiment, name the independent variable. A The temperature of the water bath B The condition of the chicken liver C The amount of hydrogen peroxide D The amount of bubbles formed	8. Noem die onafhanklike veranderlike vir die eksperiment. A Die temperatuur van die waterbad B Die toestand van die hoenderlewer C Die hoeveelheid waterstofperoksied D Die hoeveelheid borrels wat gevorm word

9. Which one of the following is not a fixed variable?

A The amount of chicken liver

B The condition of the chicken liver

C The amount of hydrogen peroxide

D The amount of liquid that was displaced by the oxygen

9. Watter een van die volgende is nie 'n vaste veranderlike nie?

A Die hoeveelheid hoenderlewer

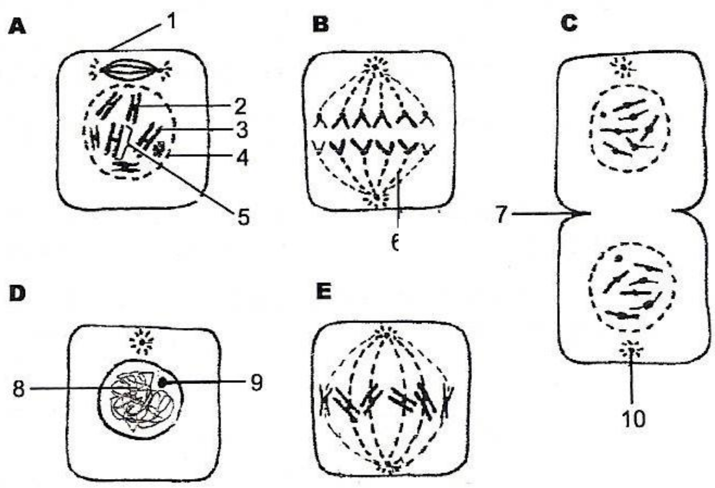
B Die toestand van die hoenderlewer

C Die hoeveelheid waterstofperoksied

D Die hoeveelheid vloeistof wat deur die suurstof verplaas word

Study the following representation of a division process and answer the questions 10 to 13 that follow:

Bestudeer die volgende voorstellings van 'n delingsproses en beantwoord vrae 10 tot 13 wat volg:



(Sterrenberg et al., 2014:3.33)

10. Which one of the following represent the correct sequence of the phases of the cell division process?

A iv), i), ii), v), iii)

B iv), i), v), ii), iii)

C i), iv), ii), v), iii)

D i), iv), v), ii), iii)

10. Watter een van die volgende stel die korrekte volgorde van die fases van die seldelingsproses voor?

A iv), i), ii), v), iii)

B iv), i), v), ii), iii)

C i), iv), ii), v), iii)

D i), iv), v), ii), iii)

11. If a parent cell has twelve chromosomes, how many chromosomes will each of the daughter cells have following meiosis?

A Forty-eight

11. Indien die ouersel twaalf chromosome besit, hoeveel chromosome sal elke dogtersel na meiose hê?

A Agt en veertig

B Twenty-four C Twelve D Six	B Vier en twintig C Twaalf D Ses
12. At the metaphase plate during metaphase I of meiosis, there are A chromosomes consisting of one chromatid. B unpaired duplicated chromosomes. C bivalents. D no crossing-over.	12. By die metafase-plaat tydens metafase I van meiose, is daar A chromosome wat uit een chromatied bestaan. B ongepaarde gedupliseerde chromosome. C bivalente. D geen oorkruising nie.
13. At the metaphase plate during metaphase II of meiosis, there are A chromosomes consisting of one chromatid. B unpaired duplicated chromosomes. C bivalents. D homologous pairs of chromosomes.	13. By die metafase-plaat tydens metafase II van meiose, is daar A chromosome wat uit een chromatied bestaan. B ongepaarde gedupliseerde chromosome. C bivalente. D homoloë pare chromosome.
14. When a cell is placed in a hypotonic solution, A solute exits the cell to equalize the concentration on both sides of the membrane. B water exits the cell toward the area of lower solute concentration. C water enters the cell toward the area of higher solute concentration. D solute exits and water enters the cell.	14. Wanneer ‘n sel in ‘n hipotone oplossing geplaas word, sal A die oplossing uit die sel beweeg om die konsentrasies aan beide kante van die membraan dieselfde te maak. B water uit die sel beweeg na gebied met laer konsentrasie oplossing. C water die sel inbeweeg na gebied met hoër konsentrasie oplossing. D die oplossing uit die sel en water inbeweeg.
15. When a cell is placed in a hypertonic solution, A solute exits the cell to equalize the concentration on both sides of the membrane. B water exits the cell toward the area of lower solute concentration. C water enters the cell toward the area of higher solute concentration. D solute exits and water enters the cell.	15. Wanneer ‘n sel in ‘n hipertone oplossing geplaas word, sal A die oplossing uit die sel beweeg om die konsentrasies aan beide kante van die membraan dieselfde te maak. B water uit die sel beweeg na gebied met laer konsentrasie oplossing. C water die sel inbeweeg na gebied met hoër konsentrasie oplossing. D die oplossing uit die sel en water inbeweeg.

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

<u>POSTTEST 1 – ANSWER SHEET / ANTWOORDBLAD LIFE 111</u>

1 A B C D

Motivation / Motivering: **Contains no fats**

2 A B C D

Motivation / Motivering: **Contains most proteins**

3 A B C D

Motivation / Motivering: **Contains most fats**

4 A B C D

Motivation / Motivering: **Half of nutrients are fat**

5 A B C D

Motivation / Motivering: **Body temperature / optimum temperature for catalase**

6 A B C D

Motivation / Motivering: **Body temperature / optimum temperature for catalase**

7 A B C D

Motivation / Motivering: **Effect**

8 A B C D

Motivation / Motivering: **Cause**

9 A B C D

Motivation / Motivering: **Dependent**

10 A B C D

Motivation / Motivering: **Meiosis I**

11 A B C D

Motivation / Motivering: **Reduction of chromosome number**

12 A B C D

Motivation / Motivering: **Reduction of chromosome number**

13 ~~A~~ B C D

Motivation / Motivering: **No reduction of chromosome number**

14 A ~~B~~ C D

Motivation / Motivering: **Hipotonic high water potential**

15 A B ~~C~~ D

Motivation / Motivering: **Hypertonic low water potential**

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

PRETEST 2 LIFE 111

Various possible options are provided as answers to the following questions. Choose the correct answer and cross only the letter (A - D) next to the question number on the answer sheet, for example 1. E.
Each answer must be motivated.

The diagram below shows details of an experiment in which three similar tablecloths with identical blood stains, were washed in an enzyme-containing powder solution in the same washing machine at three different temperatures, 15°C, 37°C and 65°C.
Study the diagram and answer the questions 1 to 3 that follow:

Verskeie moontlike opsies word as antwoorde vir die volgende vrae verskaf. Kies die antwoord en deurkruis slegs die letter (A – D) langs die vraagnommer op die antwoordblad, byvoorbeeld 1. E.
Elke antwoord moet gemotiveer word.

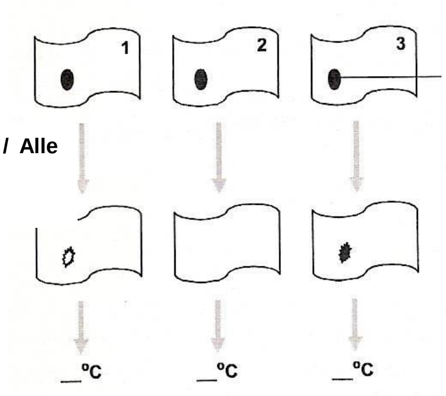
Die onderstaande diagram toon die besonderhede van 'n eksperiment waarin drie soortgelyke tafeldoeke met identiese bloedvlekke, teen drie verskillende temperature, 15°C, 37°C en 65°C in dieselfde wasmasjien met 'n waspoeier wat ensieme bevat, gewas is.
Bestudeer die diagram en beantwoord vrae 1 tot 3 wat volg:

Before washing / Voordat gewas is

blood stain / bloedvlek

All table cloths are washed for 10 minutes / Alle tafeldoeke is vir 10 minute gewas

Result after washing / Resultaat nadat gewas is gewas is



(Sterrenberg, 2009:3.34)

1. Suppose you had to conduct this investigation, which one of the following is a possible hypothesis for the experiment?

   A The enzyme functions optimally at 2°C

   B The enzyme functions optimally at 90°C

   C The enzyme functions optimally at 37°C

   D Different temperatures have an effect on the action of the enzyme

1. Indien jy die ondersoek moes uitvoer, watter een van die volgende is 'n moontlike hipotese vir die eksperiment?

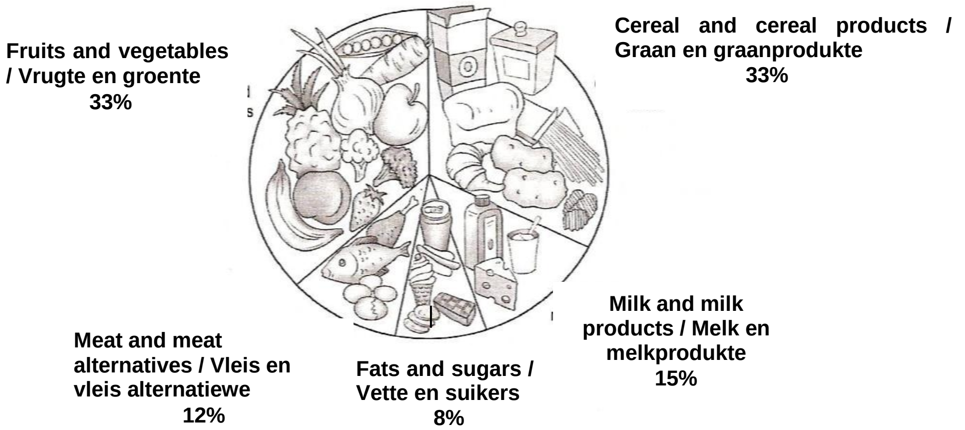
   A Die ensiem funksioneer optimaal by 2°C

   B Die ensiem funksioneer optimaal by 90°C

   C Die ensiem funksioneer optimaal by 37°C

   D Verskillende temperature het 'n effek

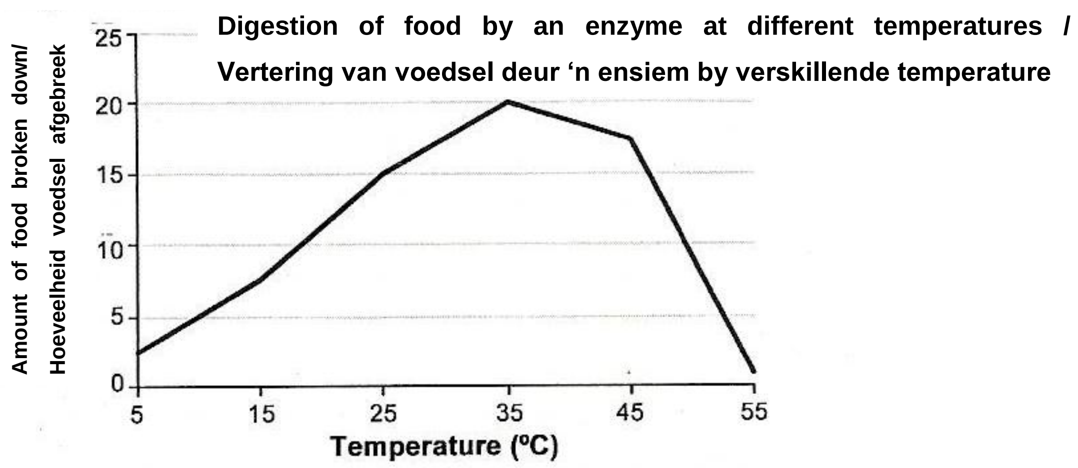
	op die werking van die ensiem
2. For this experiment, name the dependent variable. A Different temperatures B The time period of 10 minutes C Result after washing D The size of the blood stains	2. Noem die afhanklike veranderlike vir die eksperiment. A Verskillende temperature B Die tydperiode van 10 minute C Resultate nadat gewas is D Die grootte van die bloedvlekke
3. At what possible temperature was each of the tablecloths 2 and 3 washed respectively? A 15°C and 37°C B 37°C and 65°C C 15°C and 65°C D 37°C and 15°C	3. By watter moontlike temperatuur is elk van die tafeldoeke 2 en 3 onderskeidelik, gewas? A 15°C en 37°C B 37°C en 65°C C 15°C en 65°C D 37°C en 15°
Study the accompanying representation of the recommended daily allowance of the different food groups and answer questions 4 and 5 that follow:	Bestudeer meegaande voorstelling van die aanbevole daaglikse inname van die verskillende voedselgroepe en beantwoord vrae 4 en 5 wat volg:



(Sterrenberg & Fouché, 2013:2.57)

If a total of 18 portions is consumed per day, calculate the number of portions that should come from	Indien 'n totaal van 18 porsies per dag ingeneem word, bereken die aantal porsies wat uit elk van die volgende voedselgroepe ingeneem behoort te word:

4. fruits and vegetables. A 7 B 6 C 5 D 4	4. vrugte en groente A 7 B 6 C 5 D 4
5. meats and meat alternatives as well as fats and sugars respectively. A 7 and 6 B 6 and 3 C 3 and 2 D 2 and 1	5. vleis en vleis alternatiewe asook vette en suikers onderskeidelik. A 7 en 6 B 6 en 3 C 3 en 2 D 2 en 1
Use the information in the graph below to answer the questions 6 to 8:	Gebruik die inligting in die onderstaande grafiek om vrae 6 tot 8 te beantwoord.

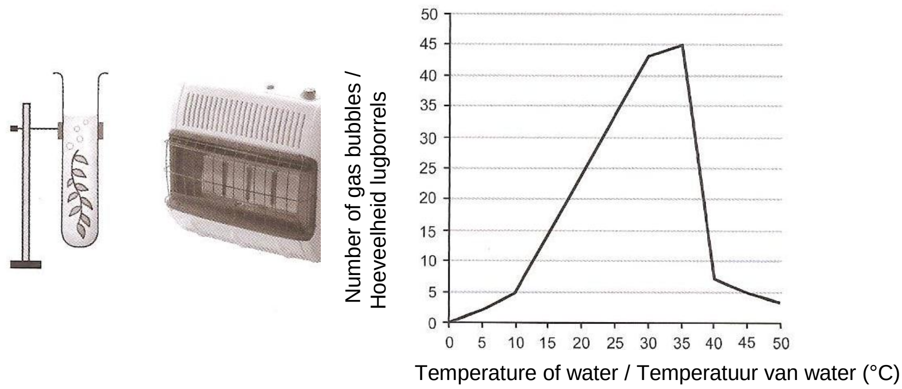


(Sterrenberg, 2009:3.33)

6. At which temperature does the enzyme work optimally? A 5°C B 35°C C 45°C D 55°C	6. By watter temperatuur werk die ensiem optimaal? A 5°C B 35°C C 45°C D 55°C
7. What amount of food is broken down at 25°C?	7. Hoeveel voedsel word by 25°C afgebreek?

A 2.5 mg/h B 7.5 mg/h C 15 mg/h D 20 mg/h	A 2.5 mg/h B 7.5 mg/h C 15 mg/h D 20 mg/h

8. Use the following steps to explain the shape of the graph between 5°C and 35°C: i) optimum temperature ii) enzyme activity is low iii) at low temperatures v) enzyme activity increases vi) temperature rises A vi), ii), iii), i), v) B iii), v), vi), i), ii) C iii), ii), vi), i), v) D iii), ii), vi), v), i)	8. Gebruik die volgende stappe om die vorm van die grafiek van 5°C tot 35°C te verduidelik: i) optimum temperatuur ii) ensiemaktiwiteit laag iii) by lae temperatuur v) ensiemaktiwiteit neem toe vi) temperatuur styg A vi), ii), iii), i), v) B iii), v), vi), i), ii) C iii), ii), vi), i), v) D iii), ii), vi), v), i)
A practical investigation was conducted to determine the effect of water temperature on the rate of photosynthesis of a water plant, using the apparatus shown below. The number of bubbles of gas released per minute was measured at a number of different temperatures. Study the accompanying results and answer questions 9 to 12 that follow:	‘n Praktiese ondersoek word uitgevoer, met behulp van apparate soos in die onderstaande voorstelling, om te bepaal of watertemperatuur ‘n effek het op die tempo waarteen ‘n waterplant fotosinteer. Die aantal gasborrels wat per minuut vrygestel word, word by verskillende water temperature gemeet. Bestudeer die bygaande resultate en beantwoord vrae 9 tot 12 wat volg:

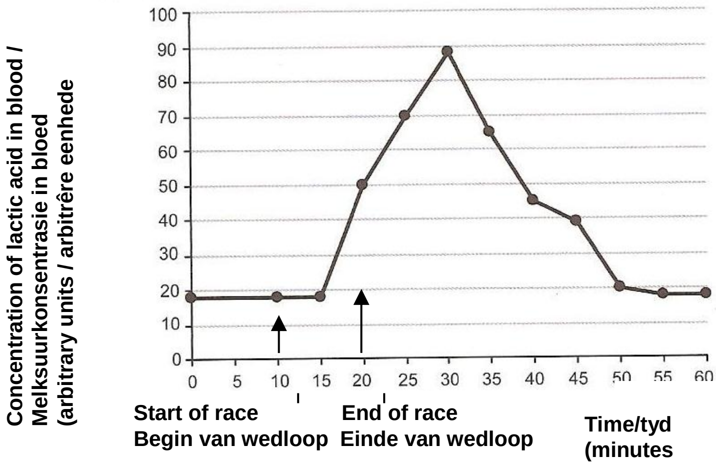


(Sterrenberg & Fouché, 2013:2

9. For this experiment, name the dependent variable. A Temperature of water	9. Noem die afhanklike veranderlike vir die eksperiment. A Watertemperatuur

B Number of gas bubbles C Amount of heat applied D Amount of sunlight present	B Hoeveelheid gasborrels C Hoeveelheid hitte toegepas D Hoeveelheid sonlig teenwoordig

10. For this experiment, name the independent variable. A Temperature of water B Number of gas bubbles C Amount of heat applied D Amount of sunlight present	10. Noem die onafhanklike veranderlike vir die eksperiment. A Watertemperatuur B Hoeveelheid gasborrels C Hoeveelheid hitte toegepas D Hoeveelheid sonlig
11. At what temperature is the rate of photosynthesis the highest? A 10°C B 30°C C 35°C D 40°C	11. By watter temperatuur is die tempo van fotosintese die hoogste? A 10°C B 30°C C 35°C D 40°C
12. How many gas bubbles are produced at 38°C? A 10 B 15 C 20 D 25	12. Hoeveel gasborrels word by 38°C geproduseer? A 10 B 15 C 20 D 25
The concentration of lactic acid in the blood of an athlete was measured at intervals before, during and after a long-distance race, which lasted 10 minutes. The results are represented in the accompanying graph. Study the graph and answer questions 13 to 15 that follow:	Die melksuur konsentrasie in die bloed van ‘n atleet is met tussenposes gemeet voor, gedurende en na afloop van ‘n langafstandwedloop wat 10 minute geduur het. Die resultate word deur die bygaande grafiek voorgestel. Bestudeer die grafiek en beantwoord vrae 13 tot 15.



13. What is the normal lactic acid concentration in the blood?

A 18 arbitrary units

B 20 arbitrary units

C 40 arbitrary units

D 90 arbitrary units

13. Wat is die normale melksuur konsentrasie in die bloed?

A 18 arbitrêre eenhede

B 20 arbitrêre eenhede

C 40 arbitrêre eenhede

D 90 arbitrêre eenhede

14. For how long did the concentration of lactic acid continue to increase after the end of the race?

A 10 minutes

B 30 minutes

C 35 minutes

D 50 minutes

14. Vir hoe lank het die melksuur konsentrasie, na afloop van die wedloop, steeds toegeneem?

A 10 minute

B 30 minute

C 35 minute

D 50 minute

15. How long did it take after the race to compensate for the oxygen debt?

A 10 minutes

B 30 minutes

C 35 minutes

D 55 minutes

15. Hoe lank, na die afloop van die wedloop, het dit geneem om van die suurstof skuld ontslae te raak?

A 10 minute

B 30 minute

C 35 minute

D 55 minute

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

PRETEST 2 – ANSWER SHEET / ANTWOORDBLAD LIFE 111

1 A B ~~C~~ D

Motivation / Motivering: **Body temperature / bio-enzyme**

2 A B ~~C~~ D

Motivation / Motivering: **Effect**

3 A ~~B~~ C D

Motivation / Motivering: **Body temperature and enzyme denatured at high temperature**

4 A ~~B~~ C D

Motivation / Motivering: **33% = 0.33 van 18 = 6**

5 A B C ~~D~~

Motivation / Motivering: **12% en 8% = 0.12 en 0.08 van 18 = 2 en 1**

6 A ~~B~~ C D

Motivation / Motivering: **Maximum activity**

7 A B ~~C~~ D

Motivation / Motivering: **Direk eweredig**

8 A B C ~~D~~

Motivation / Motivering: **Explain sequence of graph**

9 A ~~B~~ C D

Motivation / Motivering: **Effect**

10 ~~A~~ B C D

Motivation / Motivering: **Cause / bring about the change**

11 A B ~~C~~ D

Motivation / Motivering: **Optimum – max reaction**

12 A B C ~~D~~

Motivation / Motivering: **Direk eweredig**

13 ~~A~~ B C D

Motivation / Motivering: **Constant level before exercise**

14 ~~A~~ B C D

Motivation / Motivering: **30 – 20 min = 10min**

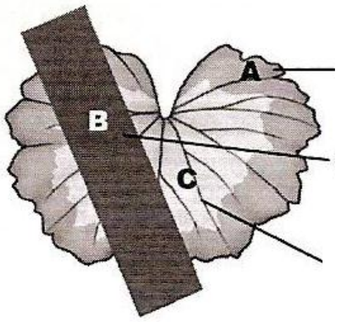
15 A B ~~C~~ D

Motivation / Motivering: **55 – 20 min = 35min**

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

POSTTEST 2 LIFE 111

Various possible options are provided as answers to the following questions. Choose the correct answer and cross only the letter (A - D) next to the question number on the answer sheet, for example 1. E. Each answer must be motivated. In an investigation to determine whether two factors are essential for photosynthesis to occur successfully, the accompanying variegated leaf was used. It was partially covered with foil. The destarched plant was placed in the sun for few hours and then tested for the presence of starch. Study the accompanying diagram and answer questions 1 to 3 that follow:	Verskeie moontlike opsies word as antwoorde vir die volgende vrae verskaf. Kies die antwoord en deurkruis slegs die letter (A – D) langs die vraagnommer op die antwoordblad, byvoorbeeld 1. E. Elke antwoord moet gemotiveer word. In 'n ondersoek om die noodsaaklikheid van twee faktore vir suksesvolle fotosintese vas te stel, is die bygaande gevlekte blaar gebruik, waarvan 'n gedeelte met tinfoelie toegeplak is. Die ontstyselde plant is 'n paar uur in die son geplaas en daarna vir stysel getoets. Bestudeer die bygaande diagram en beantwoord vrae 1 tot 3 wat volg:



(Sterrenberg & Fouché, 2013:2.54)

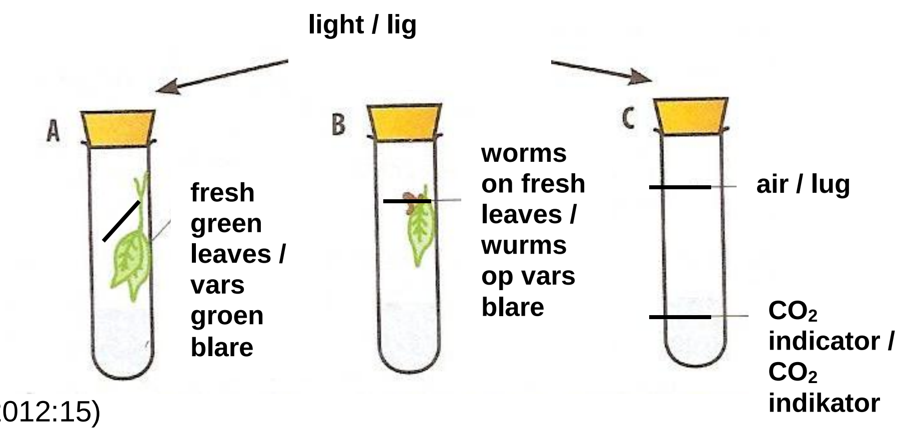
1. Which TWO factors were simultaneously tested for? A Sunlight and plant colours B Plant colours and carbon dioxide C Carbon dioxide and sunlight D Sunlight and chlorophyll	1. Vir watter TWEE faktore word hier gelyktydig getoets? A Sonlig en plantkleure B Plantkleure en koolstofdioksied C Koolstofdioksied en sonlig D Sonlig en chlorofil

2. Which ONE of the following is the most appropriate hypothesis for this experiment? A Sunlight and plant colours are essential for photosynthesis. B Plant colours and carbon dioxide are essential for photosynthesis.. C Carbon dioxide and sunlight are essential for photosynthesis. D Sunlight and chlorophyll are essential for photosynthesis.	2. Watter EEN van die volgende is die mees geskikte hipotese vir die eksperiment? A Sonlig en plantkleure is noodsaaklik vir fotosintese. B Plantkleure en koolstofdioksied is noodsaaklik vir fotosintese. C Koolstofdioksied en sonlig is noodsaaklik vir fotosintese. D Sonlig en chlorofil is noodsaaklik vir fotosintese.
3. Which ONE of the following indicate the most appropriate independent variables for this experiment? A Sunlight and starch B Starch and carbon dioxide C Carbon dioxide and sunlight D Sunlight and chlorophyll	3. Watter EEN van die volgende dui die mees geskikte onafhanklike veranderlikes vir die eksperiment aan? A Sonlig en stysel B Stysel en koolstofdioksied C Koolstofdioksied en sonlig D Sonlig en chlorofil
Plants require carbon dioxide, water and light to produce sugar during photosynthesis. Assume a plant requires 4 units water, 4 units carbon dioxide and 10 units of light to produce 2 glucose units. Study the following table of data from the five plants and answer questions 4 to 7 that follow:	Plante benodig koolstofdioksied, water en lig om glukose tydens fotosintese te produseer. Veronderstel ‘n plant het 4 eenhede water, 4 eenhede koolstofdioksied en 10 eenhede lig nodig om 2 eenhede glukose te produseer, Bestudeer die volgende tabel met vyf plante se data, en beantwoord vrae 4 tot 7 wat volg:

Plant	Units water / Eenhede water	Units / Eenhede CO_2	Units light / Eenhede lig
i)	16	16	20
ii)	16	12	30
iii)	20	16	20
iv)	20	20	40
v)	16	40	16

4. Which plant produced the most glucose? A ii) B iii) C iv) D v)	4. Watter plant het die meeste glukose geproduseer? A ii) B iii) C iv) D v)

5. If plant v) received another 14 units of light, how many more units of glucose will it be able to produce? A 1 B 2 C 3 D 4	5. Indien plant v) nog 14 eenhede lig sou ontvang, hoeveel eenhede glukose sou dit kon produseer? A 1 B 2 C 3 D 4
6. How many more units of light does plant iv) require to produce 10 units of glucose? A 10 B 15 C 20 D 25	6. Hoeveel eenhede lig het plant iv) nóg nodig om 10 eenhede glukose te produseer? A 10 B 15 C 20 D 25
7. Which factor/s prevents plant i) from producing more glucose? Unit/s A water, CO_2 and light. B water and CO_2. C CO_2 and light. D light only.	7. Watter faktor/e by plant i) verhoed dat meer glukose geproduseer word? Eenhede A water, CO_2 en lig. B water en CO_2. C CO_2 en lig. D lig alleenlik.
An experiment was set up as shown in the diagram below. All the test tubes were kept in the light. Study the information below and answer questions 8 to 11.	'n Eksperiment is opgestel soos in die bygaande diagram aangetoon. Al die proefbuise is in lig gehou. Bestudeer die bygaande inligting en beantwoord vrae 8 tot 11.



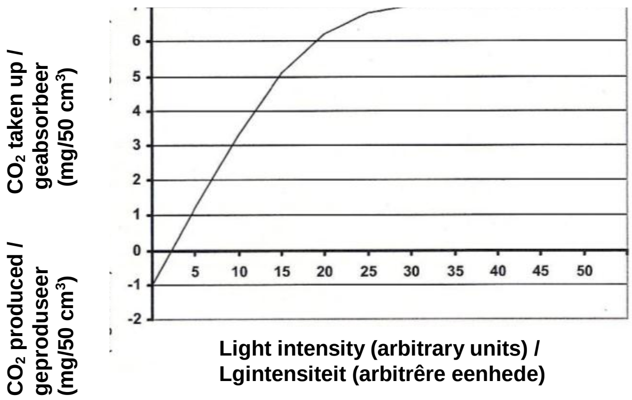
(Gebhardt *et al*., 2012:15)

A change in the concentration of carbon dioxide in the test tubes causes an orange indicator to change colour as follows: • normal amounts of CO_2 : indicator - orange	'n Verandering in die konsentrasie van koolstofdioksied in die proefbuise laat die indikator soos volg verkleur: • normale hoeveelheid CO_2 : indikator - oranje

• low amounts of CO_2 : indicator - purple • higher amounts of CO_2 : indicator - yellow	• klein hoeveelheid CO_2 : indikator - pers • groot hoeveelheid CO_2 : indikator - geel
8. Which ONE of the following indicates the most appropriate dependent variable for this experiment? A Concentration of carbon dioxide B Colour of the indicator C Bright sunlight D Complete darkness	8. Watter EEN van die volgende dui die mees geskikte afhanklike veranderlike vir die eksperiment aan? A Konsentrasie van koolstofdioksied B Kleur van indikator C Helder sonlig D Algehele donkerte
9. Suggest the colour of the indicator at the end of the experiment in test tubes A, B and C respectively. A Yellow; yellow; orange B Purple; yellow; orange C Purple; orange; yellow D Yellow; purple; orange	9. Stel voor wat die kleur van die indikator in proefbuise A, B en C onderskeidelik aan die einde van die eksperiment sal wees. A Geel; geel; oranje B Pers; geel; oranje C Pers; oranje; geel D Geel; pers; oranje
Apply the following to questions 10 and 11: Leaves and worms of equal biomass were then hung together in another test tube, D, containing fresh orange indicator. Suggest what the colour of the indicator in D might be	Pas die volgende op vrae 10 en 11 toe: Blare en wurms met gelyke biomassa word dan saam in ‘n ander proefbuis, D, geplaas wat vars oranje indikator bevat. Stel voor wat die kleur van die indikator in D moontlik sal wees
10. after three hours in bright sunlight. A Purple B Yellow C Orange D None of above	10. ná drie uur in helder sonlig. A Pers B Geel C Oranje D Nie een van bogenoemde nie
11. after six hours in complete darkness. A Purple B Yellow C Orange D None of above	11. ná ses uur in algehele donkerte. A Pers B Geel C Oranje D Nie een van bogenoemde

Study the following equation and answer questions 12 and 13 that follow:	Bestudeer die volgende vergelyking en beantwoord vrae 12 en 13 wat volg:
$\overbrace{C_6H_{12}O_6 + 6O_2}^{A} \longrightarrow \underbrace{6CO_2 + 6H_2O}_{B} + \text{energy}$	
12. What process is represented by this equation? A Photosynthesis: A – oxidation; B – reduction B Respiration: A – oxidation; B – reduction C Photosynthesis: A – reduction; B – oxidation B Respiration: A – reduction; B – oxidation 13. The process of reduction entails the A loss of electrons. B removal of hydrogen atoms. C gain of electrons. D reducing of oxygen. An investigation was conducted to determine the relationship between light intensity and the release and uptake of carbon dioxide by the leaves of a plant. The results are indicated in the graph below. Study the graph and answer questions 14 and 15.	12. Watter proses word deur die vergelyking voorgestel? A Fotosintese: A – oksidasie; B – reduksie B Respirasie: A – oksidasie; B – reduksie C Fotosintese: A – reduksie; B – oksidasie B Respirasie: A – reduksie; B – oksidasie 13. Die proses van reduksie behels die A verlies van elektrone. B verwydering van waterstofatome. C wins van elektrone. D vermindering van suurstof. ‘n Praktiese ondersoek is gedoen om die ver-wantskap tussen ligintensiteit en die produksie en absorpsie van koolstofdioksied in die blare van plante te bepaal. Die resultate word in die bygaande grafiek getoon. Bestudeer die grafiek en beantwoord vrae 14 en 15.

The relationship between light intensity and the release and uptake of CO_2 /
Die verwantskap tussen ligintensiteit en vrystelling en opname van CO_2



(Sterrenberg & Fouché, 2013:2.55)

14. Within what range of light intensities is carbon dioxide released?

    A -1 to 0 arbitrary units

    B 0 to 2.5 arbitrary units

    C 2.5 to 35 arbitrary units

    D more than 35 arbitrary units

15. At a light intensity of above 25 units, the amount of carbon dioxide taken up remains the same. Which of the following limiting factors provide an explanation for this observation?

    A CO_2 availability

    B H_2O availability

    C The rate at which glucose is transported away from the photosynthetic cells

    D All of above

14. Tussen watter reeks ligintensiteite word koolstofdioksied geproduseer?

    A -1 tot 0 arbitrêre eenhede

    B 0 tot 2.5 arbitrêre eenhede

    C 2.5 tot 35 arbitrêre eenhede

    D meer as 35 arbitrêre eenhede

15. By ‘n ligintensiteit van meer as 25 eenhede, bly die hoeveelheid koolstofdioksied wat geabsorbeer word, konstant. Watter van die volgende beperkende faktore verskaf ‘n verklaring vir die waarneming?

    A CO_2 beskikbaarheid

    B H_2O beskikbaarheid

    C Die tempo waarteen glukose weg vanaf die fotosintetiserende selle vervoer word.

    D Al die bogenoemde

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
VAAL TRIANGLE CAMPUS

POSTTEST 2 – ANSWER SHEET / ANTWOORDBLAD LIFE 111

1 A B C ~~D~~

Motivation / Motivering: **Tin foil prevent sunlight from entering and green part contain chlorophyll**

2 A B C ~~D~~

Motivation / Motivering: **Contain both correct cause and effect**

3 A B C ~~D~~

Motivation / Motivering: **Cause**

4 A B ~~C~~ D

Motivation / Motivering: **8 units of sugar (16 water, 16 CO_2, 40 light)**

5 A B ~~C~~ D

Motivation / Motivering: **16 units of light + 14 = 30 therefore 3 more**

6 ~~A~~ B C D

Motivation / Motivering: **50 – 40 = 10 units of light**

7 A B C ~~D~~

Motivation / Motivering: **With 20 more light units it will double the amount of sugars**

8. ~~A~~ B C D

Motivation / Motivering: **Effect**

9 A ~~B~~ C D

Motivation / Motivering: **Plant and worm respire more than plant only – C only serves as control**

10 ~~A~~ B C D

Motivation / Motivering: **Worm respirates and plant photosynthesize at max-**

11 A ~~B~~ C D

Motivation / Motivering: **Both organisms respire and high levels of CO_2**

12 A ~~B~~ C D

Motivation / Motivering: **Respiration since oxidation is the loss of electrons and reduction is the gain of electrons**

13 A B ~~C~~ D

Motivation / Motivering: **Reduction gain electrons and hydrogen atoms**

14 A ~~B~~ C D

Motivation / Motivering: **According the graph below x-axis**

15 A B C ~~D~~

Motivation / Motivering: **All the factors are limiting photosynthesis**

APPENDIX D

THINKING MAPS OF PARTICIPANTS

21

① $\frac{6}{7}$ ② $\frac{5}{7}$

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts	✓	✓	The Thinking Map displays evidence of minimal or no concepts		
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map	✓	✓	The thought processes utilized are incorrectly linked to the Thinking Map		
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)	✓	✓	The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)		
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea	✓		The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.		✓
Originality	The Thinking Map displays new and creative facts about the concept/idea	✓		The Thinking Map only reflects a basic and simplistic understanding of the concept/idea		✓
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	✓	✓	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	✓	✓	The technical structure of the Thinking Map is laid out incorrectly		

Gained more info on Glycolysis. Now know that it does not require Oxygen.

Mader, S & Windelspecht, M

21

Glycolysis

Takes place in the cytoplasm outside of the mitochondria.
Breaks down C_6 glucose → C_3, C_3 pyruvate molecules.

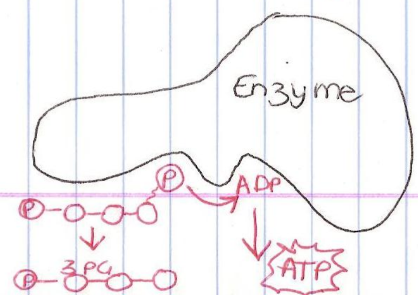
Glycolysis	
inputs	Outputs
6 C glucose	2 pyruvate
2 NAD^+	2 NADH
2 ATP	2 ADP
4ADP + 4Ⓟ	4 ATP Ⓣ
	2 ATP net gain.

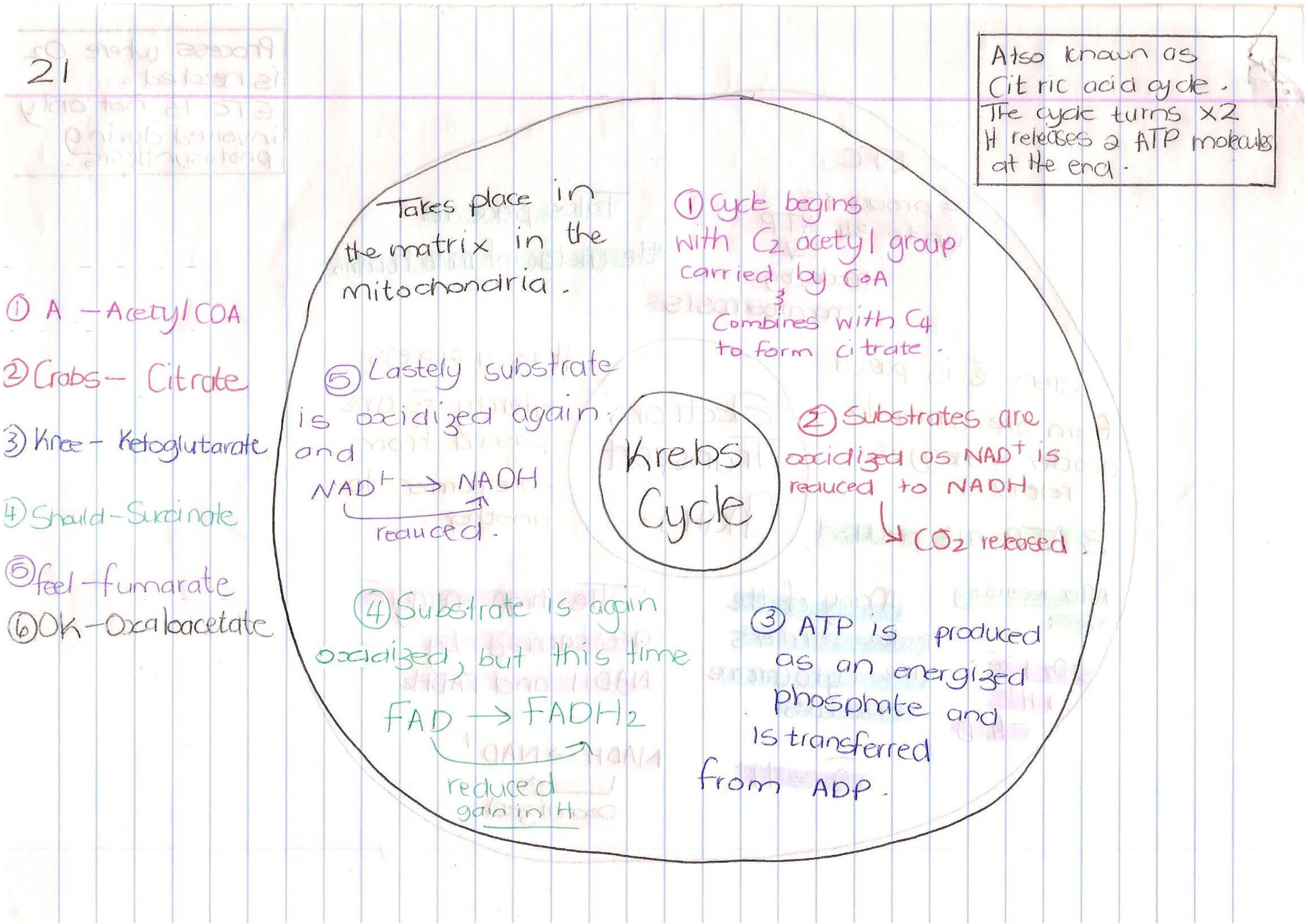
Energy – Investment step

- ATP is used to jump start glycolysis.
- 2 ATP are used to activate glucose by adding a Ⓟ.
- Glucose → C_3, C_3
- Each G3P has a Ⓟ group.
- Ⓟ group is acquired from ATP.

Energy – Harvesting step

- Oxidation of G3P occurs but removal of H^+.
- In duplicate reactions:
  $2NAD^+ + 4e^- + 2H^+ \rightarrow 2NADH$
- When O_2 is available, NADH molecule carriers 2 ↑ energy electrons to ETC $= NAD^+$
- Phosphate group is used to synthesize ATP later.
- Substrate – level ATP synthesis.




21
Also known as Citric acid cycle. The cycle turns x2 + releases 2 ATP molecules at the end.
Krebs Cycle
Takes place in the matrix in the mitochondria.
① Cycle begins with C_2 acetyl group carried by CoA
Combines with C_4 to form citrate.
② Substrates are oxidized as NAD^+ is reduced to NADH
CO_2 released.
③ ATP is produced as an energized phosphate and is transferred from ADP.
④ Substrate is again oxidized, but this time
FAD → $FADH_2$
reduced
gain in H
⑤ Lastely substrate is oxidized again and
NAD^+ → NADH
reduced.
① A – AcetylCOA
② Crabs – Citrate
③ Kree – Ketoglutarate
④ Shauld – Succinate
⑤ feel – fumarate
⑥ OK – Oxaloacetate

39

① 4/7 ② 3/7

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts	X		The Thinking Map displays evidence of minimal or no concepts		X
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map	X	X	The thought processes utilized are incorrectly linked to the Thinking Map		
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)			The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)	X	X
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea			The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	X	X
Originality	The Thinking Map displays new and creative facts about the concept/idea			The Thinking Map only reflects a basic and simplistic understanding of the concept/idea	X	X
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	X	X	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	X	X	The technical structure of the Thinking Map is laid out incorrectly		

39

Phases of Cellular Respiration

Transition phase

- Occurs twice per glucose molecule.
- Takes place in matrix of mitochondria
- Converts two molecules of 3 carbon Pyruvate from glycolysis
- Oxidation occurs to move electrons by NAD^+
- NADH is formed because of oxidation from Pyruvate
- 2 NADH carry electrons to the electrons transport chain

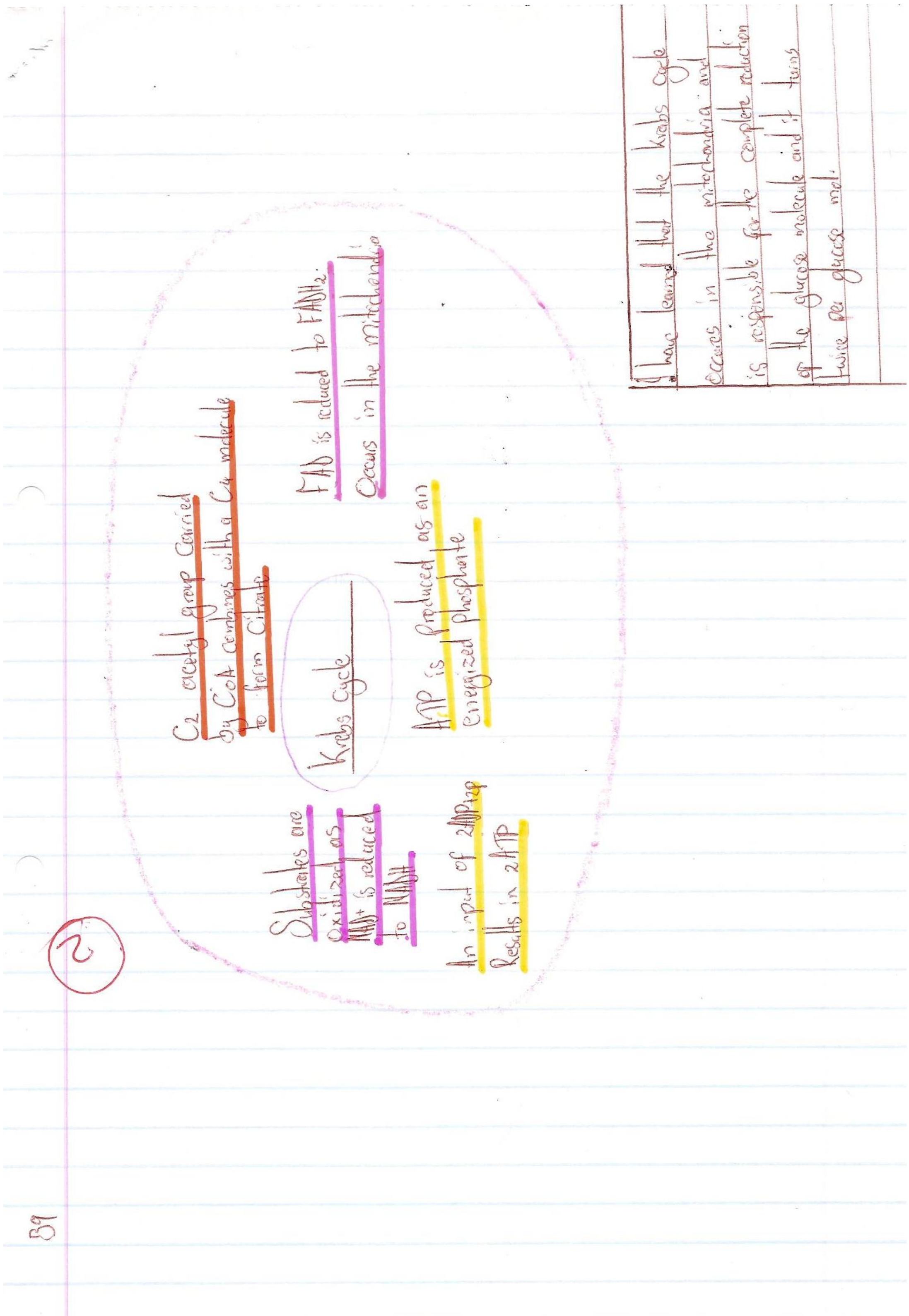
Glycolysis

- Breaking down of glucose
- Takes place outside the mitochondria
- Does not require Oxygen (Anaerobic)
- Oxidation occurs to result NADH
- ATP is used to jump start glycolysis

Electron transfer System

- Located in cristae of mitochondria
- NADH and $FADH_2$ take electrons to ETC
- FADH delivers electrons after NADH
- Electrons move via Redox reaction

Glycolysis take place outside the mitochondria and does not require O_2. Other phases of cellular respiration take place inside the mitochondria. During these phases CO_2 and H_2O the end products of cellular respiration and ATP the main outcome of respiration are produced.

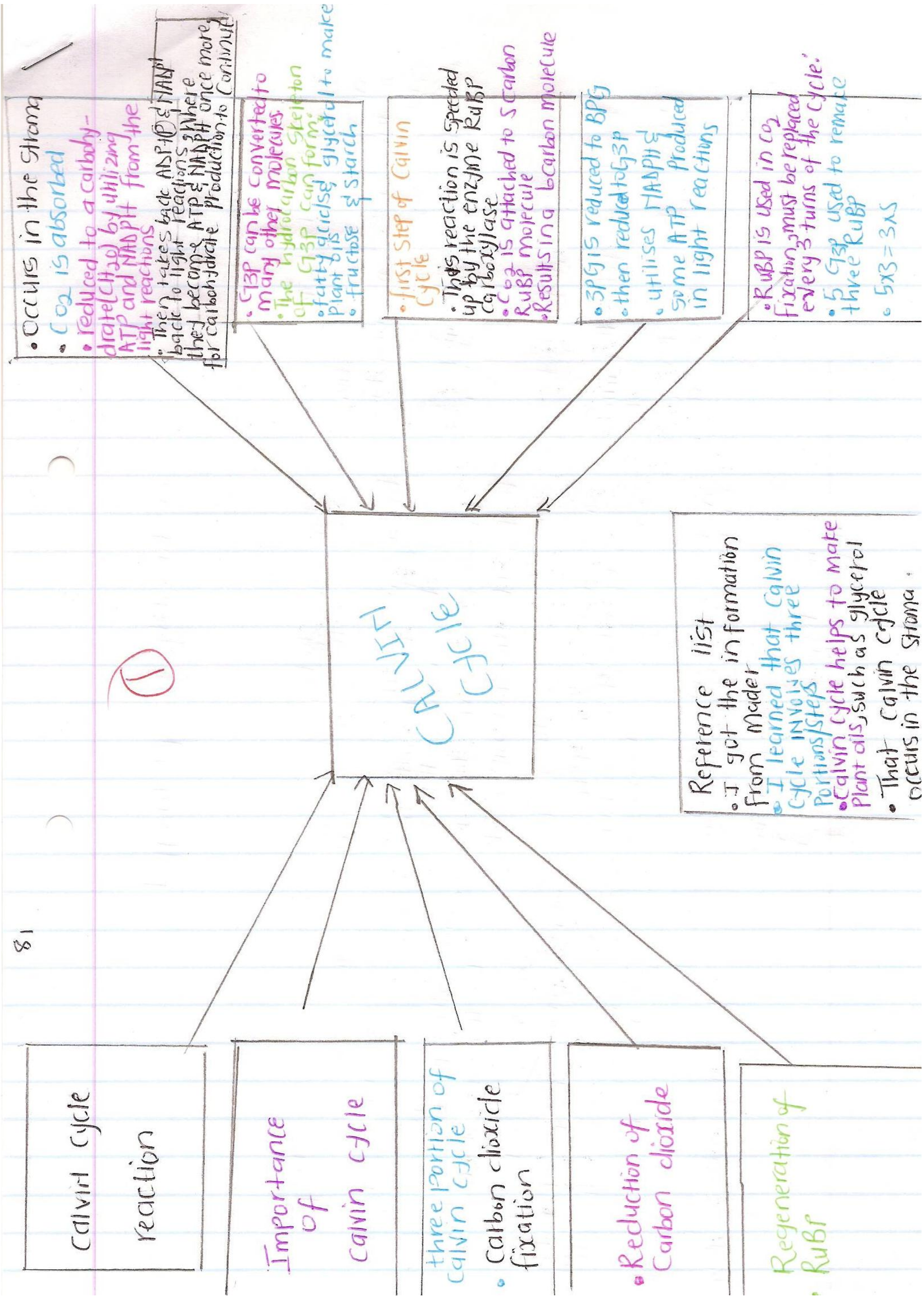

39
2
Krebs Cycle
C2 acetyl group Carried by CoA combines with a C4 molecule to form Citrate
Substrates are Oxidized as NAD+ is reduced to NADH
FAD is reduced to FADH2. Occurs in the mitochondria
An input of 2ADP+2P Results in 2ATP
ATP is Produced as an energized Phosphate
I have learned that the krebs cycle occures in the mitochondria and is responsible for the complete reduction of the glucose molecule and it turns twice per glucose mol.

81

① $\frac{6}{7}$ ② $\frac{7}{7}$

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts	X	X	The Thinking Map displays evidence of minimal or no concepts		
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map	X	X	The thought processes utilized are incorrectly linked to the Thinking Map		
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)	X	X	The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)		
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea		X	The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	X	
Originality	The Thinking Map displays new and creative facts about the concept/idea	X	X	The Thinking Map only reflects a basic and simplistic understanding of the concept/idea		
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	X	X	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	X	X	The technical structure of the Thinking Map is laid out incorrectly		


81
Calvin cycle reaction
Importance of calvin cycle
three portion of calvin cycle
• carbon dioxide fixation
• Reduction of Carbon dioxide
Regeneration of RuBP
CALVIN CYCLE
• Occurs in the Stroma
• CO_2 is absorbed
• reduced to a carbohydrate(CH_2O) by utilizing ATP and NADPH from the light reactions
• Then takes back ADP+(P) & NADP+ back to light reactions, where they become ATP & NADPH once more, for carbohydrate production to continue
• G3P can be converted to many other molecules
• The hydrocarbon skeleton of G3P can form:
• fatty acids & glycerol to make plant oils
• fructose & starch
• first step of Calvin cycle
• This reaction is speeded up by the enzyme RuBP carboxylase
• CO_2 is attached to 5 carbon RuBP molecule
• Results in a 6 carbon molecule
• 3PG is reduced to BPG
• then reduced to G3P
• utilises NADPH & some ATP produced in light reactions
• RuBP is used in CO_2 fixation, must be replaced every 3 turns of the cycle.
• 5 G3P used to remake three RuBP
• 5x3 = 3x5
Reference list
• I got the information from Mader
• I learned that Calvin cycle involves three portions/steps
• Calvin cycle helps to make plant oils, such as glycerol
• That Calvin cycle occurs in the Stroma.

81

Different types of photosynthesis

C_3 plant

the mesophyll cells contain well-formed chloroplast, and are arranged in parallel layers. In C_3 plants,

CO_2 is taken up by the Calvin cycle directly in mesophyll cells.

C_3 Plants tend to have an advantage when the weather is moderate.

C_3 plants such as Kentucky blue-grass Predominate in the cooler parts of the United States (early summer)

In hot, dry climates, Stomata must close. to avoid wilting, CO_2 decreases, O_2 increases

O_2 combine with RuBP instead of CO_2, problem = Photorespiration

C_3 plats use the enzyme RuBP carboxylase to fix CO_2 to RuBP in mesophyll cells.

C_4 plant

the bundle sheath cells and the mesophyll cells contain chloroplast.

the mesophyll cells are arranged concentrically around the bundle sheath cells.

C_4 plants fix CO_2 to PEP, using the enzyme PEP carboxylase (PEPcase).

The result is oxalocetate, a C_4 molecule.

C_4 Photosynthesis enables some plants to avoid photorespiration.

Photorespiration does not occur in C_4 leaves because PEPcase does not combine with O_2.

C_4 plants form a C_4 molecule in mesophyll cells Prior to releasing CO_2 to the Calvin cycle in bundle sheath cells. by midsummer, crabgrass, a C_4 Plant begins to predominate.

C_4 plants are adapted to areas of high temperatures & limited rainfall

CAM photosynthesis

CAM stands for crassulacean-acid metabolism: the crassulaceae is a family of flowering sacculent (water containing) plants, such as jade plants, that live in warm, dry regions of the world.

CAM is Partitioning by the use of time.

The advantage of partitioning is to conserve water

Fix CO_2 during night, CO_2 is released during the day, increasing efficiency of photosynthesis.

During the day the Stomata closes,

This helps to conserve water, but CO_2 cannot enter the plant

Frame of reference

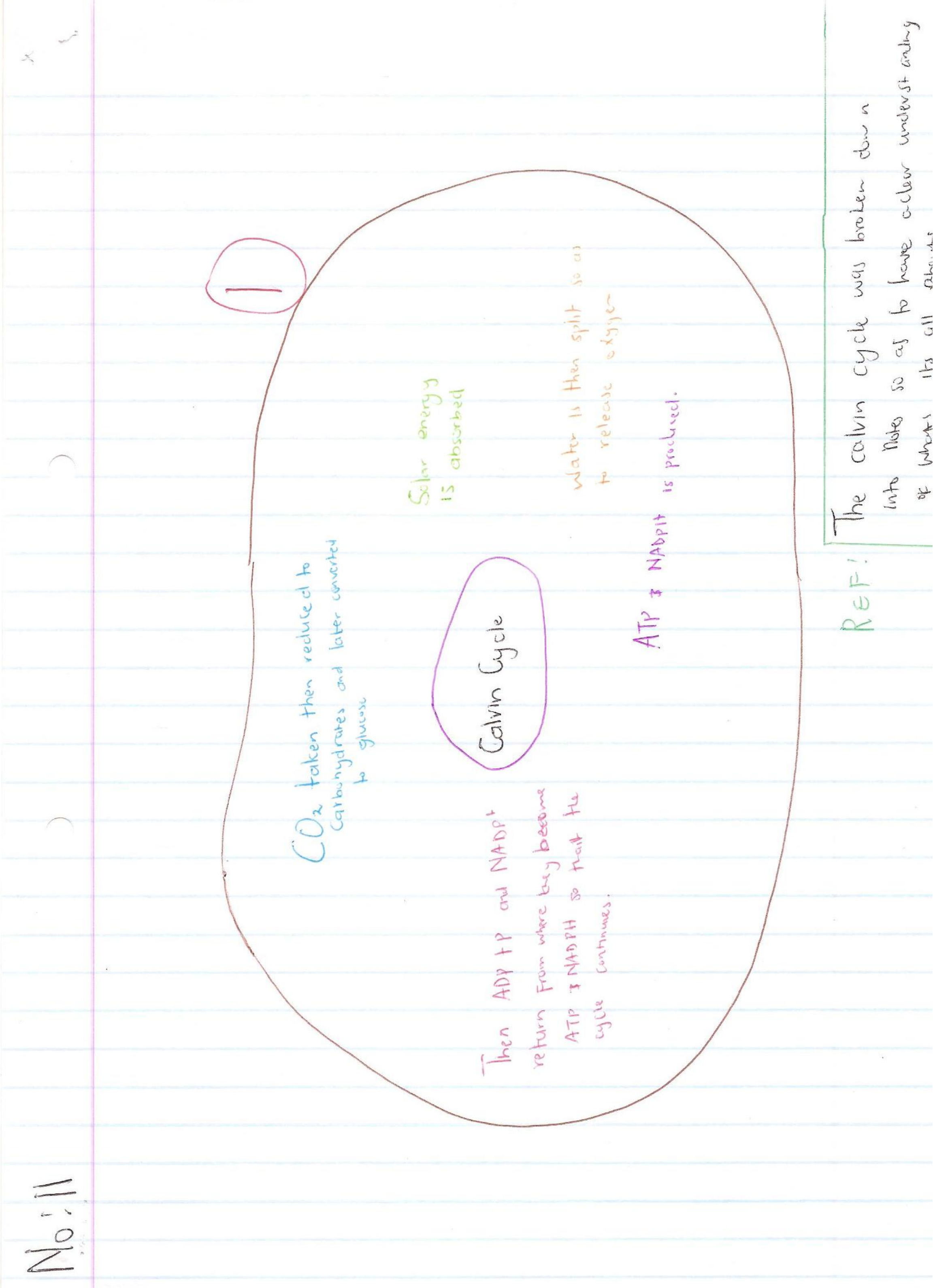
- I've learned that there are 3 types of photosynthesis,
- Each has its own roles
- That C_4 plants can avoid Photorespiration
- I got the information from Mader.

11

1 3/7 2 4/7

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts		X	The Thinking Map displays evidence of minimal or no concepts	X	
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map		X	The thought processes utilized are incorrectly linked to the Thinking Map	X	
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)			The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)	X	X
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea			The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	X	X
Originality	The Thinking Map displays new and creative facts about the concept/idea			The Thinking Map only reflects a basic and simplistic understanding of the concept/idea	X	X
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	X	X	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	X	X	The technical structure of the Thinking Map is laid out incorrectly		


No: 11
1
CO_2 taken then reduced to Carbohydrates and later converted to glucose
Solar energy is absorbed
Then ADP + P and NADP+ return from where they become ATP & NADPH so that the cycle continues.
Calvin Cycle
water is then split so as to release oxygen
ATP & NADPH is produced.
REF!
The calvin cycle was broken down into notes so as to have a clear understanding of what's its all about

2

Types Of Photosynthesis

C_3 Photosynthesis

CO_2 is taken up by calvin cycle directly in the mesophyll cells

Consist of leaves with openenings called the stomata and the mesophyll contains a well-formed chloroplast

CO_2 decreases in leaves and O_2 rise RuBP combine with RuBP Carboxylase This is called photorespiration.

REFERENCE

I learnt about the different types of Photosynthesis of which I knew nothing about.

C_4 Photosynthesis

C_4 plants form C_4 molecule in mesophyll cells prior to release CO_2 to the calvin cycle

Consist of a leaf with bundle sheath cells and mesophyll cells contain chloroplast.

Photorespiration does not occur, PEPcase does not combine with O_2.

CAM Photosynthesis

CAM plants use PEPCase to fix some CO_2

CAM plants only open their stomata at night.

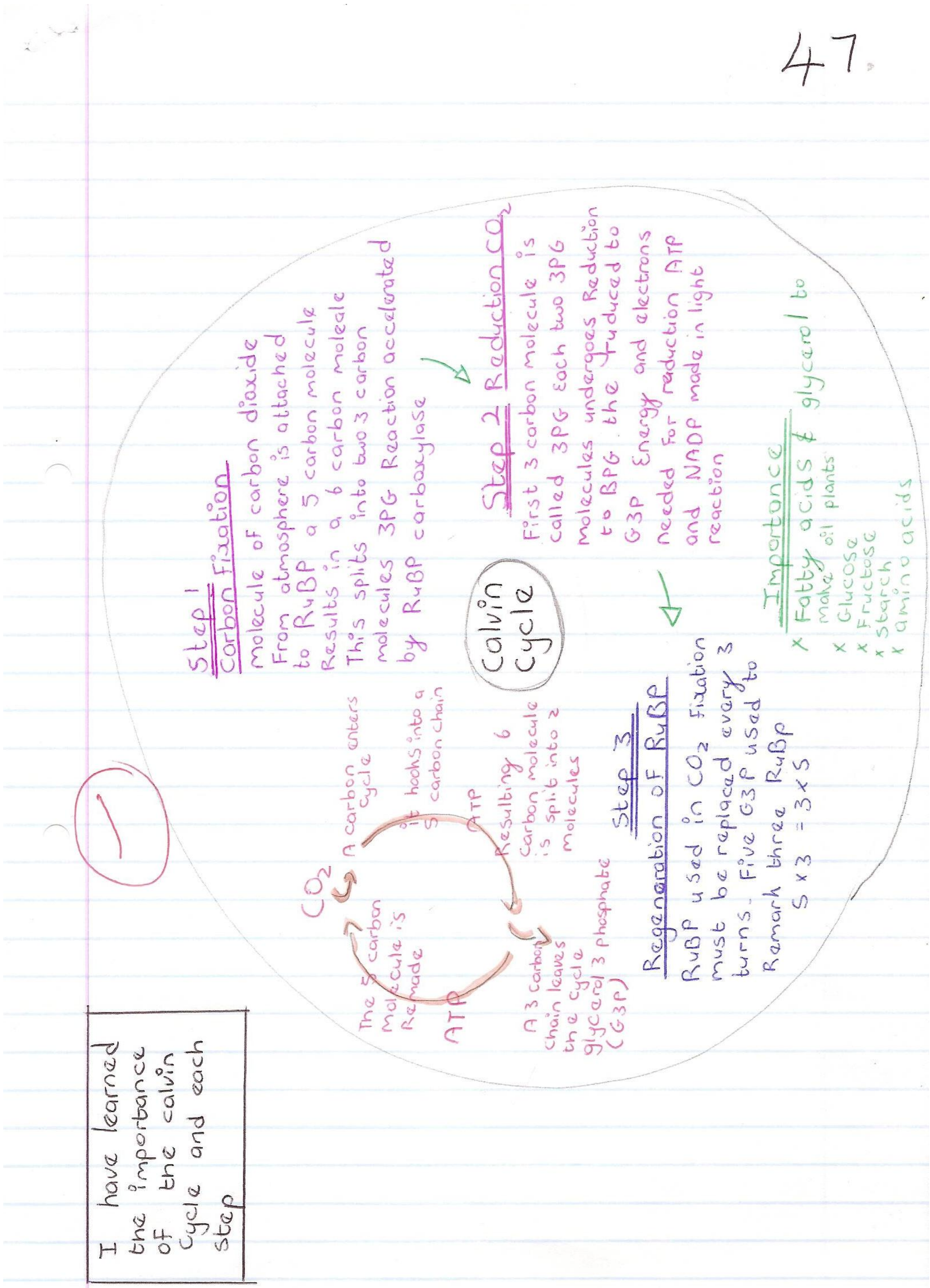
Water is conserved but CO_2 cannot enter the plant ∴ Photosynthesis in CAM plants is minimal because a limited amount of CO_2 is fixed at night.

47

① 5/7 ② 6/7

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts	X	X	The Thinking Map displays evidence of minimal or no concepts		
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map		X	The thought processes utilized are incorrectly linked to the Thinking Map	X	
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)	X	X	The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)		
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea			The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	X	X
Originality	The Thinking Map displays new and creative facts about the concept/idea	X	X	The Thinking Map only reflects a basic and simplistic understanding of the concept/idea		
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	X	X	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	X	X	The technical structure of the Thinking Map is laid out incorrectly		


47.
I have learned the importance of the calvin Cycle and each step
Step 1
Carbon Fixation
Molecule of carbon dioxide From atmosphere is attached to RuBP a 5 carbon molecule Results in a 6 carbon moleale This splits into two 3 carbon molecules 3PG Reaction accelerated by RuBP carboxylase
Step 2 Reduction CO2
First 3 carbon molecule is called 3PG Each two 3PG Molecules undergoes Reduction to BPG. the Tuduced to G3P Energy and electrons needed for reduction ATP and NADP made in light reaction
Step 3
Regeneration of RuBP
RuBP used in CO2 Fixation must be replaced every 3 turns. Five G3P used to Remark three RuBp
5 x 3 = 3 x 5
Calvin Cycle
CO2
A carbon enters cycle
it hooks into a 5 carbon chain
ATP
Resulting 6 carbon molecule is split into 2 molecules
A 3 carbon chain leaves the cycle glycerol 3 phosphate (G3P)
ATP
The 5 carbon Molecule is Remade
Importance
x Fatty acids & glycerol to make oil plants
x Glucose
x Fructose
x starch
x amino acids

That There are different photosynthesis For different climates

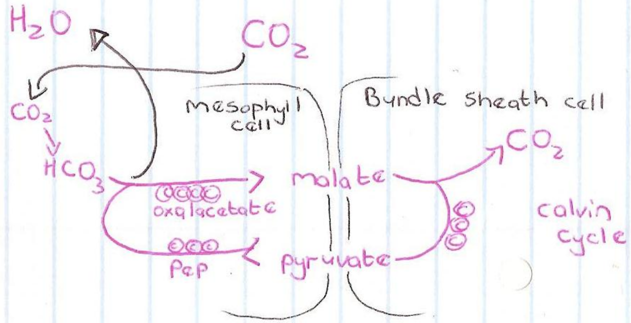
Photosynthesis

2

47

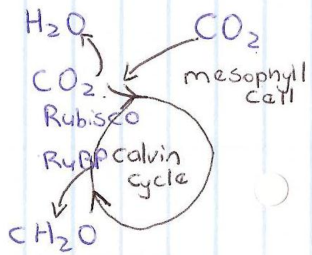
C_4 Photosynthesis

- X Hot, dry climates
- X CO_2 decreases & O_2 increases
- X O_2 starts combining with RuBP instead of with CO_2
- X Problem = photorespiration CO_2 released in presence of light instead of used



C_3 Photsynthesis

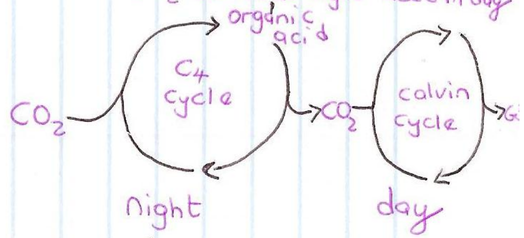
- X Fix CO_2 to Pep a C_3 molecule
- X Forms oxalocetate a C_4 molecule
- X hot dry climates
- X avoid photorespiration
- X net productivity about 2-3 x C_3 plats
- X in cool moist can't compete with C_3



cam photosynthesis

- X Fix CO_2 during night
- X storing it as 4 carbon acid malate
- X CO_2 is released during day
- X concentrated around enzyme RuBisco
- X Increasing efficiency of Photosynthesis

CO_2 stored at night used in day

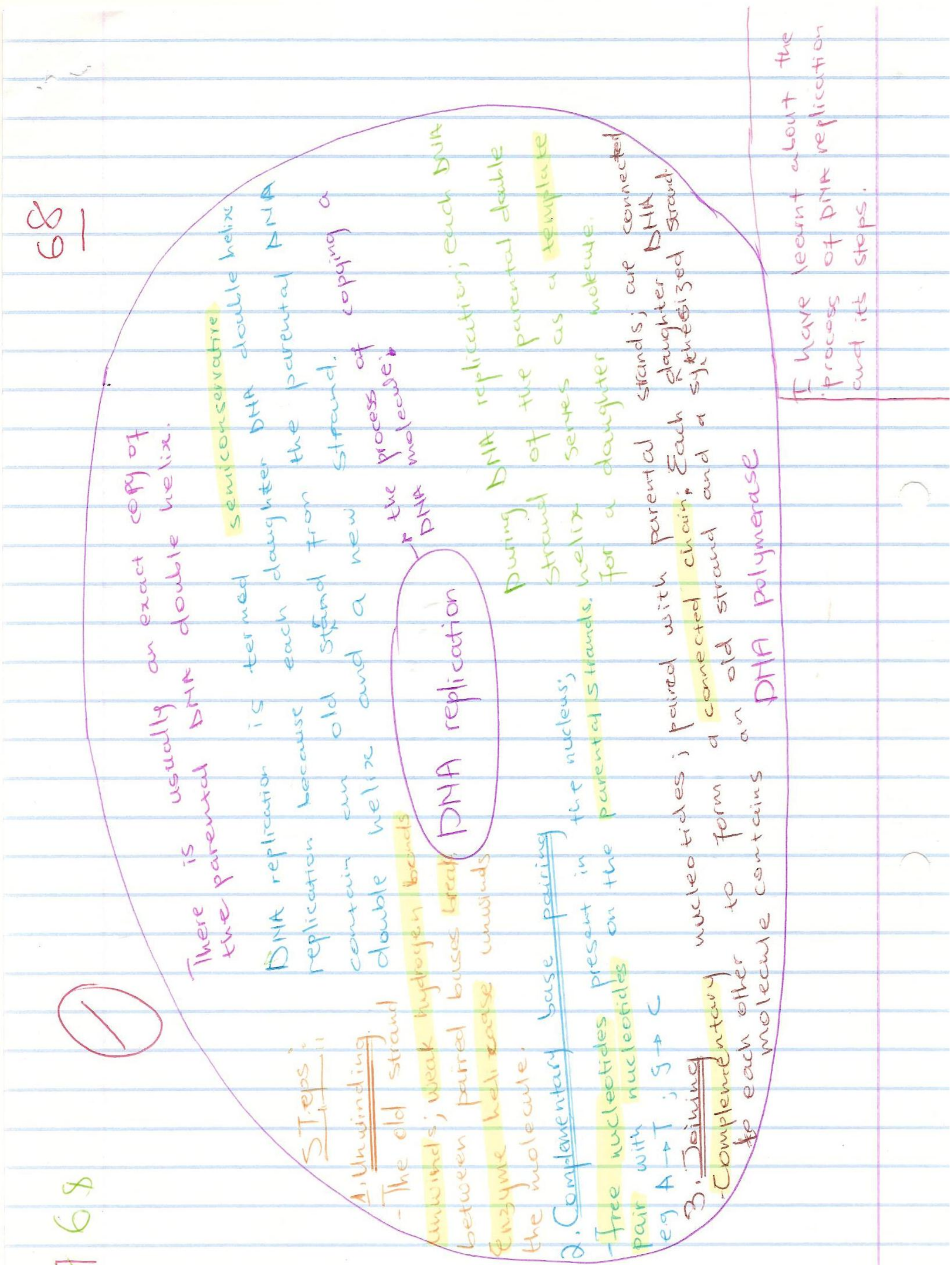


68

1 6/7 2 5/7

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts	X	X	The Thinking Map displays evidence of minimal or no concepts		
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map	X	X	The thought processes utilized are incorrectly linked to the Thinking Map		
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)	X	X	The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)		
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea			The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	X	X
Originality	The Thinking Map displays new and creative facts about the concept/idea	X		The Thinking Map only reflects a basic and simplistic understanding of the concept/idea		X
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	X	X	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	X	X	The technical structure of the Thinking Map is laid out incorrectly		

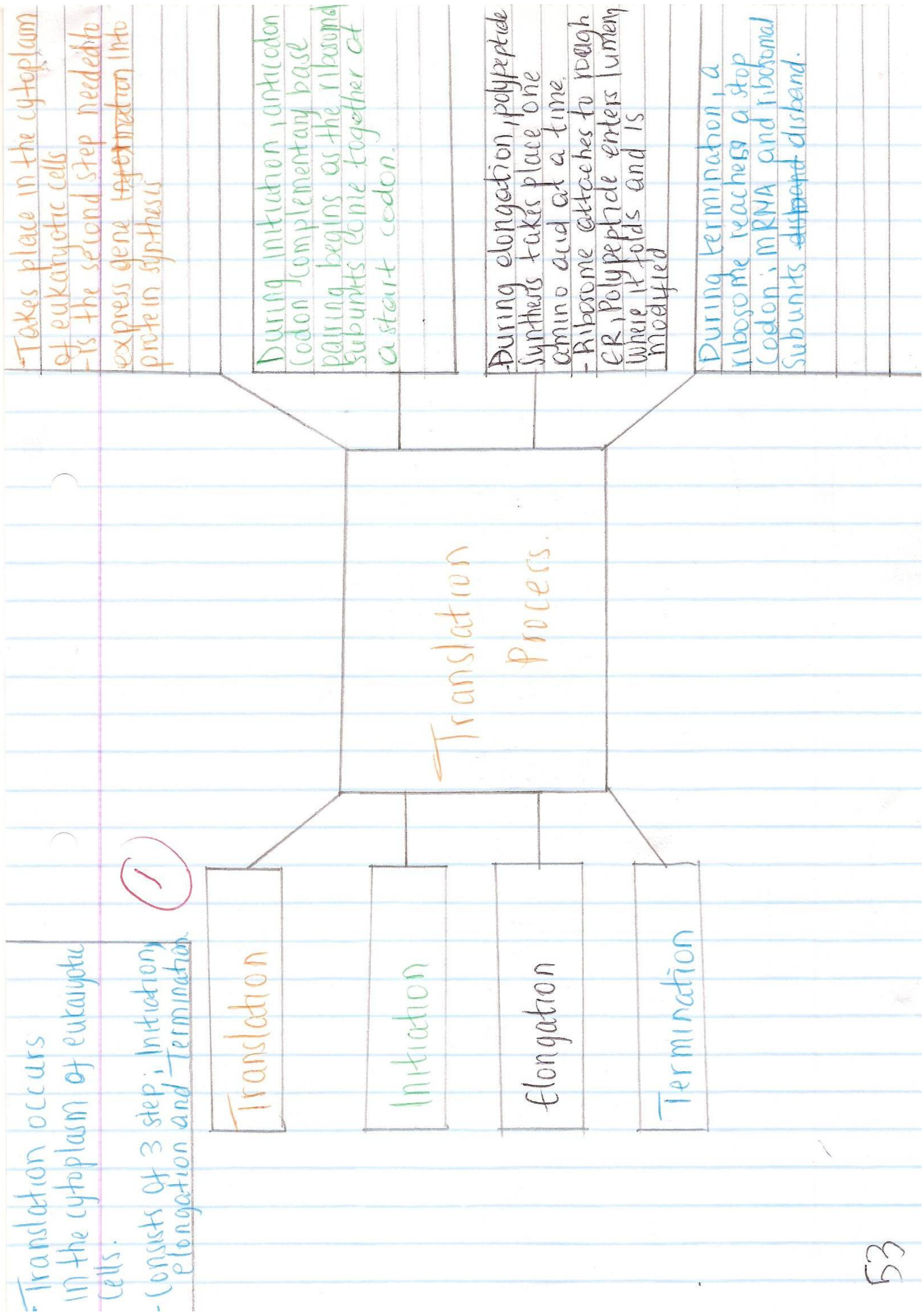

168
68
There is usually an exact copy of the parental DNA double helix.
DNA replication is termed semiconservative replication because each daughter DNA double helix contain an old strand from the parental DNA double helix and a new strand.
DNA replication
the process of copying a DNA molecule;
STeps:
1. Unwinding
- The old strand unwinds; weak hydrogen bonds between paired bases break Enzyme helicase unwinds the molecule.
2. Complementary base pairing
- Free nucleotides present in the nucleus; pair with nucleotides on the parental strands.
e.g A → T ; G → C
During DNA replication; each DNA strand of the parental double helix serves as a template for a daughter molecule.
3. Joining
- Complementary nucleotides ; paired with parental strands; are connected to each other to form a connected chain; Each daughter DNA molecule contains an old strand and a synthesized strand.
DNA Polymerase
I have learnt about the process of DNA replication and its steps.

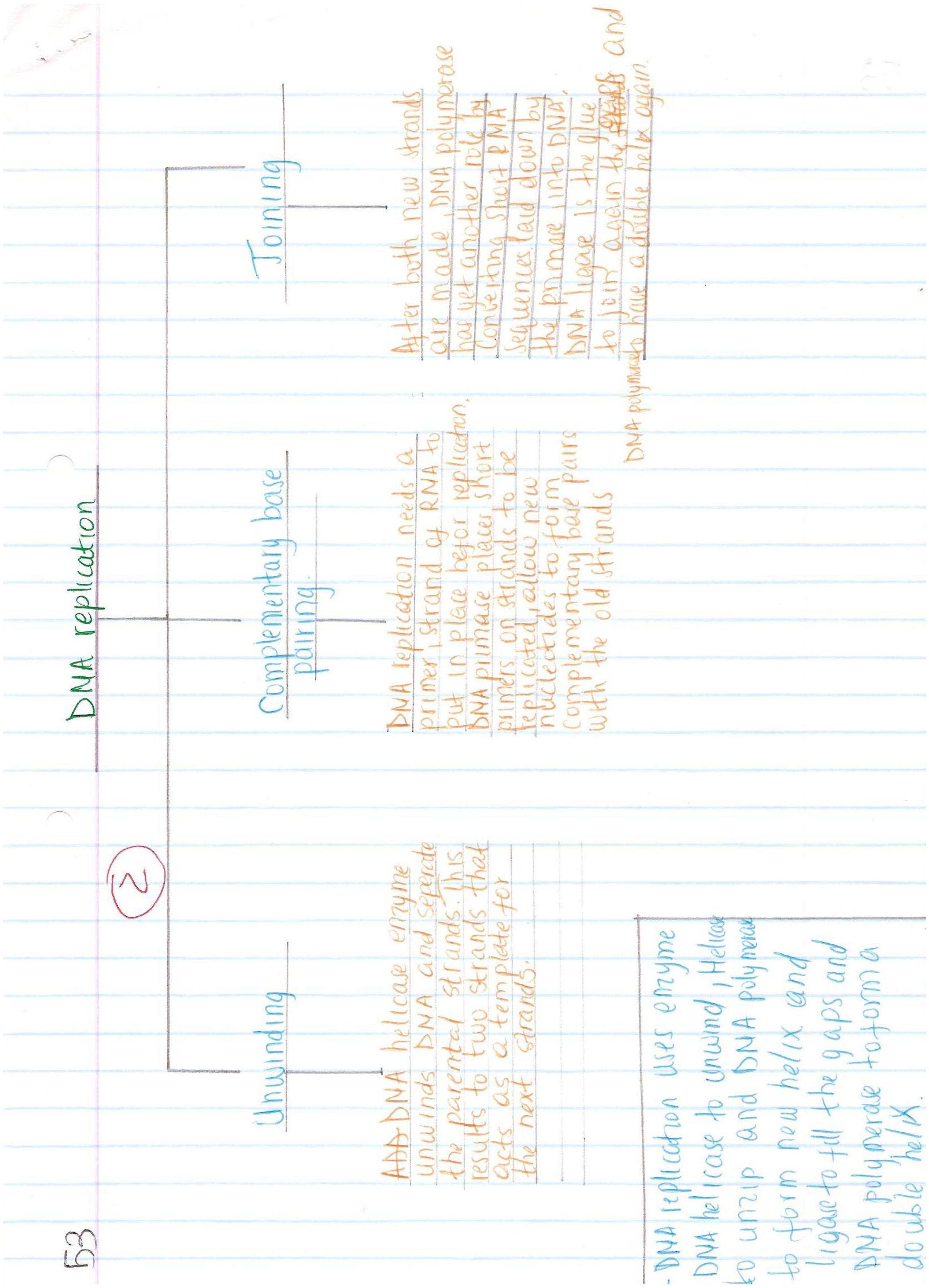
S3

① 5/7 ② 4/7

Table 1: Thinking Maps Checklist

Criteria	Complete	1	2	Incomplete	1	2
Sufficiency / fluency of ideas	The Thinking Map displays evidence of multiple concepts	X	X	The Thinking Map displays evidence of minimal or no concepts		
Thought process (Verb or keyword linked to Thinking Map)	The thought processes utilised are correctly linked to the Thinking Map	X	X	The thought processes utilized are incorrectly linked to the Thinking Map		
Collaborative Development	The Thinking Map displays evidence of collaborative consultation (Different colours used to add concepts and ideas)	X		The Thinking Map displays evidence of minimal or no collaborative consultation (No evidence of different colours used to add concepts and ideas)	~~X~~	X
Flexibility	The concepts / ideas presented in the Thinking Map vary significantly from one another and reflect deeper thought about the concept/idea			The concepts / ideas presented in the Thinking Map are all very similar and do not differ. No deeper thought about the concept/idea is reflected.	X	X
Originality	The Thinking Map displays new and creative facts about the concept/idea			The Thinking Map only reflects a basic and simplistic understanding of the concept/idea	X	X
Elaboration	The Thinking Map displays fine and rich detail about the concept/idea.	X	X	The Thinking Map displays no finer and rich detail about the concept /idea.		
Layout	The technical structure of the Thinking Map is laid out correctly	X	X	The technical structure of the Thinking Map is laid out incorrectly		


- Translation occurs in the cytoplasm of eukaryotic cells.
- Consists of 3 step; Initiation, elongation and Termination
1
Translation
Initiation
Elongation
Termination
Translation Process.
- Takes place in the cytoplasm of eukaryotic cells
- Is the second step needed to express gene ~~information~~ into protein synthesis
During initiation, anticodon codon complementary base pairing begins as the ribosomal subunits come together at a start codon.
- During elongation, polypeptide synthesis takes place one amino acid at a time.
- Ribosome attaches to rough ER, Polypeptide enters lumen, where it folds and is modified
During termination, a ribosome reaches a stop codon; mRNA and ribosomal subunits ~~disband~~ disband.
53


53
DNA replication
2
Unwinding
Complementary base pairing.
Joining
~~ADD~~ DNA helicase enzyme unwinds DNA and seperate the parental strands. This results to two strands that acts as a template for the next strands.
DNA replication needs a primer, strand of RNA to put in place befor replication, DNA primase places short primers on strands to be replicated, allow new nucleotides to form complementary base pairs with the old strands
After both new strands are made, DNA polymerase has yet another role by converting short RNA sequences laid down by the primase into DNA. DNA ligase is the glue to join again the ~~strands~~ gaps and DNA polymerase to have a double helix again.
- DNA replication uses enzyme DNA helicase to unwind, Helicase to unzip and DNA polymerase to form new helix and ligase to fill the gaps and DNA polymerase to form a double helix.

APPENDIX E

OPEN RESPONSES TO QUESTIONS

EXPERIMENTAL GROUP 1

Pre-test 1 and Post-test 1B – Examples of motivations

Question number and ideal answer	Examples of good motivations	Examples of poor motivations
1. Steps are given in diagram.	*“When a person is conducting a scientific investigation, he should undergo the same steps as shown”; “for every experiment carried out, there are certain steps to follow”; “it includes steps to follow”.*	*“Not all the investigations include water”; “… because the lettuce plant grow bigger”; “it has all the components of a good experiment”.* Many students did not provide any motivation for their answer.
2. Observation – what you see.	*“An observation is what you see”; “.. this is because during investigation you can see…”; “is to see whether or not …”.*	*“The aim of the question was ..”; “one tray received more water”; “…due to the requirements of photosynthesis..”.*
3. Cause	*“The independent variable is responsible for the results”; “it cannot be manipulated”; “the water is the variable that changes the growth”.*	*“Bigger plants are more likely to stay big”; “sunlight will not effect the growth”; “the plant cannot undergo photosynthesis”.*
4. Statement with cause and effect.	*“…a scientific prediction which involves both the dependent and independent variables”; “it is a statement”; “… a prediction that should be proved”.*	*“Because plant will grow bigger”; “because scientists wants to test the theory of water”; “the question of the experiment was about…”*
5. Effect	*“ The dependent variable are controlled by the independent variable”; “… the plant depend on the amount of water”; “… the plant depend on the water”.*	*“The experiment proves lettuce grow bigger”; “… more water must be added”.* No motivation provided.
6. According the scientific method	*“When a scientific investigation is conducted …”; “… when you design an experiment, you must follow the correct steps”; “…first you need to know the reason why the experiment is conducted”.*	*“It is the correct setup to design an …”; “… one has to know which way they need to go’; “… the aim comes first”.*
7. Statement with cause and effect.	*“A hypothesis is a scientific prediction”; “… predict from the investigative question…”; “… predict the outcome”.*	*“Investigation is about a boiling cup of water and sugar”; “ ... sugar dissolves faster”; “… particles of sugar dissolve more in water”.*

Question number and ideal answer	Examples of good motivations	Examples of poor motivations
8. Cause	*"In order for more sugar to dissolve the water must be heated"; "… sugar depends on cup of heated water"; " ...for sugar to dissolve depend on heat".*	*"Sugar is the one that's going to be tested"; "… it does not depend on water or sugar"; "… it does not depend on anything".*
9. Effect	*"Heat determines how much sugar dissolves"; "… the person conducting the experiment has control over the amount of heat"; "… heat is influencing the sugar..."*	*"Heat will be increased"; "… a cup of water that contains sugar"; "… it does not depend on anything".*
10. Must be the same in cause and effect.	*"It is not effected during the experiment"; "… cup of water does not change"; "… cup of water must be constant".*	*"Because this experiment is about the water carrying ability"; "… so the result could be more appropriate"; "… the results of the experiment".*
11. According to the introduction	*"…the experiment was done in order to check the water-carrying capacity"; "… from the introduction…"; "… the scientist is investigating the water-carrying capacity".*	*"The soil type were placed in funnels"; "… the soil types differ"; "… dependent and independent variables are there".*
12. Cause	*"Different types of soil were used"; "… the volume of filtrate depends on the soil type"; "… soil sample is independent".*	*"The time determines the volume.."; "… because it changes the whole experiment"; "… time only will tell us the best…".*
13. Effect	*"The volume depends on the soil type"; "… it depends on the soil sample"; "… volume is affected by the type of soil".*	*"The person investigating can control filter papers"; "… it is water-carrying capacity that depends on other factors"; "… it depends on the time".*
14. According to the introduction	*"They are not effected during the experiment"; "… they don't change"; "… they need to remain the same during the experiment".*	*"This is made fair for every soil type..."; "… for the results to be more accurate"; "… all these three variables need to be equalised…".*
15. Linked to question	*"…the conclusion in response to the question"; "… clay has the best carrying capacity"; "… sand has a low carrying capacity".*	*"The spaces between the clay particles are small"; "… volume of filtrate in clay did not increase"; "… it takes longer time for water to infiltrate".*

Post-test 1 – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Contains no fats	*"Don't contain fats"; "… it consists of only carbohydrates"; " …does not have fat".*	*"It has a lot of fats"; "… has less fats"; "… it has more fats".*
2. Contains most proteins	*"Has much protein in food"; " ... the more proteins, the faster growth"; "… more amount of protein…".*	*"Because it has lots of fats"; "… because there are more carbohydrates and fewer proteins"; " ... it does not contain fats".*
3. Contains most fats	*"Contains a lot of fat"; "… consist mainly of fats".*	*"Because it contains all three types of energy sources"; "…contains a lot of carbohydrates"; "… because it has all the food types".*
4. Half of nutrients are fat	*"It occupies 50% of chart"; "… it took half of the pie chart"; "… fats is 50%…".*	*"… more amounts of carbohydrates"; "… fats is a quarter of the food types"; " … one that has a medium percentage…".*
5. Body temperature / optimum temperature for catalase	*"At 37ºC that's where enzyme catalase started the reaction"; "… normal function is at 37ºC"; "… body temperature is 37ºC".*	*"Because we have different variable temperatures"; "... will vary due to different temperatures"; "… hypothesis is only a prediction".*
6. Body temperature / optimum temperature for catalase	*"Enzyme function best at optimal temperature which is 37ºC"; "… enzymes usually most effective at body temperature"; "… that is the suitable temperature for catalase".*	*"Because enzyme function best at optimal temperature"; "… the temperature is high"; "… because water is boiling".*
7. Effect	*"It depends on the temperature of the water bath"; "… because temperature determines the effect"; "… the temperature of the water bath causes the effect".*	*"… the bubbles formed and is dependent on water"; "… condition of the liver depends on the water"; "… the catalase will have an effect on the liver".*
8. Cause	*"The temperature of the water bath"; "… the temperature is the cause"; "… because temperature is the one that cause…".*	*"The condition of the chicken liver"; "… the amount of hydrogen provided…"; "… it is what must be observed".*
9. Dependent	*"The variable that has to stay the same"; "… it varies according to the temperature"; "… it is a dependent variable".*	*"Because the amount of liquid oxygen…"; "… the amount of liquid displaced was not a variable"; "… liquid in different beakers".*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
10. Meiosis I	*"… correct sequence of meiosis I"; "… phases of meiosis I"; "… meiosis is a reduction division process".*	*"The sequence starts with interphase and ends with telophase"; "… because in cell division always in the nucleus…"; "… mitosis stages are …".*
11. Reduction of chromosome number	*"Meiosis is a reduction division"; "… after meiosis only half the number in daughter cells"; "… it is a reduction process".*	*"Mitosis half's the number"; "… meiosis is the doubling of chromosomes"; "… 1 parent give rise to 2 daughter cells".*
12. Reduction of chromosome number	*"homologous chromosomes align at equator"; " … the results of crossing over"; "… chromosomes are still in pairs".*	*"… there are chromatids not chromosomes"; "… they are not aligned at metaphase I"; "… chromosomes have already crossed…".*
13. No reduction of chromosome number	*"The chromosomes have been halved in meiosis I"; "… crossing over had already occurred in prophase I"; "… chromatid moving from centre".*	*"…so that the daughter cell has both maternal and paternal material"; "… sister chromosomes align at equator"; "… chromosomes align in pairs".*
14. Hypotonic high water potential	*"End osmosis take place"; "… water will move from high to low concentrations"; "… the water enters the cell to lower concentration".*	*"Water moves away from the cell…"; "… the solution is hydrophobic"; "… hypo means water is available".*
15. Hypertonic low water potential	*"The water drains from the solute"; "… the water exits the vacuole"; "… hypertonic is the higher solute and less water concentration".*	*"Water enters the cell"; "… the vacuole moves towards the cell membrane"; "… because water exits".*

Pre-test 2 and post-test 2B – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Body temperature / bio-enzyme	*"At 37ºC the enzyme functioned…"; "… at 37ºC the enzyme functions at its peak"; "…the stain is gone at 37ºC".*	*"The enzymes did not remove the stains at the same temperature"; "… the temperature is too high and enzyme denature"; "… a statement that shows both variables".*
2. Effect	*"Results are depending on the temperature"; "… the results depend on the temperature"; "… results after washing depends on the temperature in order for the enzymes to function".*	*"The size of the blood stain"; "… different temperature cause different results"; "… temperature depend on the time".*
3. Body temperature and enzyme denatured at high temperature	*"Enzymes function optimally at 37ºC and denature at 3"; "… tablecloth 2 was washed at 37ºC and tablecloth 3 higher which denature the enzyme"; "… the enzyme functions optimally at 37ºC and lost its function at 65ºC".*	*"Tablecloth 2 is very clean"; "… the higher the temperature the better function the enzymes"; "… enzymes need heat to function well".*
4. 33% = 0.33 van 18 = 6	*"33/100 X 18 = 6"; "5.94; 33/100 x 18".* The only correct answer.	*"It is six portions of the total consumed"; "… they are the highest that were consumed"; "… because we have to consume 3 meals /day".*
5. 12% en 8% = 0.12 en 0.08 van 18 = 2 en 1	*"12/100 x 18 = 2.16 and 8/100 x 18 = 1.44"; " 12% is 2 and 8% is 1"; "12% of 18 is 2 and 8% of 18 is 1".* The only correct answer.	*"Percentages will be reduced to decimals"; "… when you subtract 3 from 6, 3 is left for milk"; "… the graph is at its highest point at 25ºC".*
6. Maximum activity	*"Temperature at its peak"; "… whereby the most amount of food is broken down"; "… 20 mg/h is broken down at 35ºC".*	*"This is because at 5ºC 3-4 mg/h has been broken down"; "… it has reached an equilibrium".*
7. Linear	*"Where graph corresponds with 15mg/h"; "… amount of 15mg/h is at a conjunction with 25ºC"; "… at 25ºC the amount of food broken down is indicated as 15mg/h".*	*"According to the graph"; "… the temperature increases and more food are being broken down".*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
8. Explain sequence of graph	*“According the shape of the graph…”; “… enzyme function low at low temperature and as the temperature increases, they speed up the function”; “… enzyme activity started at low temperature and rise to a point of optimum”.*	*“This sequence best describe the shape”; “… it started at low temperature and increases”; “… at the beginning of the graph, there is no enzyme activity…”.*
9. Effect / Y-axis	*“ …different temperatures different number of bubbles...”; “… it depend on the temperature of the water”; “… they are depending on the temperature”.*	*“Temperature of water depend on the number of gas bubbles”; “… the temperature of the water depend on the rate of photosynthesis”; “… temperature of water is dependent”.*
10. Cause / bring about the change	*“We are testing its effect on photosynthesis”;* *“… temperature of water has an effect on the results”; “… it causes the change in gas bubbles”.*	*“The amount of sunlight”; “… amount of sunlight cannot be controlled’; “… the amount of sunlight cannot be controlled”.*
11. Optimum – max reaction	*“The graph reaches its peak at 35ºC”; “… the number of bubbles are more at 35ºC”; “… it produces the most gas bubbles”.*	*“The maximum height; optimal temperatures”; “… as gas bubbles decrease, water content also decreases”; “… this is the highest temperature”.*
12. Linear	*“According the graph…”; “… as indicated in graph”; “… a right angle is formed where 38ºC and 25 bubbles join together”; “… according to the graph”.*	*“The water temperature is decreasing”; “… the temperature is not really high at that point”; “… because the temperature is high”.*
13. Constant level before exercise	*“Because the number of arbitrary units are constant”; “… this is where the line is prior to the race”; “… starting point and normal levels”.*	*“The race has not begun…”; “… 90 arbitrary units are the highest”; “… because the lactic acid last for ten minutes in the blood”.*
14. 30 – 20 min = 10 min	*“The race ended at 20 minutes, continued to increase until 30 minutes which means 10 minutes”; “… it continued to increase from 20 to 30”.* The only correct answer.	*“Lasted for 50 minutes”; “… as in line graph”; “… it took 10 minutes to decrease”; “… because it become higher”.*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
15. 55 – 20 min = 35 min	*“Temperature drop to normal in 55 minutes which was 35 minutes after the race”.* The only correct answer.	*“The concentration of lactic acid is now going back”; “… it is the time for lactic acid concentration to go back”; “… the concentration remain constant”.*

Post-test 2 – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Tinfoil prevent sunlight from entering and green part contain chlorophyll	*"Leaf covered with tin foil and contain green part"; "… sunlight and plant colour…"; "… variegated leaf test chlorophyll and covered part test sunlight".*	*"CO2 and sunlight were tested"; "… to test whether chlorophyll is necessary for photosynthesis"; "… test was performed with a variegated leaf"; "… colour of leaf will change if CO2 is present".*
2 Contain both correct cause and effect	*"Plant needs both for photosynthesis"; "… they were both tested; the statement mention the two variables tested".*	*"Sunlight is the main source that allows photosynthesis"; "… they indicate if photosynthesis has occurred"; "… sunlight and CO2 are…".*
3. Cause	*"Chlorophyll depends on sunlight"; "… they both cause the effect"; "… they do not change nor depend on any variable".*	*"CO2 and sunlight depend on nothing"; "… the leaf depends on sunlight"; "… they are both effected".*
4. 8 units of sugar (16 water, 16 CO_2, 40 light)	*"It produced 8 units of glucose".* The only correct answer.	*"They use more units of light compared to the rest"; "… glucose were influenced by light"; "… more CO2 is present, so CO2 will be reduced".*
5. 16 units of light + 14 = 30 therefore 3 more	*"14 + 14 = 30 : 3".* The only correct answer	*"6 + 14 = 4 glucose"; "… each plant requires 4 units of light"; "… there has been an addition in the light units"; "… more units of light will result in more units of glucose".*
6. 50 – 40 = 10 units of light	*"it already has 8 units of glucose and only needs 2 to make 10".* The only correct answer.	*"20/4 = 10"; "… it will be able to produce 4 more glucose units"; "… if more light is added the plant will produce more food*".
7. With 20 more light units it will double the amount of sugars	*"Double the amount of sugars".* The only correct answer.	*"The number of CO2 and H2O units is too low"; "… because it receives less units of CO2 and H2O"; "… the light units are less".*
8. Effect	*"The colour of the indicator depends on the CO2 concentration"; "… the effect refer to the colour of the indicator"; "… the colour of the indicator is an effect".*	*"There is air produced and CO2 indicator"; "… concentration depends on sunlight for energy and green plant to produce CO2"; "… the concentration of CO2 determines the indicator".*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
9. Plant and worm respire more than plant only – C only serves as control	*"Worm will add CO2 during respiration, plant will use CO2 during photosynthesis".* The only correct answer.	*"B contains living organisms"; "Test tube A will have higher amounts of CO2"; "… worm will take out CO2".*
10. Worm respires and plant photosynthesize at max-	*"The CO2 produced by the worms will be used by the plant to produce oxygen"; "… the worm produce CO2 and the plant use CO2"; "… the worm respirates and the plant photosynthesise".*	*"Light intensity does not affect the availability of CO2"; "… the colours were already present in test tubes A, B and C"; "… the worms would have produced more CO2 in the test tube".*
11. Both organisms respire and high levels of CO_2	*"In complete darkness CO2 will be at its highest"; "CO2 will be produced by both organisms"; "… photosynthesis does not take place, only respiration".*	*"It will not be exposed to any type of a light so it might have very low levels"; "… the worm and plant photosynthesise"; "… low amounts of CO2".*
12. Respiration since oxidation is the loss of electrons and reduction is the gain of electrons	*"Respiration undergoes reduction to produce H2O"; "… because the end products of photosynthesis are needed"; "… the breaking down of carbohydrates".*	*"Because during photosynthesis oxidation takes place before reduction"; "… because this is a reduction process that take place"; "… because in A the molecules are large and in B they are smaller".*
13. Reduction gain electrons and hydrogen atoms	*"Reduction gain electrons"; "… electrons that are lost in oxidation in a form of hydrogen are being gained"; "… there is a gain of electrons in the equation".*	*"Reduction is the removal of hydrogen atoms"; "… oxygen is removed from hydrogen"; "… the loss of electrons".*
14. According the graph below x-axis	*"After 2.5 arbitrary units CO2 is taken up"; "… according graph below x-axis".*	"After 2.5 *CO2 is released"; "… from 0 it is taken in"; "… height does not play a role in CO2 being released".*
15. All the factors are limiting photosynthesis	*"Because they all contribute to photosynthesis"; "… photosynthesis requires the presence of all mentioned"; "… they are all limiting the process".*	*"More CO2 has been taken in and used for photosynthesis"; "… when H2O is available it works hand in hand with CO2"; "… because water availability causes a light reaction".*

EXPERIMENTAL GROUP 2

Pre-test 1 and post-test 1B – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Steps are given in diagram.	*"When conducting an experiment, there are steps that needs to be followed"; "… the scientific method are used in every scientific investigation"; "… because the steps must be followed".*	*"In scientific investigations, the scientific method is the best"; "… the steps include different stages"; "… it has no aim".*
2. Observation – what you see.	*"...the plant height in one tray was taller"; "… one tray has bigger plants than the other"; "… one tray has grown lettuce plants".*	*"she is doing an experiment and need a result"; "… the height in the two trays are not the same"; "… the other tray receives more water".*
3. Cause	*"…we can change the amount of water"; "… the growth of the plants depends on water"; "… water is used to determine the result".*	*"Because we are investigation its effect on plants"; " ..lettuce needs water"; "… the more water, the more they grow".*
4. Statement with cause and effect.	*"It has not yet been proven"; " ..a statement that needs to be proven"; " … is a statement".*	*"... a possible outcome"; "… because water fertilises the roots"; "… because that is what the investigator suspected".*
5. Effect	*"The dependent variable is the effect"; "… the growth of the plants…"; "… the result will depend on this variable".*	*"plants are dependent on water"; "… the amount of sunlight cannot be changed"; "… the bigger the plant, the more water it needs".*
6. According the scientific method	*"The steps of the scientific method must be followed"; "… it is the scientific manner"; "… scientific investigations should be ordered this way".*	*"They must be in that order…"; "… to reject or accept the hypothesis"; "… you need to know your aim".*
7. Statement with cause and effect.	*"Hot water allows more sugar to dissolve"; " … a statement that needs to be proven"; "… sugar dissolves quicker if the water is hot".*	*"Sugar as a solid substance can be more solved"; "… particles move faster in boiling water"; "… the question was all about…".*
8. Cause	*"The sugar dissolving is dependent on the heat"; "… the water need to be heated for the sugar to dissolve"; " … sugar depends on hot water to dissolve".*	*"The cup of water depends on the heat for the sugar"; "… sugar is dependent on cup of water"; "… the cup of water will depend on the amount of heat".*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
9. Effect	*"The heat is what we change and has an effect on sugar"; "… because sugar depends on heat to dissolve"; " ..the effect tested".*	*"..the one that give us results"; "… the sugar should be constant"; "… we are not depending on cup of water".*
10. Must be the same in cause and effect.	*"Accept for sugar and hot water, all other variables must be constant"; "… amount of water must stay the same"; "… same cup and amount of water has to be used".*	*"Cup of water should be kept constant"; "… because without water, sugar cannot dissolve"; "… because there are different volumes in sol".*
11. According to the introduction	*"… scientist is investigating the water-carrying capacity of soil"; "… question based on different soil types"; "… comparing the water-carrying capacity of soil".*	*"Water was added in all three types of soil"; "… it is the aim of the investigation"; "… the longer the soil is dipped in water, the greater the filtration".*
12. Cause	*"it's the variable that cause the effect"; "… soil type can be changed"; "… soil types are different, making the time of filtration different".*	*"it determines how much water is absorbed"; "… time does not depend on the volume"; "… the volume of the filtrate was observed".*
13. Effect	*"We depend on soil types to check water carrying-capacity"; "… volume of filtrate depends on soil types"; "… tested the effect of the cause".*	*"It depends on the volume of water"; "… soil depends on water…"; "… the more time, the more filtration".*
14. According to the introduction	*"The variables must not be changed"; "… they were kept the same"; "… the variables stay the same".*	*"it is important that they are fixed'; "… because they are all available"; "… they are all variables".*
15. Linked to question	*"Clay has the best water-carrying capacity"; "… spaces between clay particles are small"; "…; "sand filtrates more water".*	*"The spaces between the particles are very small"; "… it absorbs more water than the other types of soil"; "… it filters less water".*

Post-test 1 – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Contains no fats	*"They contain the least fats"; "… lack of fat"; "… there are no fat…".*	*"Because there are no carbohydrates"; "… it has about 70% fats"; "… has more fat than other proteins".*
2. Contains most proteins	*"They have more proteins"; "… proteins are responsible for growth"; "… more proteins found here which …"; "… contains the most proteins".*	*"because they contain a lot of oil"; "… because the pie chart line is in the middle"; "… because fats influence growth".*
3. Contains most fats	*"Contains most fat"; "… fats are the main source of energy"; "… because fats contain more energy".*	*"it is a form of glucose"; "… carbohydrates is a source of energy"; "… protein are essential for energy"; "… it is the structural component of the body".*
4. Half of nutrients are fat	*"Fats take up half of the pie chart"; "… half consists of fat"; "… it is 50% fats".*	*"Its half of carbohydrates and proteins"; "… fats are represented as a quarter of the chart"; "… fat is a total of 75% of total".*
5. Body temperature / optimum temperature for catalase	*"The internal environment functions optimally at 37ºC"; "… this is the best temperature at which catalase functions"; "… enzyme functions best at 37ºC".*	*"Hypothesis is supposed to be a statement"; "… the temperature is not too high or too low"; "… the hypothesis has both variables".*
6. Body temperature / optimum temperature for catalase	*"Enzymes most active at body temperature"; "… enzyme function best at optimum temperature"; "… the temperature seems at optimal…".*	*"it changes as more variables are added"; "… catalyst speed up reaction under high temperature"; "… what can be controlled".*
7. Effect	*"Because it depends on the temperature"; "… temperature is what we change"; "… because the condition of it depends on temperature".*	*"The matter that is tested, the cause"; "… because it causes the effect"; "… it is what we are testing for".*
8. Cause	*"The condition of the chicken liver depends on temperature"; "… we have to use different temperature…"; "… temperature has an effect".*	*"The chicken liver is the one that reacts"; "… hydrogen peroxide determines the reaction"; "…the amount of bubbles formed".*
9. Dependent	*"The condition of the liver"; "… different temperatures"; "… water temperature"; "… during different temperatures".*	*"The amount of hydrogen peroxide"; "… because it is not weight"; "… the liquid that was displaced".*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
10. Meiosis I	*"This is meiosis…"; "… the process of meiosis…"; "… the correct sequence of meiosis".*	*"…the first stage for DNA replication"; "… correct sequence for cell division"; "… correct steps for cell division".*
11. Reduction of chromosome number	*"…reduction of chromosome number"; "… it is the reduction process of …"; "… meiosis halves the number of chromosomes".*	*"Both parents will transfer equal number of chromosomes"; "… it replicates and …"; "… at the end daughter cells receive the same number of chromosomes".* .
12. Reduction of chromosome number	*"Due to the process of meiosis"; "… chromosomes already reduced"; "… chromatids move to poles".*	*"The chromosomes are duplicated"; "… crossing over has already taken place"; "… chromosomes are in homologous pairs".*
13. No reduction of chromosome number	*"Chromosomes line up on equator"; "… reduction has halved the number of chromosomes"; "…the chromatids are about to split".*	*"The metaphase of meiosis"; "… telophase has not occurred"; "… chromosomes are in homologous pairs".*
14. Hypotonic high water potential	*"large amount of water molecules"; "… through osmosis water moves from higher to lower"; "… because the lower concentration of water in solute concentration".*	*"The water will separate from the solution"; "… water enters the area of high …"; "… the cell get swollen".*
15. Hypertonic low water potential	*"Higher solute concentration"; "… the cell shrinks"; "… cell expands as water enters".*	*"Water exits…"; "… will go to the point of high concentration …"; "… the cell will change its shape".*

Pre-test 2 and post-test 2B – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Body temperature / bio-enzyme	*"Because it has both dependent and independent variables"; "… all variables are mentioned in the statement"; "… the enzyme functions optimally at 37ºC".*	*"The hypothesis should include a different temperature"; "… enzymes act at different temperatures"; "… hypothesis only a prediction".*
2. Effect	*"The result after washing and is dependent on enzyme activity"; "… the results depend on the temperatures"; "… it depends on the different temperatures".*	*"The stains are not measured"; "…the size of the blood stains are observed"; "… there cannot be results without the experiment".*
3. Body temperature and enzyme denatured at high temperature	*"The enzyme function best at body temperature"; "… 37ºC worked optimally and at 65ºC was denatured".*	*"Because the blood stains are not removed at 15ºC and 37ºC"; "… tablecloth 2 was washed under 37ºC and the enzyme worked effectively".*
4. 33% = 0.33 van 18 = 6	*"Because 33% of 18 is 6"; "... 33% of 18 is 5.94".*	*"Because it is the biggest portion per day"; " …if 4 comes from fruit, the rest comes from 18".*
5. 12% en 8% = 0.12 en 0.08 van 18 = 2 en 1	*"12/100 x 18 = 2.16 and 8/100 x 18 = 1.44"; "12% is 2 and 8% is 1"; "12% of 18 is 2 and 8% of 18 is 1".*	*"Because 1 and 2 will balance the portions"; "… their percentages are the lowest"; "… variation from meats and alternatives".*
6. Maximum activity	*"Best results as enzyme is optimally active"; "… amount of food broken down at that point is high"; "… most of the food is broken down".*	*"More amount of food is digested"; "… the ratio of meat to meat"; "…* No motivation supplied.
7. Linear	*"At 25ºC the amount of food broken down is indicated as 15mg/h"; "… where graph corresponds with 15mg/h"; "… amount of 15mg/h is at a conjunction with 25ºC".*	*"The temperature increases and more food are being broken down"; "… according to the graph".*
8. Explain sequence of graph	*"Steps follow line of graph"; "… sequence starts with low temperature and rises as temperature rises"; "… according to the graph".*	*"The graph shows that enzymes are inactive at low and again at high temperature"; "… the enzyme temperatures start at low"; "… when temperatures increase, the enzyme reaction increases".*

9.	Effect	*"They are effected by the temperature"; "… the number of gas bubbles is the effect"; "… the gas bubbles will indicate the effect".*	*"Temperature will be determined by the amount of heat provided"; "… the effect of water temperature"; "… it is the variable that can be changed".*
10.	Cause / bring about the change	*"The temperature causes this…"; "… it is use to see the effect on the number of gas bubbles"; "… the temperature of the water bring about the change".*	*"The variable that cannot be changed"; "… the heat applied serves as the cause"; "… there will be no measured bubbles".*
11.	Optimum – max reaction	*"Temperature where most bubbles are formed"; "… from graph and use ruler with vertical line drawn from 35ºC"; "… maximum bubbles appear at 35ºC".*	*"Because that is the moderate temperature"; "… at 30ºC the amount of gas bubbles are higher"; "… because the graph shows at 40ºC".*
12.	Linear	*"According the graph.."; "… at 38ºC the corresponding value is 25 gas bubbles".*	*"Graph shows 20"; "… the water is warmed for more minutes"; "… the number of bubbles quickly decreases".*
13.	Constant level before exercise	*"According graph the level before exercise"; "… measured before the race"; "… before the race it is 18".*	*"before the race the lactic acid is 20…"; "… lactic concentration is higher when the athlete is stationary".*
14.	30 – 20 min = 10 min	*"Lactic acid concentration increased after 10 minutes"; "…* 30 – 20 min = 10 minutes".	Wrong calculations.
15.	55 – 20 min = 35 min	*"The lactic acid went back to its normal count at 55 min, this was 35 minutes after the race"; "* 55 – 20 min = 35 min.	Wrong calculations.

Post-test 2 – Examples of motivations

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
1. Tinfoil prevent sunlight from entering and green part contain chlorophyll	*"Part of leaf was covered with tin foil and other parts contain chlorophyll"; "… plants require sunlight and chlorophyll to photosynthesise"; "… the foil is testing whether sunlight is necessary and green if chlorophyll is essential".*	*"Because CO2 and sunlight are essential …"; "… the plant colour was white and green"; "… these factors are essential for photosynthesis".*
2. Contain both correct cause and effect	*"A statement with both variables"; "… testable statement with cause and effect"; "… both dependent and independent variables in prediction".*	*"CO2 is necessary for photosynthesis"; "… that is what the investigation is about"; "… that is what you change in the experiment".*
3. Cause	*"They are factors that cannot be changed"; "… both causes the effect; can be controlled".*	*"CO2 and sunlight are needed"; "… the leaf depends on CO2 and sunlight …"; "… CO2 and sunlight are the ones causes the effects".*
4. 8 units of sugar (16 water, 16 CO2, 40 light)	*"It produced 8 units of glucose".* The only correct answer.	*"Has the most light, CO2 and H2O total"; "… the light unit is high"; "… it accumulates a lot of CO2 which is then converted to glucose"; "… because it has the highest units of CO2, H2O and light".*
5. 16 units of light + 14 = 30 therefore 3 more	*"14 + 14 = 30 : 3".* The only correct answer.	*"14 will be added to the 6 which makes it 20 units"; "… it receives more amount of light"; "… because each unit of light will reduce 1 CO2 to a glucose".*
6. 50 – 40 = 10 units of light	*"It already has 8 units of glucose and only needs 2 to make 10".* The only correct answer.	*"The more the units of light, the better"; "… 20 units…"; "… more light results in more glucose produced".*
7. With 20 more light units it will double the amount of sugars	*"Double the amount of sugars".* The only correct answer.	*"There is less water and CO2. Plants need all three to produce glucose"; "… plant 1 has small units of these factors"; "… more units of light will result in more units of glucose".*
8. Effect	*"The change in colour depends on CO2 concentration"; "… this relates to the effect"; "… this is what you cannot change".*	*"It changes according to the concentration of CO2"; "… it influences the change in colour"; "… the colour depends on the concentration of CO2".*

Question number and ideal answer	Examples of good motivation	Examples of poor motivation
9. Plant and worm respire more than plant only – C only serves as control	*"Worm will add CO2 during respiration, plant will use CO2 during photosynthesis".* The only correct answer.	*"CO2 is reduced"; "… the indicator cause the colour change…"; "… in test A the leaves absorb CO2 so it will be poor".*
10. Worm respires and plant photosynthesiz e at max-	*"Normal, plant takes in CO2 which was released by worms"; "… worm releases CO2 and plant absorbs CO2 during photosynthesis".*	*"A change in concentration of CO2 exposed to light"; "… photosynthesis will occur during 3, 6 hours of sunlight needed"; "… the worm might die and cause CO2 to rise".*
11. Both organisms respire and high levels of CO2	*"CO2 concentration would increase since both release CO2 in dark"; "… both respirate and release CO2"; "… high amounts of CO2 as both release CO2".*	*"The CO2 might be used up"; "… remain orange as there is no sunlight to charge up the reaction"; "… during dark phase plants uses a lot of CO2".*
12. Respiration since oxidation is the loss of electrons and reduction is the gain of electrons	*"Glucose is oxidized and reduced to CO2 and H2O"; "… glucose was oxidized since it lost electrons"; "O2 was reduced because it gained electrons".*	*"Indicates the equation of photosynthesis"; "… O2 is being oxidized"; "… the by-product are the same of that of photosynthesis".*
13. Reduction gain electrons and hydrogen atoms	*"Reduction is gaining of electrons"; "… you gain electrons"; "… .reduction gain electrons or hydrogen atoms".*	*"H2O is oxidized and CO2 is reduced"; "… reduction is represented"; "…* No motivation provided.
14. According the graph below x-axis	*"CO2 is produced between those units"; "… below the x-axis on graph".*	*"CO2 was still increasing between 2.5 to 35 arbitrary units"; "… CO2 increases rapidly"; "… it is shown in the graph".*
15. All the factors are limiting photosynthesis	*"All three important in the process of photosynthesis"; "…all the factors may limit photosynthesis"; "… they are all contributing factors".*	*"Some of the factors must be absent"; "… H2O is produced during the process"; "… more glucose is produced since there is enough sunlight".*