An analysis of Life Sciences textbooks' representation of the relationship between photosynthesis and respiration

by

Bianca Venter

12022382

A dissertation submitted in fulfilment of the requirements for the degree of

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(General)

in the Faculty of Education, University of Pretoria

Supervisor: Dr A.L. Abrie

November 2023

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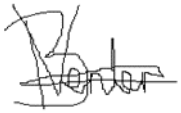

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Faculty of Education

Department: **Department of Science, Mathematics & Technology Education**

Supervisor: **Dr Abrie**

Student name and number: **Bianca Venter 12022382**

Contact number: **073 842 2038**

Email address: **u12022382@tuks.co.za**

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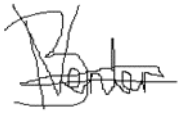

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Abstract

Topics such as photosynthesis and respiration are interrelated. From the literature, it is evident that learners cannot make the connections between topics such as photosynthesis and respiration, and for this reason it is important that textbooks make these connections; it is thus important that the content within textbooks is accurate and of good quality. This study analysed three Grade 10 and 11 South African Life Sciences textbook series to determine how the textbooks represent the relationship between concepts of photosynthesis and respiration, especially as these topics relate to what occurs in plants. The textbooks were analysed to determine whether the content is in accordance with the CAPS document. Subsequently, the content of the textbooks was compared to the standards as set by the AAAS, ASPB and NGSS. Common misconceptions regarding photosynthesis and respiration were identified from the existing literature and the textbooks were investigated for the extent to which these misconceptions are addressed in the textbooks. This study found that the two topics (photosynthesis and respiration) are discussed in two separate sections. There is limited mention of photosynthesis in the respiration chapter, and respiration in the photosynthesis chapter, so that links between the two topics are not well made. Even though the content is in accordance with what is stated in the CAPS document, the textbooks could make the flow of matter and energy more explicit. It was found that the Grade 10 textbooks lay down a foundation for the Grade 11 content and links the structure of the organelles (chloroplasts and mitochondria) and organs (leaf) to photosynthesis and respiration. With regards to the misconceptions, it was found that the textbooks do not directly address these, and even though correct facts are given in the textbooks, this might not be sufficient to correct the misconceptions that learners might have. The results of this study could highlight potential problems and challenges related to how textbooks relate the concepts of photosynthesis and respiration, and could contribute to further research and the design of quality curriculum materials.

Key words: photosynthesis; respiration; textbook analysis; misconceptions; Life Sciences

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Student: Bianca Venter

Student number: 12022382

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M.Sc (Wildlife Management) (University of Pretoria)
B.Sc. (Hons) Wildlife Management (University of Pretoria)
B.Sc. (Hons) Industrial Psychology (University of the Witwatersrand)
Diploma (Economics and Public Finance) (UNISA)
H.E.D (UNISA)

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Cell 083 388 3861
Email lukeprkns@gmail.com

Abbreviation list

AAAS	American Association for the Advancement of Science
ASPB	American Society of Plant Biologists
ATP	Adenosine 5'-triphosphate
CAPS	Curriculum and Assessment Policy Statement
DBE	Department of Basic Education
FET	Further Education and Training
NCS	National Curriculum Statement
NGSS	Next Generation Science Standards

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An analysis of Life Sciences textbooks' representation of the relationship between photosynthesis and respiration

Chapter 1: Introduction

1.1. Introduction and background

Textbooks are some of the oldest instructional instruments (Khine, 2013; O'Keeffe, 2013; Sunday, 2014) and play an important role in ensuring that the curricular goals are achieved (Ramnarain & Chanetsa, 2016; Ramnarain & Padayachee, 2015). Teachers rely heavily on textbooks because they are a crucial instrument in the schooling system (Ngwenya & Arek-Bawa, 2019; Sunday, 2014); they not only help teachers develop learning material, but also aid in teaching (Fuyudloturromaniyyah, 2015; Ramnarain & Chanetsa, 2016; Ramnarain & Padayachee, 2015). The knowledge learners acquire during their schooling years will lay down a foundation for lifelong learning. It is therefore important that textbooks not only present content, but also make connections between concepts in order to contribute to learners' understanding (Roseman et al., 2010).

Plants play an important role in human lives, for example, providing food, fuel, building materials and oxygen (Abrie, 2015; Hershey, 1993; Kissi & Dreesmann, 2018). However, despite the important role that plants play, humans tend not to recognise plants within their environment (Brownlee et al., 2023; Wandersee & Schussler, 1999). Negative attitudes towards plants might be exacerbated by the inadequate representation of plant sciences within the curriculum and textbooks. Teaching materials may also be responsible for the neglect of plants. Textbooks often contain mistakes which can cause misconceptions amongst learners; these errors within the textbooks might arise because the authors have limited knowledge of plants. The reason why plants are neglected in school might be due to the fact that people are not inherently interested in plants (Abrie, 2015).

Learners' lack of interest in plants and the inadequate exposure to plants at school level may lead to botanical illiteracy (Uno, 2009). It was found that few students enter Botany courses and if they do, they have misconceptions about concepts pertaining to the plant sciences (Link-Pérez & Schussler, 2013; Uno, 2009). It should be mentioned that textbooks often separate concepts and this hinders learners from forming an interconnected understanding of related concepts (Abrie, 2015).

Stakeholders criticise textbooks with inadequate content for the poor learning outcomes of learners, although it is not only textbooks that determine the learners' outcomes (Sunday,

2014). Quality curriculum materials, when used properly, can be a powerful tool in teaching and learning science, but these materials should contribute to the learners' understanding and knowledge. If the materials do not fulfil this role, they are inadequate for use, even if the content is correct and age-appropriate (Stern & Roseman, 2004). In this study, textbook analysis was used to determine whether the textbooks made clear the link between plants, and the topics of photosynthesis and respiration.

1.2. Problem statement

An integrated understanding of systems is one of the goals of science education (Lin & Hu, 2003). It is for this reason that the quality and accuracy of the content within textbooks are crucial (Khine, 2013); the quality of instruction is influenced by the quality of the textbook (Ramnarain & Padayachee, 2015). Both learners and teachers are limited in their ability to link related curricular content when the curriculum material is of poor quality (Stern & Roseman, 2004).

The importance of understanding that concepts relate to one another is due to the complex nature of biology (Lin & Hu, 2003). In a study by Lin and Hu (2003) it was found that learners struggled to comprehend the inter-relationship between concepts pertaining to energy flow and the cycling of matter, but that learners understood these two concepts when examined individually. Learners also struggled to understand the relationship between the living and the non-living components in the ecosystem. The difficulty of understanding how concepts relate to each other may be a consequence of textbooks covering the concepts under different sections or chapters (Lin & Hu, 2003; Stern & Roseman, 2004). Textbooks used in Taiwan contained the necessary content, but the concepts were divided into chapters (Lin & Hu, 2003). Stern and Roseman (2004) also found that textbooks included topic headings, but that this, however, did not mean that the important concepts were addressed. These main or important concepts were discussed alongside unrelated ideas, or sophisticated ideas, and learners failed to focus on the concepts of importance (Stern & Roseman, 2004).

Textbooks must make the connections between concepts explicit (Stern & Roseman, 2004), as it appears that learners cannot make the connection between concepts by themselves (Roseman et al., 2010). Learners, for example, know that plants photosynthesise but have a misconception that plants do not have cellular respiration (Amir & Tamir, 1990; Uno, 2009). They therefore fail to understand that the chemical potential energy in the bonds of the glucose molecules (produced during photosynthesis) is converted into adenosine 5'-triphosphate (ATP) during cellular respiration. Learners will better understand topics such as photosynthesis and the cycling of carbon through the ecosystem if they are able to trace matter

within and between biological systems (Wilson et al., 2006). A better understanding of matter and energy transformation and conservation, as well as digestion and food webs, will be gained if learners understand topics such as respiration better (Bergan-Roller et al., 2018). It was found that textbooks fail to make the connections between concepts; the instructional material focuses on the process of photosynthesis and respiration but fails to include the idea that substances are transformed into other substances. Textbooks also, for example, discuss plant structures, such as organelles or organs, and the fact that there is food stored in the roots and stems, but fail to mention that the stored food is made during photosynthesis, which is discussed in another chapter of the textbook (Stern & Roseman, 2004).

The ability of the learner to understand concepts such as photosynthesis and respiration, especially as they relate to plants, is also influenced by their prior knowledge and reasoning ability (Roseman et al., 2010; Yenilmez & Tekkaya, 2006). Textbooks should add to the learners' prior knowledge and relate concepts to ensure in-depth learning (Roseman et al., 2010). It is important that teachers are aware of the learners' prior knowledge and for this reason teaching materials should guide the teacher in terms of the possible misconceptions and prior knowledge that learners have (Stern & Roseman, 2004); teachers' awareness of the misconceptions amongst the learners might improve teaching and learning (Yenilmez & Tekkaya, 2006). Teaching and learning materials, however, do not attend to the prior knowledge before introducing new concepts and these materials rarely alert teachers about the misconceptions and how to address them (Stern & Roseman, 2004). Roseman et al. (2010) also found that textbooks did not support teachers in teaching, as these textbooks did not make connections between the related concepts.

It has been reported that there are limited studies with regard to textbook analysis (Sunday, 2014); especially Science textbooks in the South African context (Ramnarain & Padayachee, 2015). Considering the research done thus far, it is important that textbooks should be of a high quality, making the necessary connections between concepts for learners to fully understand the content of the Life Sciences. This study therefore assessed how South African Life Sciences textbooks represent the relationships between interrelated concepts of photosynthesis and respiration, especially as they relate to plants. Learners struggle to see the relationship between photosynthesis and respiration in plants. This might be due to the fact that they do not appreciate that plants respire (Al khawaldeh & Al Olaimat, 2010; Amir & Tamir, 1990; Jayanti & Sri Rahayu, 2019; Keleş & Kefeli, 2010; Parker et al., 2012; Uno, 2009). Respiration in animals remains problematic, but the relationship between the concepts of photosynthesis and respiration in plants involves a further layer of complexity. It is for this

reason that the study focused on the relationship between the interrelated concepts of photosynthesis and respiration, especially as they relate to plants.

1.3. Purpose of the study

The purpose of this study was to analyse Grade 10 and 11 Life Sciences textbooks to determine how the textbooks represent the relationship between concepts of photosynthesis and respiration, especially as they relate to plants, but also the relationship between photosynthesis in plants and respiration in animals and other organisms. The textbooks were analysed to determine whether the content of photosynthesis and respiration presented within the textbooks are in accordance with the Curriculum and Assessment Policy Statement (CAPS) document (DBE, 2011). The content of the textbooks was also assessed to make sure that the necessary connections between photosynthesis and respiration are made and whether the content, activities, experiments and illustrations show this relationship. The content of the textbooks was compared to the standards set by the American Association for the Advancement of Science (AAAS) (AAAS, 1993), the American Society of Plant Biologists (ASPB) (ASPB, 2022) and the Next Generation Science Standards (NGSS) (NSTA, 2014). These American guidelines were used in this study as there are no comparable standards in South Africa. Common misconceptions regarding photosynthesis and respiration were identified and the textbooks were investigated for the extent to which these misconceptions are addressed in South African Life Sciences textbooks.

1.4. Research questions

The study was guided by the following questions:

1.4.1. Primary question

How do South African Grade 10 and 11 Life Sciences textbooks represent the interrelated concepts of photosynthesis and respiration, especially as they relate to plants?

1.4.2. Secondary questions

- How does the content of photosynthesis and respiration within the textbooks align with what is stated in the CAPS document?
- How do textbooks present the relationship between photosynthesis and respiration?
- How do textbooks and the CAPS document align with the scientific consensus according to the AAAS, ASPB and NGSS?
- How are misconceptions addressed in the textbooks?

1.5. Concept clarification

The following concepts are used throughout the paper. The definition and connection to this study is given below:

1.5.1. Life Sciences and Biology

Life Sciences is the study of living organisms and their interaction with the environment and each other. Life Sciences comprises a variety of sciences, such as Biochemistry, Botany, Zoology, and Genetics. Life Sciences and Biology are subjects taught in the FET phase. Life Sciences is comparable to Biology in other countries (DBE, 2011). In South Africa the subject Biology was changed to Life Sciences when the National Curriculum Statement (NCS) curriculum was introduced (Ramnarain & Padayachee, 2015). The terms Life Sciences and Biology will be used interchangeably within this study, depending on the context.

1.5.2. Textbook analysis

Textbook analysis refers to an in-depth investigation of textbooks through the use of evaluation procedures to determine the strengths and shortcomings of those textbooks (Fuyudloturromaniyyah, 2015).

1.5.3. Scientific literacy

Scientific literacy refers to the knowledge and understanding of science by the public (Laugksch, 2000; McComas, 2013); this knowledge and understanding enables the public to make informed decisions, take part in a society and enter careers related to science and technology (McComas, 2013). Scientific literacy also includes an appreciation of the goals, limitations and nature of science (Laugksch, 2000).

1.5.4. Benchmarks for Science Literacy

The Benchmarks for Science Literacy is the project statement for Project 2061, an American project designed to improve science education (AAAS, 2023). It states what learners should know in terms of Science, Mathematics and Technology. These benchmarks can be used to design a curriculum, as they provide specific learning objectives and help to guide teachers in determining what knowledge and skills learners should have to become science-literate (AAAS, 2022).

1.5.5. Photosynthesis

A reductive process that occurs in plants, algae and certain prokaryotes where light energy is converted to chemical energy and stored as organic compounds (Raven et al., 2014; Reece et al., 2011). The electrons gained from the oxidation of water are used to reduce carbon dioxide to glucose (Raven et al., 2014).

1.5.6. Respiration

An oxidative process where organic molecules are broken down and an electron transport chain is used to produce ATP (Reece et al., 2011). Oxygen is used as an electron acceptor to oxidise glucose to carbon dioxide (Raven et al., 2014).

1.5.7. Plant blindness

Plant blindness includes a person's inability to notice and appreciate plants, as well as the inability to recognise the importance thereof in the biosphere (Allen, 2003; Jose et al., 2019; Parsley, 2020).

1.5.8. Misconceptions

Thoughts and ideas that are inconsistent with scientific knowledge (Kumandaş et al., 2019). Scientifically inaccurate ideas (Coley & Tanner, 2015).

1.6. Chapter overview

Chapter 1 provided the background to the study by mentioning the important role that textbooks play within the education sector. However, it is important to mention that the teaching materials may be responsible for the lack of interest in plants, as well as misconceptions about topics pertaining to the plant sciences; topics such as photosynthesis and respiration. Chapter 1 proposed that one of the problems is that learners struggle to comprehend interrelated topics, such as photosynthesis and respiration, and that the reason might be because textbooks cover the topics under different sections and fail to make the necessary connections. Chapter 1 also gave the purpose of this study and listed the research questions. The chapter ended off with a clarification of concepts that are used throughout the study. Chapter 2 includes the literature review, as well as the conceptual framework.

Chapter 2: Literature review

2.1. Introduction

Textbooks can be useful tools for improving the teaching and learning of scientific knowledge (Liu & Khine, 2016; Roseman et al., 2010). This is due to the fact that many teachers rely heavily on textbooks when teaching (Ramnarain & Chanetsa, 2016; Roseman et al., 2010). The content being taught and how it is taught is often determined by textbooks (Wang, 1998). Stern and Roseman (2004) mentioned that teachers use textbooks 95% of the time and the teachers depend on the textbooks for content or pedagogical knowledge. Another study found that teachers rely on the textbooks 90% of the time and for this reason quality textbooks are important (O'Keeffe, 2013). According to Liu and Khine (2016) teachers reported that textbooks are an important source of information when teaching and that for this reason the accuracy and the quality thereof is of utmost importance. Any inconsistencies or omissions within the textbooks can lead to misconceptions amongst learners (Khine, 2013; Liu & Khine, 2016).

Textbooks determine what topics are taught and also how these topics are taught (Johnston, 2018; Stern & Roseman, 2004). It is thus important that textbooks provide support when it comes to teaching and learning so that learners gain an in-depth understanding of topics (Stern & Roseman, 2004).

Textbook analysis seeks to assist in choosing the most suitable books to convey in-depth understanding and knowledge to learners (Fatima et al., 2015). Analysing and evaluating the curriculum and curricular materials are important in the education sector. By doing so one can make decisions regarding the curriculum and implementation thereof. Analysing textbooks is considered to form part of curriculum development (Fatima et al., 2015; O'Keeffe, 2013; Sunday, 2014). The availability of learning and teaching materials influences the course and effectiveness of science teaching (Wang, 1998).

This literature review includes the topics of plant blindness, botanical literacy, textbooks in the Life Sciences, misconceptions, the relationship between photosynthesis and respiration, structure and function, and the flow of energy and matter.

2.2. Plant blindness

Learners have limited knowledge of plants. Many consider only flowering plants as true plants and do not consider, for example, trees to be a plant (Barman et al., 2003). A misconception held by learners is that plants need food in a similar way to people. The learners also think

that air and oxygen are the same thing (Barman et al., 2003). These misconceptions and others, as mentioned in the section on misconceptions, might be due to plant blindness. Plant blindness includes a person's inability to notice and appreciate plants, as well as the inability to recognise the importance thereof in the biosphere (Allen, 2003; Brownlee et al., 2023; Jose et al., 2019; Parsley, 2020). Plants are seen as inferior to animals (Jose et al., 2019). When shown pictures, learners are better able to identify animals (Brownlee et al., 2023; Parsley, 2020). Plants are not seen as individual units, but rather as a "large green backdrop" (Parsley, 2020; Thomas et al., 2020).

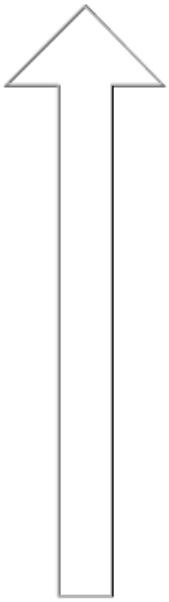
Plant blindness amongst learners may be due to the underrepresentation of plants in textbooks (Jose et al., 2019; Parsley, 2020) and teachers using animal examples much more than plants (Allen, 2003; Pany, 2014), for example when teaching a topic such as respiration. If teachers only talk about respiration (and gas exchange) as it occurs in animals and humans, the development of the misconception that plants do not respire will follow easily. Learners' attitudes towards plants and related topics also play a role; they tend to show more interest in other organisms (Parsley, 2020). Textbooks and instruction where plants are considered important, inspiring teachers, practical activities involving plants, awareness of the importance of plants and educational experiences providing equal exposure to plants, animals and microbes are some of the things that may address the problem of plant blindness (Allen, 2003; Jose et al., 2019).

Owing to the fact that learners tend to overlook and show disinterest in plants, they also do not gain the knowledge of processes essential for life, for example photosynthesis (Pany, 2014). It is thus important that textbooks clearly make the required connections between interrelated topics such as photosynthesis and respiration, especially as these processes occur in organisms such as plants, as we can conclude from the literature that some teachers often fail to use plants as an example to teach about processes such as respiration (Allen, 2003; Pany, 2014; Uno, 2009).

2.3. Botanical literacy

Individuals who are biologically literate possess the basic knowledge and inquiry skills and demonstrate interest (Uno, 2009). Four types of biological literacy (Figure 1 below) were mentioned by Uno (2009). At the "nominal level", learners can identify concepts as biological, but may have misconceptions about these concepts (McComas, 2013; Uno, 2009). The learners are only able to recognise concepts, but struggle when they have to describe or define them (Uno, 2009). Learners tend to identify the correct concept, but they do not understand the concept fully (Amir & Tamir, 1990). At the "functional level" learners can use and define

biological terms, but only due to memorisation (Uno, 2009). At this level simple scientific vocabulary is used (McComas, 2013). At the "structural level" learners are able to explain biological terms in their own words, understand the concepts and have procedural knowledge and skills (Uno, 2009). The "multidimensional level" is the level where learners understand how the biological concepts fits into the whole, understand the interactions and know the nature and history of biology (McComas, 2013; Uno, 2009). According to Uno (2009), learners often enter courses at the "nominal level" and exit at the "functional level". It is for this reason that teachers and learning materials should consider the learners' prior knowledge and build on that knowledge (Uno, 2009).



Level	Scientific literacy
Multidimensional	not only has understanding, but has developed perspectives of science and technology that include the nature of science the role of science and technology in personal life and society
Structural : conceptual and procedural	demonstrates understanding and a relationship between concepts and can use processes with meaning
Functional	can use scientific and technological vocabulary but usually this is only out of context as is the case for example in a school test of examination
Nominal	can recognise scientific terms but does not have a clear understanding of the meaning

Figure 1: Four levels of Biological Literacy (Birzina, 2011), figure used with permission from the author.

A relationship exists between concept development and the learners' prior knowledge (Lumpe & Staver, 1995). Teachers should encourage higher levels of literacy so that learners understand the process of science and understand how the concepts of biology fit into each other and into the whole (Uno, 2009). It is thus important that quality textbooks contribute to the development of multidimensional literacy. The links between concepts, such as photosynthesis and respiration, should be understood in terms of the flow of matter, as well as the flow of energy. Learners should understand that while photosynthesis only occurs in plants, respiration is a process that occurs in all living organisms, including plants. Learners should furthermore understand the importance of the process of photosynthesis and respiration in their daily lives.

2.4. Textbooks and the Life Sciences

Learners find topics such as photosynthesis and respiration difficult to understand. The nature of science, the teaching methods and textbooks are some of the reasons why learners find it difficult to study Biology (Çimer, 2012). Textbooks play an important role in the teaching of science. However, the content of some science textbooks has been questioned due to poor presentation of facts and inadequate elaboration (Soyibo, 1995). The poor content within textbooks as well as the overloaded curricula cause learners to learn through memorisation and prevent in-depth, meaningful learning. The way in which teachers teach biology can lead to disinterest in learners. Learning biology is also difficult if learners lack an understanding of the relationship between what is taught and their daily lives. Even teachers' subject knowledge can have an influence on learners and their attitude towards learning biological topics (Çimer, 2012). The resources available, lesson time and the learning materials, and pre-knowledge, can also add to or alleviate the difficulties in studying biology (Abrie, 2015; Çimer, 2012). Teachers need to make the links between topics clear, helping learners to see the bigger picture, which will lead to meaningful learning. The learning environment also influences the learner's attitude towards biology (Çimer, 2012).

According to the literature, learners are not inherently interested in plants or botany (Balas & Momsen, 2014; Link-Pérez & Schussler, 2013; Uno, 2009). Learners are not prone to recognise plants in their environment and for this reason also do not see the importance of plants in their lives and the role of plants in the biosphere (Balas & Momsen, 2014; Uno, 2009). Learners' worldviews and their understanding of how concepts apply to one another are not only influenced by the curriculum and textbooks, but also by their lifestyle and their experience within their own environment (Natarajan et al., 2002). The learners' knowledge of plants, according to botanists, is not adequately facilitated by school curricula and instruction (Link-Pérez & Schussler, 2013). Stern and Roseman (2004) also found that the curriculum materials they analysed did not take the learners' previous knowledge into consideration, and by using these materials learners could not gain the necessary understanding of key concepts.

Textbooks include less plant content than animal content (Balas & Momsen, 2014; Link-Pérez & Schussler, 2013). In the South African curriculum, it was found that topics focussing on plants are the least prominent. The time spent on teaching topics based on plant sciences is less than that allocated to other topics within the Life Sciences (Abrie, 2016). In a study by Uno (2009), in the USA, it was found that plant biology only makes up 20% of biology courses at high school level. Uno (2009) stated that only 14% of the six best-selling biology textbooks are devoted to the study of plants. Concepts such as respiration apply to both plants and animals; however, it was found that animals alone are usually used in the discussion of these

topics (Abrie, 2015; Uno, 2009). Furthermore, few pictures of plants and trees are given in textbooks, even though several plant names are cited (Brownlee et al., 2023; Natarajan et al., 2002). It was also found that pictures of animals had captions with specific names in comparison to pictures of plants which was labelled only with simple terms such as leaf and flower (Brownlee et al., 2023; Link-Pérez & Schussler, 2013). Teachers depend on textbooks for teaching and seldom go beyond the textbooks (Johnston, 2018; Natarajan et al., 2002; Uno, 2009). Due to the limited representation of plants in the textbooks, teachers tend to use plants less frequently (Uno, 2009). The study of plants is not only influenced by inadequate exposure to plants, but also by the inherent disinterest of learners, poor instruction, learning materials such as textbooks, and physical and social settings (Natarajan et al., 2002; Uno, 2009). The formation of misconceptions may be due to the content selected by teachers and the information provided in textbooks (Cañal, 1999; Kumandaş et al., 2019; Sanders & Cramer, 1992). Learners' interactions and experiences with other people and the world around them develop their conceptions (Lumpe & Staver, 1995; Sanders & Cramer, 1992), which sometimes include misconceptions, and therefore the goal of science education is to promote a clear understanding of concepts (Lumpe & Staver, 1995).

Learners struggle to discuss the process of photosynthesis and according to Barman et al. (2003), learners stated that the sun helps the plant to make food, but they could not make a link between photosynthesis and carbon dioxide. The process of photosynthesis and how energy is passed through the ecosystem is unclear to learners (Barman et al., 2003). It is thus important for textbooks to make the link between related concepts. Learners do not always understand the link between photosynthesis and respiration as they do not always appreciate that plants respire. This is a common misconception, as mentioned in section 2.8.

2.5. Relationship between photosynthesis and respiration and their function in the ecosystem

Figure 2 (below) shows what learners are supposed to know, by the end of their school career, in terms of photosynthesis and respiration.

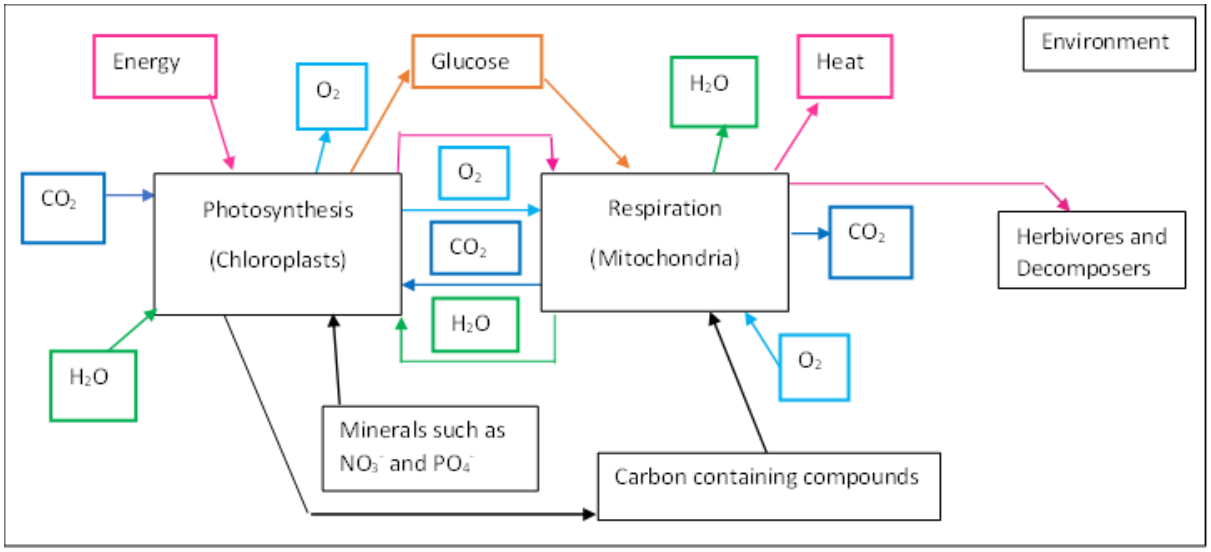


Figure 2: Expert representation of photosynthesis and respiration developed from Raven et al., 2014.

It is expected that learners can make the connections between the concepts of photosynthesis and respiration as shown in Figure 2 above. Water, oxygen, glucose and carbon dioxide are cycled between the chloroplast and mitochondria (Raven et al., 2014). There is thus flow of matter as the glucose from photosynthesis is converted to carbon dioxide during respiration, which may be used again in photosynthesis or released. Water is split during photosynthesis to form oxygen, the oxygen binds to hydrogen during respiration to form water, which serves as a raw material of photosynthesis. Energy flow also occurs. The radiation energy is used during the process of photosynthesis and converted into chemical energy stored in the glucose molecule, as well as in a number of ATP molecules. The chemical energy from the glucose molecule (produced during photosynthesis) is used to make ATP during respiration. The ATP in turn provides energy for photosynthesis (Raven et al., 2014; Reece et al., 2011).

According to the AAAS (2009a), the transfer of energy and matter links organisms to one another and to the environment. Knowledge of this relationship between organisms and their environment is gained across grade levels. From Grades 9 to 12 it is mentioned that learners should be able to link the conservation of matter to the flow of energy. They should understand that energy is stored in molecules produced during photosynthesis and released during oxidation (AAAS, 2009a). It is thus important that textbooks clarify the relationship between photosynthesis and respiration, as well as the flow of matter and energy between organisms and through the trophic levels in the ecosystem.

2.6. Structure and function

An important concept within biology and physiology is the relationship between structure and function. Within biology, structure refers to “the organisation of parts to form an organ, system,

or living thing". Structures can be described by different properties or characteristics. Function, on the other hand, is defined as "the special, normal, proper physiologic activity of a body or an organ". Function refers to what the object or thing does and why it does it (Michael, 2021). There is always a relationship between structure and function; the structure determines the function and if there are changes to the structure, the function is also changed (and vice versa). An understanding of the structure is needed in order to understand the function. Learners need to look at the structure (anatomy and morphology) and function (physiology) to fully understand concepts (Michael, 2021). For example, an understanding of the structure of the leaf (tissue and cell layers) and cell organelles (mitochondria and chloroplast) is required to understand the processes of photosynthesis and respiration. Learners do not appreciate that plants have both chloroplasts and mitochondria, they often think that only animals have mitochondria. Learners have a misconception that plants do not respire, as mentioned in section 2.8.

2.7. Flow of energy and matter

A study done by Bergan-Roller et al. (2018) found that learners find topics such as respiration difficult and hold misconceptions about the topic of respiration. Learners confuse respiration with photosynthesis and gas exchange. The difficulty of understanding respiration might be due to the fact that learners do not understand topics such as matter, and energy transformation and conservation (Bergan-Roller et al., 2018). Photosynthesis and respiration are considered interrelated due to the fact that the processes combine to supply energy to organisms. Radiant energy is converted to chemical energy within the carbohydrate molecule during photosynthesis. The chemical energy is converted to energy within the ATP molecule during respiration. This energy allows photosynthesis to continue. By ignoring the flow of matter, learners can come to the conclusion that photosynthesis and respiration are opposite reactions and isolate the two processes' function (Brown & Schwartz, 2009).

Learners seem to know that there are cyclical processes that take place within the ecosystem. However, they think that these processes involve the creation and destruction of matter. Instruction that traces matter through the ecosystem might correct these misconceptions held by learners (AAAS, 2009b). It is thus important that textbooks make the cycling of matter clear.

2.8. Misconceptions about photosynthesis and respiration

Biology misconceptions are acknowledged as a major problem in a student's understanding or perception of science (Saat et al., 2016). Research noted that learners have misconceptions about photosynthesis and respiration (Al khawaldeh & Al Olaimat, 2010; Bergan-Roller et al.,

2018; Lumpe & Staver, 1995; Parker et al., 2012; Sanders & Cramer, 1992), and that textbooks and other learning materials contribute to these misconceptions (Parker et al., 2012; Stern & Roseman, 2004). Learning materials, for example, state that light is necessary for making sugars in plants. Learners now conclude that light energy is an important "ingredient" and like the other reactants it is "used up". The learners fail to understand that the light energy is converted to chemical energy and stored; they lack the understanding that energy cannot be created nor destroyed (Stern & Roseman, 2004).

Misconceptions are exacerbated by the incorrect use of terminology in textbooks and by teachers, for example "respiration" and "cellular respiration". Some textbooks use the word "respiration" for both biochemical processes and the physical exchange of gases by organisms; this may cause confusion among learners (Sanders & Cramer, 1992). Learners confuse respiration with breathing and gas exchange, and think that plants breathe like animals (Cañal, 1999; Lin & Hu, 2003; Sanders & Cramer, 1992; Yenilmez & Tekkaya, 2006). The role of oxygen in respiration is another concept that learners struggle with, and many learners have a misconception that carbon dioxide is used instead of oxygen during the fermentation reactions. Learners also think that glucose is the only reactant used in respiration (Al khawaldeh & Al Olaimat, 2010).

Some learners even think that plants do not have cellular respiration (Al khawaldeh & Al Olaimat, 2010; Amir & Tamir, 1990; Parker et al., 2012; Uno, 2009). This is due to the fact that teachers use animals and microorganisms as examples when teaching respiration (Uno, 2009). Examples containing animals are used twice more than that of plants to explain content in the textbooks (Link-Pérez & Schussler, 2013). Furthermore, teachers teach photosynthesis and respiration separately, adding to the learners' lack of understanding that photosynthesis and respiration are interrelated concepts (Lin & Hu, 2003).

Learners believe that plants breathe in carbon dioxide and exhale oxygen. The learners learn that oxygen is a product of photosynthesis, but they do not understand that plants also use oxygen (Barman et al., 2003).

Teachers should incorporate plant examples when teaching major biological concepts (Uno, 2009). Again, the lack of plant examples could be due to the inadequate coverage in textbooks. A study by Natarajan et al. (2002) found that there is a mismatch between the learners' conceptions and textbook science.

Learners must be able to connect information and facts about different concepts with one another (Uno, 2009). It was found, however, that learners are unable to recognise the

interrelationships among concepts. Concepts are often separated within textbooks and this hinders learners from forming an interconnected or holistic understanding of related concepts. Learners found it difficult to comprehend relationships between the living and non-living components. An emphasis should be placed on the understanding of the living world as a whole and the inter-relationships within it, in other words learners need to develop an understanding of a concept and all other concepts relating to it (Lin & Hu, 2003).

Researchers state that for learners to better understand global issues such as food supply and energy flow, they need an in-depth understanding of concepts such as photosynthesis and respiration (Lumpe & Staver, 1995). It was found that many instructional materials focus on the process of photosynthesis and respiration, in other words the chemical equations, and do not include the idea that substances are transformed to other substances (Stern & Roseman, 2004). It was recommended by the AAAS (1993) that learners not only understand the process in terms of reactants and products within a chemical reaction, but also that learners understand that substances are transformed and that the amount of matter stays constant throughout the process. The focus within the learning material was, however, on naming reactants and products or comparing the processes of photosynthesis and respiration (Stern & Roseman, 2004). It was also mentioned by Al khawaldeh and Al Olaimat (2010) that misconceptions are not addressed by textbooks or in the classroom. Textbooks must thus enable learners to make the correct connections between concepts of photosynthesis and respiration in order to limit their misconceptions.

2.9. Conclusion

Learners' abilities to organise knowledge may be hindered by knowing disconnected facts and not fully understanding how concepts relate to one another (Uno, 2009). Within the educational sector learners are expected to relate only to the subject matter, which is decontextualised, and taught by different teachers across grades (Natarajan et al., 2002). It was also found that biological knowledge is represented and taught within separate sections of the textbook (Lin & Hu, 2003). The organisation of knowledge adds to the problem that learners are unable to fully understand and interpret the world because they only know the individual concepts and do not understand the interconnected concepts (Lin & Hu, 2003; Natarajan et al., 2002). Textbooks must thus make the relationship between the concepts of photosynthesis and respiration clear to enable learners to develop an in-depth understanding of these concepts.

Learners struggle to understand the relationship between photosynthesis and respiration, especially as they relate to plants, and this might be due to the fact that most learners are not inherently interested in plants (Uno, 2009) and they do not realise that respiration occurs in

both plants and animals (Al khawaldeh & Al Olaimat, 2010; Amir & Tamir, 1990; Jayanti & Sri Rahayu, 2019; Keleş & Kefeli, 2010; Parker et al., 2012; Uno, 2009). The literature, however, suggests that learners are more motivated when they find tasks interesting and meaningful (Uno, 2009). Real-life examples will help learners become more inquisitive, especially toward plants (Natarajan et al., 2002; Uno, 2009). Learning is promoted if interest is provoked within the learners (Lin & Hu, 2003). A better understanding of concepts may be achieved when learners have the opportunity to apply concepts to their daily lives (Amir & Tamir, 1990).

2.10. Conceptual framework

A conceptual framework is a description of the elements within the research problem and derived from concepts (Sefotho, 2018).

This study was guided by the conceptual framework in Figure 3 that follows. The conceptual framework has been developed from the literature, as there is no existing framework in the literature. This conceptual framework shows the relationship between textbook content and learner knowledge (prior knowledge, pre-conceptions, or misconceptions) and how this relationship influences the learners' understanding of interrelated concepts of photosynthesis and respiration.

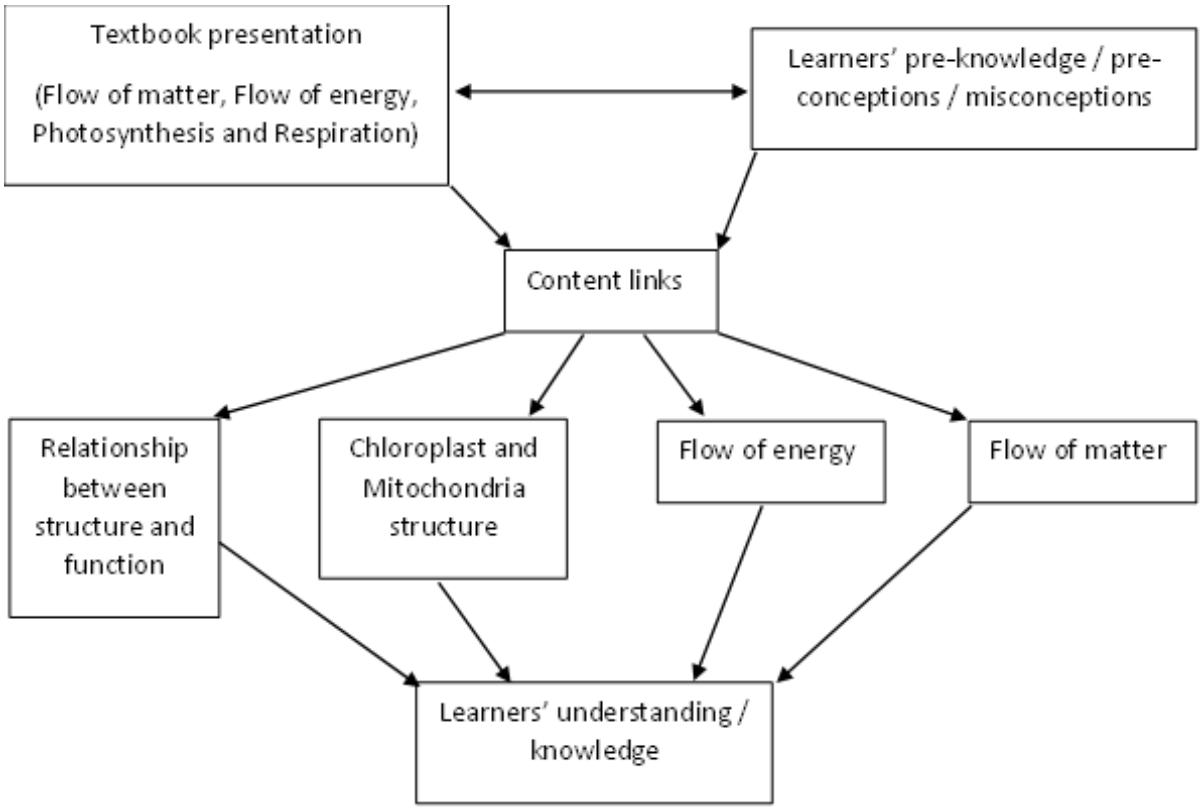


Figure 3: Conceptual framework of the interaction between textbook presentation and learners' understanding / knowledge.

I focused on the sections of the textbooks that discuss photosynthesis and respiration, and looked at how the flow of matter and energy is presented within these sections and whether the textbook developers made the necessary links between the interrelated concepts. Learners' knowledge, pre-conceptions or misconceptions are influenced not only by textbooks but also by their prior experiences and what they were taught in the past (Natarajan et al., 2002; Sunday, 2014). Research found that textbooks and other learning materials contribute to learners' knowledge, pre-conceptions or misconceptions (Parker et al., 2012; Stern & Roseman, 2004).

The learners need to know that there is a relationship between structure and function. They must be able to explain where the processes of photosynthesis and respiration occur, and be able to distinguish between the structure of the chloroplast and mitochondrion. My aim was therefore to determine how South African Life Sciences textbooks present the relationship between the concepts of photosynthesis and respiration, and how the textbooks and the CAPS document compare to the standards set by the AAAS. Analysing the data allowed me to draw conclusions about the understanding and knowledge that the textbooks create.

2.11. Chapter overview

Chapter 2 included the literature review, as well as the conceptual framework. It is apparent from the literature review that there is a scarcity of literature pertaining to Life Sciences textbook analysis, specifically focussing on the representation of the relationship between photosynthesis and respiration, within the South African context. It is also important to note that a greater quantity of older literature, rather than current literature, is available. With the literature in mind, this study therefore assessed how South African Life Sciences textbooks represent the relationship of interrelated concepts of photosynthesis and respiration, especially as they relate to plants. Chapter 3 includes the research methodology and shows how it aligns with the research questions and purpose of the study as mentioned in Chapter 1. Chapter 3 includes the methodological paradigm and the research design, sampling technique and data collection methods, and ends with the quality criteria and ethical considerations.

Chapter 3: Research methodology

The methodological paradigm and research methodology, including the research design, sampling technique and data collection methods, was as follows:

3.1. Paradigmatic approaches

3.1.1. Epistemological paradigm – Interpretivism

A paradigm is a set of beliefs about reality. It is a worldview or framework that guides the researcher throughout the study (Sefotho, 2018). A paradigm is the lens through which one interprets reality (Maree, 2017). Certain philosophical views are presented by a paradigm. Epistemology is a philosophical assumption of how reality is realised. Epistemology can be seen as a way in which knowledge is acquired and is based on a paradigm (Sefotho, 2018).

Interpretivism, as an epistemological paradigm, is often linked to qualitative research (Goldkuhl, 2012). The qualitative researcher is involved in the research process, analysing, and seeking understanding to make meaning of certain phenomena. The interpretivist paradigm accepts multiple realities that are constructed and is subjective (Goldkuhl, 2012; Sefotho, 2018). A holistic understanding of the study is one of the principles of interpretivism (Goldkuhl, 2012); interpretivism does not discover the absolute truth, but rather constructs meaning (Sefotho, 2018). Document or content analysis, interviews and observation are some of the multiple methods used in qualitative research (Denicolo & Becker, 2012).

For the purpose of this study interpretivism was used for qualitative research. This study aimed at analysing Grade 10 and 11 Life Sciences textbooks to determine whether the necessary links are made between the interrelated concepts of photosynthesis and respiration. I applied qualitative data collection methods by analysing documentation and textbooks to seek understanding. The subjectivity of the interpretivist paradigm indicates that I would have to make meaning of the analysis in terms of my own experiences. The interpretivist paradigm guided the study in terms of methodology, and it is therefore important as it shows how knowledge and understanding was obtained and how data was collected and analysed.

3.1.2. Methodological paradigm

For this study, a qualitative research approach was followed. Qualitative research uses words rather than numbers to produce understanding about a certain phenomenon (Azungah, 2018; Maree, 2017; Saldana, 2011). Qualitative research enables one to acquire a detailed explanation of the data collected in order to answer the research questions (Maree, 2017).

The researcher is actively involved when conducting qualitative research (Creswell, 2007; Saldana, 2011) and participants have the opportunity to voice or show their views and understanding about the phenomenon being studied (Azungah, 2018). In this study I was actively involved in textbook analysis, producing meaning and understanding in terms of the way in which textbooks make connections between related topics.

During qualitative research, the researcher interprets the observed phenomenon. A potential challenge of qualitative research might be the researcher's prior knowledge, experience and own interpretation of the data, due to the fact that this could influence the interpretations made (Creswell, 2007). This challenge was overcome by reflection and inter-rater reliability.

Qualitative research is time-consuming and thus demands commitment (Creswell, 2007). To ensure that the research was conducted as planned, a schedule was followed.

3.2. Research design

A research design is a framework describing in detail the procedures to be followed to obtain information and data required to answer a specific question. A research design describes the methods used to select participants or units of analysis, gather data, and analyse the data. A design is chosen based on the researcher's perspectives; this will influence the way in which data is collected (Akhtar, 2016; Maree, 2017).

Content analysis is a research methodology in which procedures are used to make inferences from the written text; inferences and conclusions about the content are made (Prasad, 2008). In content analysis, the words used in the text are categorised based on certain rules or coding. Content analysis is useful when examining trends or patterns within documents or other texts (Stemler, 2001). Content analysis can be applied to visual data, textual data, and audio data (Stemler, 2015). It includes letters, diaries, journals, messages on the radio or television, minutes of a meeting, newspaper content, books, advertisements, documents, folk songs, short stories and symbols (Bowen, 2009; Prasad, 2008). Written text is used most often when content analysis is done (Stemler, 2015). In qualitative content analysis, data is reduced due to the categorisation of the data (Schreier, 2014; Stemler, 2001). The researcher will only focus on aspects related to the research question (Schreier, 2014). In this study, textbooks were analysed according to a table (Appendix A) set up based on the model used by Stern and Roseman (2004), as well as on the standards outlined by the AAAS, ASPB and NGSS. The findings from the textbook analysis were organised into categories in this table (Appendix A). From this table I was able to draw conclusions about the way in which related topics of photosynthesis and respiration are represented in the textbooks and if the necessary

connections are made. The analysis allowed me to draw conclusions about the extent to which misconceptions are addressed in the textbooks. Literature was studied to compile a table (Table 3, Appendix B) with misconceptions that learners might have.

Document analysis is an efficient method due to the fact that the documents (for the purpose of this study, textbooks) are selected with a purpose in mind (Bowen, 2009). Qualitative document or content analysis is used to create a deep understanding of a phenomenon through describing the meaning of qualitative data (Bowen, 2009; Schreier, 2014). Documents and other written texts are used in everyday life and by analysing these, one can make sense of different social settings (Coffey, 2014). Providing a detailed description and drawing conclusions about a phenomenon is the main focus of qualitative content analysis (Schreier, 2014). The analysis can also assist in making future decisions (Coffey, 2014). The researcher's own interpretation will also be evident during the analysis process and there is thus a need for reflexivity (Coffey, 2014). In this study, textbook analysis was conducted from an interpretivist perspective, due to the fact that the analysis of all materials ensured that all assumptions and views were included (Schreier, 2014).

For the purpose of this study, inductive data analysis was done. Inductive reasoning is aligned with qualitative research and allows the researcher to establish patterns, make meaning and detect any irregularities from the data (Sefotho, 2018). An inductive approach starts with the data, moves to generalisations, and ends in a theory (Heath & Cowley, 2004). Khan (2014) also mentions that analysing data during an inductive approach leads to the development of generalisations, relationships and even theories. In this study the data was analysed to make generalisations and draw conclusions on how the relationship between photosynthesis and respiration is represented in the textbooks.

3.3. Sampling technique

Non-probability purposive sampling was employed in this study. Purposive sampling chooses the unit of analysis with a specific purpose in mind and is usually used in qualitative research (Creswell, 2007; Maree, 2017). The population included all Grade 10 and 11 Life Sciences textbooks used in South African schools. The sample for this study included three different Grade 10 and 11 Life Sciences textbooks series. The textbooks in the sample were selected based on what textbooks are currently used in South African schools, as well as the availability thereof at bookstores. Both the Grade 10 and Grade 11 textbook in the Understanding and Study and Master series was analysed, however, only the Grade 11 textbook in the Solutions for all series was analysed, because a Grade 10 textbook in the Solutions for all series is not available.

Non-probability sampling does however have some limitations. The fact that the unit of analysis or population is chosen with a specific purpose in mind, might not always be representative of the whole unit or population (Maree, 2017). This can be overcome by increasing the sample size or comparing the results to similar studies.

3.4. Data collection / generation

The CAPS document (DBE, 2011) was used to investigate whether the content within the textbooks aligns with the intended curriculum. The textbooks were analysed by means of an inductive, constructivist approach.

The textbooks were analysed to determine whether photosynthesis and respiration are discussed separately and whether links are made between these two related topics. I looked at the diagrams, activities, and experiments that accompany the written text, to assess whether the relationship between photosynthesis and respiration is made within the textbooks. I kept the misconceptions, as stated in the literature (Appendix B), in mind to ensure that the textbooks do not contribute to the learners' misconceptions about photosynthesis and respiration. I also looked at whether these processes, especially respiration, are explicitly shown as occurring in plants.

The findings from the textbook analysis, alongside the CAPS document, were compared to the standards as stated by the AAAS, ASPB and NGSS to ensure that the learners, as users of the textbooks, will be able to exit the schooling system with scientifically correct conceptions.

3.5. Data analysis

Three Grade 10 and 11 textbook series were used for the textbook analysis. Both the Grade 10 and Grade 11 textbook in the Understanding and Study and Master series was analysed, however, only the Grade 11 textbook in the Solutions for all series was analysed, because a Grade 10 textbook in the Solutions for all series is not available. The textbooks were analysed by means of an inductive, constructivist approach. An inductive approach allows the researcher to establish patterns, make meaning and detect any irregularities from the data (Sefotho, 2018). A constructive approach is inductive (Cooperstein & Kocevar-Weidinger, 2004). I constructed meaning from the data obtained through the analysis of the textbooks. Based on the model used by Stern and Roseman (2004) and the standards as stated by the AAAS, ASPB and NGSS, a table to analyse the textbooks had been compiled (Appendix A). I analysed the textbooks and organised the findings into categories which are presented in this table (Appendix A). I modified and added categories during the analysis process. A rater then

analysed the textbooks according to the same framework and the findings were compared and discussed to reach an agreement and ensure reliability of the results. The rater is a qualified lecturer at the University of Pretoria.

3.6. Quality criteria / Trustworthiness

Credibility, transferability, dependability and confirmability are criteria that should be considered when ensuring that the study is trustworthy (Korstjens & Moser, 2018). Credibility deals with the consistency of the reality and the research findings (Maree, 2017). Debriefing sessions, reflective notes and member checks can ensure credibility (Creswell, 2007; Maree, 2017); this was however not used in this study as these were not relevant for textbook analysis, and are only relevant where participants contribute. Other ways in which credibility can be ensured is prolonged engagement, triangulation and persistent observation (Korstjens & Moser, 2018).

Transferability allows the reader to make connections between the research study and their own reality. Transferability can be increased through detailed descriptions (Maree, 2017). The detailed descriptions give the reader the ability to transfer the information to their own reality (Creswell, 2007; Korstjens & Moser, 2018). In this study qualitative research and qualitative content (textbooks) analysis were used to create a deep understanding of a phenomenon. This description of the phenomenon enables the reader to transfer information to their own context.

The implementation of the research design is demonstrated by dependability (Maree, 2017). Dependability entails the repetition and consistency of the study and its results (Korstjens & Moser, 2018; Maree, 2017). Confirmability can be described as the degree to which the participants shape the findings, and the degree to which researcher bias is excluded. Confirmability can be increased through triangulation as well as reducing researcher bias (Maree, 2017). The interpretations made by the researcher must come purely from the data and not be based on his or her own experience, preferences or viewpoints (Korstjens & Moser, 2018). Although actively involved in content (textbooks) analysis, I had to reflect, and ensure that prior experiences and knowledge did not influence the results. I critically looked at the content of the Life Sciences textbooks to determine whether textbooks include the content it should and whether the connections between related concepts are made. A rater also analysed the textbooks according to the same framework and the findings were compared and discussed to reach an agreement; this also minimised researcher bias.

The ability to replicate the study is known as reliability (Krippendorff, 2010). Inter-rater reliability was used in this study. This ensured that the data being collected correlated well with the rater's data (Krippendorff, 2010). A rater and I analysed the textbooks and then compared our findings to draw conclusions. The more similarities there were between our findings, the more trustworthy the results were. I presented the data after an agreement was reached.

3.7. Ethical considerations

Ethics and ethical considerations are of utmost importance when conducting a research study. Ethics determines the code of conduct whereby a research study will be conducted (Denicolo & Becker, 2012). Ethics clearance was obtained from the Ethics Committee of the Faculty of Education at the University of Pretoria (see page iv).

In this study, content (textbook) analysis excluded the interaction with participants, but ethical principles determined what was right and/or acceptable during the research study, and aimed to protect everyone involved in the research study (Denicolo & Becker, 2012). It is important to note that ethics remains equally important even though this study did not include human participants. One should take care to ensure the wellbeing of those that might be implicated by the research and/or by the results being published (Cohen et al., 2007; Denicolo & Becker, 2012).

The researcher should be honest in conducting the research study as well as when writing up any findings and conclusions. In this study no information was adjusted to fit to the objectives as determined by the researcher (Ary et al., 2019; Denicolo & Becker, 2012). The researcher kept the ethical principles of the University of Pretoria in mind throughout the study.

3.8. Chapter overview

Chapter 3 included the research methodology and showed how it aligned with the research questions and purpose of the study as mentioned in Chapter 1. The methodological paradigm that guided this study was discussed, followed by the research design, sampling technique and data collection methods. The chapter was concluded with the quality criteria and ethical considerations. In the following chapter (Chapter 4) the data from the textbook analysis are presented.

Chapter 4: Data analysis and research findings

4.1. Introduction

The purpose of this chapter is to discuss the data analysis and present the research findings. The chapter starts with an overview of the research questions. This is followed by a brief discussion of the conceptual framework. Hereafter the textbooks used in this study will be listed, followed by a description of the approach that was taken for the analysis of the emerging data. The remainder of the chapter presents the data, and general trends found from the data are presented. The raw data is attached as an appendix (Appendix A).

4.2. Research questions

The following questions guided this study, as well as the data collection and analysis. The secondary questions provided guidance for the collection of the data.

The primary question:

How do South African Grade 10 and 11 Life Sciences textbooks represent the interrelated concepts of photosynthesis and respiration, especially as they relate to plants?

The secondary questions:

- How does the content of photosynthesis and respiration within the textbooks align with what is stated in the CAPS document?
- How do textbooks present the relationship between photosynthesis and respiration?
- How do textbooks and the CAPS document align with the scientific consensus according to the AAAS, ASPB and NGSS?
- How are misconceptions addressed in the textbooks?

4.3. Conceptual framework

The data as presented in this chapter are discussed in relation to the conceptual framework of this study, as described in Chapter 2. The conceptual framework has been developed from the literature, as there is no existing framework in the literature.

4.4. Textbooks analysed

The following textbooks were chosen based on what textbooks are currently used in South Africa, as well as the availability thereof at bookstores:

- Textbook series 1:
    - Understanding Life Sciences Grade 10 published by Pulse Education Services (Isaac et al., 2011).
    - Understanding Life Sciences Grade 11 published by Pulse Education Services (Isaac et al., 2012a).
- Textbook series 2:
    - Study and Master Life Sciences Grade 10 published by Cambridge University Press (Gebhardt et al., 2012a).
    - Study and Master Life Sciences Grade 11 published by Cambridge University Press (Gebhardt et al., 2012b).
- Textbook series 3:
    - Solutions for all Life Sciences Grade 11 published by Macmillan (McKay et al., 2012a). (Solutions for all Life Sciences is not available in Grade 10.)

Throughout the rest of the dissertation, the abbreviated names for the textbooks will be used.

4.5. Approach for analysis of data

A table (Table 2 in Appendix A) was set up to analyse the textbooks, based on the model used by Stern and Roseman (2004) and the standards as stated by the AAAS, ASPB and NGSS. The textbook series were analysed, and the data was organised into the table by allocating a colour to each textbook. The data was analysed by assessing each textbook (indicated in different colours within the table) separately to draw conclusions from the findings. The data from all three of the textbook series were then compared to find trends amongst the data.

4.6. Presentation of the data

The raw data are presented in the table in Appendix A. In this section the data will be summarised for each of the criteria as listed in Table 2, Appendix A. Table 1 below shows what is stated in the CAPS document (DBE, 2011) in terms of photosynthesis and respiration. This is what learners should learn in terms of the curriculum. The textbook series was also analysed to see whether the content aligns with what is stated in the CAPS document (DBE, 2011). Reference will be made to this table when presenting the findings.

Table 1: Content to be covered as stated in the CAPS document (DBE, 2011).

What is stated in the CAPS document (DBE, 2011)?	
Grade 10	**Grade 11**

p.25 Cell structure and function of mitochondria and plastids (chloroplast).
 	
p.25 Relate structure and location to function.
 	
p.28 Leaf structure – Explain structure in terms of function. Link to plant tissue and cell organelles.
 	
p.34 Energy flow through ecosystem. Oxygen and carbon cycles.
	p.42
	
	• Process of photosynthesis (equation).
	  ○ Raw materials.
	  ○ Energy.
	  ○ Formation and storage of food.
	  ○ Release of oxygen.
	  ○ Mention light and dark phase (no biochemical detail).
	• Importance of photosynthesis.
	• Effect of light, CO_2, and temperature on the rate of photosynthesis (discuss and graph).
	• Role of CO_2 enrichment, optimum light and temperature in greenhouse systems (link to global warming).
	• Role of ATP as important energy carrier in cell.
	
	p.45
	
	• Process of respiration and uses of energy.
	  ○ Aerobic respiration.
	  ▪ Site.
	  ▪ Equation.
	  ▪ Glycolysis, Kreb's cycle, Oxidative phosphorylation (no biochemical detail).
	  ○ Anaerobic respiration.
	  ▪ Production of lactic acid.
	  ▪ Equation (no biochemical detail).
	  ▪ Role of anaerobic respiration in the industry.
	  ○ Compare aerobic and anaerobic respiration (raw materials, products, energy released).

4.6.1. Textbook series 1: Understanding Life Sciences

Criterion 1: How does the Grade 10 textbook lay down the foundation needed in Grade 11? Mention chloroplast and mitochondria. Mention structure and function. Detail of gases (oxygen and carbon dioxide).

The Grade 10 Understanding Life Sciences textbook (Isaac et al., 2011), hereafter only referred to as Understanding Life Sciences Grade 10, mentions both chloroplasts and mitochondria. It is mentioned that the mitochondria are the site of respiration and that they are found in both plants and animals. It is further mentioned that chloroplasts have chlorophyll for photosynthesis and are found only in plants. Apart from the mention of mitochondria occurring in plants and animals, no further mention is made of the organisms in which photosynthesis and respiration occur. Both the structure of the mitochondria and the chloroplasts are given. The structure and function of the leaf are given, as well as the function of the different components of the leaf. It is, for example, mentioned that the palisade mesophyll contains chloroplasts, and the palisade mesophyll is adapted in such a way for maximum absorption of sunlight for photosynthesis. The adaptations of the leaf for photosynthesis and gas exchange are listed in this textbook. The gases, oxygen and carbon dioxide, are mentioned. It is stated that the intercellular spaces between the parenchyma cells allow for the transport of gases. It is further mentioned, at the carbon cycle, that carbon (from carbon dioxide) is used during photosynthesis and released (in the form of carbon dioxide) by the breakdown of organic compounds during respiration; a figure in this section of the textbook shows that the carbon (from carbon dioxide) released by respiration is again available for photosynthesis. In the section on the oxygen cycle, it is mentioned that oxygen is used during respiration and released during photosynthesis; a figure in this section shows that oxygen is released by photosynthesis and made available for respiration, while respiration releases carbon dioxide which is available for photosynthesis; here the link between photosynthesis and respiration is made explicit. In the section on energy flow and nutrient cycles in Understanding Life Sciences Grade 10, energy flow is discussed in terms of food chains, webs or pyramids. It is further mentioned in the section on nutrient recycling, that the food (containing energy, carbon dioxide, water and mineral salts) from plants is transferred to animals when they feed on plants.

Criterion 2: How are photosynthesis and respiration covered in the Grade 11 textbook? (In the same chapter or in different chapters?) To what extent does the chapter on photosynthesis refer to respiration? To what extent does the chapter on respiration refer to photosynthesis?

Within the Understanding Life Sciences Grade 11 textbook (Isaac et al., 2012a), hereafter only referred to as Understanding Life Sciences Grade 11, photosynthesis and respiration are discussed as two separate topics; however, these two topics form part of the same strand (Life processes in plants and animals). Photosynthesis is discussed in Topic 2.1 and respiration is discussed in Topic 2.3. The chapter on photosynthesis only once refers to respiration when stating that oxygen released during photosynthesis is used to release energy during respiration. The chapter on respiration refers to photosynthesis in a flow chart, as well as in three activities: one activity mentions that photosynthesis and respiration are often referred to as "opposite processes" (which might lead to misconceptions), the other activities show the cycling of matter between the chloroplasts and mitochondria and state that the glucose from photosynthesis is broken down during respiration; here the link between photosynthesis and respiration is made explicit.

Criterion 3: How does the Grade 11 textbook refer to the structure of plant organs in relation to gas exchange of photosynthesis and respiration? How does the Grade 11 content link to the Grade 10 textbook where structures are discussed?

Understanding Life Sciences Grade 11 refers to the structure of plant organs in relation to gas exchange of photosynthesis and respiration by mentioning that the double membrane of the chloroplast is permeable to water and carbon dioxide (which is needed for photosynthesis). It further mentions that the air spaces of the spongy mesophyll allow for gas exchange and that the outer membrane of the mitochondrion is permeable to oxygen and pyruvic acid (which is used in respiration).

The content in Understanding Life Sciences Grade 11 links to Understanding Life Sciences Grade 10 where structures are discussed. The structure of the chloroplasts and mitochondria given in the Grade 11 textbook links to the Grade 10 discussion of the cell organelles. The structure of the leaf was also studied in Grade 10; the intercellular spaces of the spongy mesophyll, mentioned in Understanding Life Sciences Grade 11, links to the leaf structure which was discussed in Understanding Life Sciences Grade 10.

Criterion 4: How does the Grade 11 textbook cover interrelated topics of photosynthesis and respiration for the learners to make the connections between these topics? (Refer to sub criteria 4.1–4.11 in Table 2 in Appendix A.)

Understanding Life Sciences Grade 11 covers most of the content as stated in criterion 4 in the table in Appendix A. The criteria were set based on what learners need to know about photosynthesis and respiration; Brown & Schwartz (2009), Raven et al. (2014) and Reece et

al. (2011) were referred to in setting the criteria. Understanding Life Sciences Grade 11, for example, includes a sketch associated with an activity that shows the cycling of matter between the chloroplasts and mitochondria. The textbook mentions that during photosynthesis water is split into high-energy hydrogen atoms and oxygen and that the oxygen is released into the atmosphere. It further mentions that during respiration the oxygen combines with hydrogen (during oxidative phosphorylation) to form water. The textbook states that glucose is broken down during cellular respiration and that oxygen is a requirement for respiration; however, it is not explicitly stated (except for the sketch showing the flow of matter between the chloroplasts and mitochondria) that the glucose comes from photosynthesis and that it is available for use by the mitochondria for respiration. It is stated in the textbook that glucose is broken down, during respiration, to pyruvic acid during glycolysis and that the pyruvic acid enters Kreb's cycle, with hydrogen and carbon dioxide being released. The textbook further states that during anaerobic respiration in plants, the pyruvic acid is broken down to ethanol and carbon dioxide. It is stated that carbon dioxide from the atmosphere is available for photosynthesis; however, it is not explicitly stated that the carbon dioxide from respiration is also used in photosynthesis. The textbook does not explicitly mention that the chemical energy from glucose (which is made during photosynthesis) is used in respiration to make ATP; it is, however, mentioned that glucose is an energy-rich carbohydrate, and that glucose is broken down in respiration to release energy in the form of ATP. The textbook mentions that carbon dioxide and water serve as raw materials in photosynthesis and that carbon dioxide and water are released as by-products during respiration. It is not mentioned that photosynthesis and respiration occur simultaneously in light; the light-dependent phase is discussed in the photosynthesis chapter while in the respiration chapter it is mentioned that aerobic respiration depends on oxygen. Learners might be able to make the connection that oxygen is produced during the light dependent phase of photosynthesis, and that respiration thus also occurs in light due to the fact that the process depends on the presence of oxygen. The textbook does not mention that respiration occurs continuously, day and night. The flow of matter and energy is not consistently spelled out.

Criterion 5: Does the Grade 11 textbook include the concepts / standards as set by the AAAS, ASPB and NGSS? (Refer to the concepts / standards as listed (5.1–5.14) in Table 2 in Appendix A.)

The concepts / standards as listed in criterion number 5 in Table 2 in Appendix A, was set up based on standards set by the AAAS, ASPB and NGSS. Understanding Life Sciences Grade 11 does not explicitly state that plants need water, inorganic elements, and light, however, learners might conclude that water and light are needed as these are listed as requirements

for photosynthesis. The textbook also does not explicitly state that materials can be recycled and reused; a diagram in the textbook only shows the cycling of matter, such as oxygen, glucose, carbon dioxide and water, between the chloroplasts and mitochondria. The textbook does mention that light energy is used to form ATP and release high-energy hydrogen atoms during photosynthesis; it is further mentioned that photosynthesis is important as it provides the food / energy needed by organisms at higher trophic levels. It is also stated that energy is released during respiration and that ATP is available for various processes. It is, however, not explicitly stated that energy is needed for life and growth. Understanding Life Sciences Grade 11 does mention that light energy, carbon dioxide and water are used by plants to make sugar; this is stated in the chapter where the process of photosynthesis is discussed. The textbook does not explicitly state that in living things energy can change from one form to another; it is, however, mentioned that light energy is used to from ATP, high-energy hydrogen, and glucose. The textbook further states that glucose is broken down during respiration to release energy in the form of ATP, with some of the energy released as heat. The continuous input of sunlight that keeps the flow of energy in a food web going is not mentioned in this textbook. The textbook lacks an explanation of the flow of energy between the mitochondria and chloroplasts; however, it does touch on the fact that energy is transferred from one system to another and is released, by showing a diagram of the ADP/ATP cycle. It is thus made clear that the energy from the breakdown of glucose forms ATP and the ATP is available for other processes, with some energy released as heat. The textbook mentions that photosynthesis controls the carbon dioxide and oxygen levels in the atmosphere. The textbook does not mention the production of other carbon-based molecules from the hydrocarbon backbones, however, the chemical formula given shows that glucose contain carbon, hydrogen, and oxygen. The textbook does not state that animals depend on the carbon-based molecules that plants produce. There is no description of how matter flows from plants to animals. The flow of matter and energy allowing the recombination of chemical elements to form different products is not mentioned in Understanding Life Sciences Grade 11, but the diagram in the textbook does, however, show the cycling of matter, such as oxygen, glucose, carbon dioxide and water, between the chloroplasts and mitochondria. The textbook lists the uses of energy, including growth, movement, cell division, maintaining body temperature and active transport. In the respiration chapter the process is discussed in terms of glycolysis, Kreb's cycle, and oxidative phosphorylation; here one can deduce that during respiration the bond of food molecules (glucose) and oxygen are broken, and new compounds are formed that transport energy. There is no mention of photosynthesis and respiration playing important roles in the carbon cycle. The textbook does not mention that plants play an important role in the cycling of nutrients (matter); it is, however, mentioned that plants play a role in the addition of oxygen to the atmosphere.

Criterion 6: How does the Grade 11 textbook stimulate research on the subject?

Understanding Life Sciences Grade 11 includes practical activities in both the photosynthesis chapter and the respiration chapter which might trigger the learners' interest which can lead to research on these two topics. It is important to note here that the practical activities in the respiration chapter include germinating seeds and no other practical activities including plants. The photosynthesis chapter also includes the history of the development of the knowledge of photosynthesis.

Criterion 7: Is the purpose of the Grade 11 learning material constructed in a logical sequence to empower the learners as opposed to merely providing a lot of information? (understanding as opposed to memorising)

The photosynthesis chapter starts off with history, followed by the simplified equation and the starch test. Practical activities testing the requirements of photosynthesis precede the description of the more detailed process.

The respiration chapter starts off with the uses of energy, followed by aerobic and anaerobic respiration. Aerobic and anaerobic respiration are then compared.

Learners might memorise the facts, but the practical activities and the logical sequence of the content might contribute to the learners' understanding.

Criterion 8: How does the Grade 11 textbook content provide the learners with an understanding of how these topics fit into the larger environment, and the importance thereof?

Understanding Life Sciences Grade 11 does indicate how the topics of photosynthesis and respiration fit into the larger environment. The biological importance of photosynthesis is listed; here the fact that carbon dioxide levels are controlled by photosynthesis links to global warming. The textbook mentions that carbon dioxide is released into the atmosphere by plant and animal respiration, burning of fuels and decay processes. It is further mentioned that if the carbon dioxide levels keep on rising it will be harmful for living organisms; the process of photosynthesis ensures that the carbon dioxide levels are controlled. It is also mentioned that photosynthesis releases oxygen, which is used by plants and animals to release energy during respiration. In the section on anaerobic respiration the commercial value thereof is given (biotechnology). This textbook also includes an activity that deals with respiration and sport.

Criterion 9: How does the Grade 11 textbook trigger the teacher to address preconceived ideas (misconceptions) on the topic?

Misconceptions might be dealt with by the teacher during the practical activities as set out in Understanding Life Sciences Grade 11, but whether this opportunity will be used will depend on the teacher. The textbook does not support the teacher to address misconceptions.

Criterion 10: How does the content in the Grade 11 textbook address the misconceptions held by learners?

When looking at the misconceptions as listed in Table 3 in Appendix B, Understanding Life Sciences Grade 11 gives the correct facts; however, the textbook does not address misconceptions directly. One misconception is that photosynthesis and respiration are considered opposite reactions / processes; even though the textbook mentions that photosynthesis and respiration are regarded as opposite reactions, it includes an activity in which the answers of the activity might help learners understand where the requirements / reactants come from and what happens to the products that form; they will see that even if, by looking at the chemical equations, it seems as if the processes are opposite, this is not the case. Another activity in this textbook allows learners to think about what contributes to the growth of a plant, and here learners will see that it is not only water that contributes to growth. Even though the correct facts are given, this might not be sufficient to correct any misconceptions that learners might have.

Criterion 11: How does the content of the Grade 11 textbook enable the teacher to demonstrate skills or use the knowledge?

The teacher can demonstrate knowledge and skills during the practical activities in Understanding Life Sciences Grade 11, but only if he or she is competent or so inclined.

Criterion 12: How do the activities, experiments and diagrams (in the Grade 11 textbook) contribute to the learners' understanding of the topics?

The activities, experiments and diagrams within Understanding Life Sciences Grade 11 will contribute to the learners' understanding of the topics of photosynthesis and respiration. The practical activities in both the photosynthesis and respiration chapters might help learners to better understand the concepts. The textbook contains figures which might contribute to the learners' understanding; for example, the textbook has a figure explaining the process of photosynthesis and another that shows the flow of matter between the chloroplast and mitochondria.

Criterion 13: Is pre-requisite knowledge required to understand the Grade 11 textbook content?

Pre-requisite knowledge is needed to understand the content in Understanding Life Sciences Grade 11. Understanding Life Sciences Grade 10 lays down the foundation needed; however, the Grade 11 textbook does not make explicit mention of the content in Grade 10.

4.6.2. Textbook series 2: Study and Master Life Sciences

Criterion 1: How does the Grade 10 textbook lay down the foundation needed in Grade 11? Mention chloroplast and mitochondria. Mention structure and function. Detail of gases (oxygen and carbon dioxide).

Both the mitochondria and chloroplasts are mentioned in the Grade 10 Study and Master Life Sciences textbook (Gebhardt et al., 2012a), hereafter only referred to as Study and Master Grade 10. It is mentioned that the mitochondria occur in both plants and animals and that the mitochondria are the site for respiration. The textbook mentions that plastids, which include chloroplasts, are only found in plants and that chloroplasts are the site for photosynthesis and contains chlorophyll, which absorbs sunlight. At the 'function of chloroplasts' section within this textbook, a brief description of the process of photosynthesis is given; here the textbook mentions that light energy is converted to chemical potential energy, drawing the attention of the learner to different forms of energy that flow through organisms. In this section it is also mentioned that carbon dioxide is used during the process of photosynthesis and that oxygen is released; it is further mentioned that photosynthesis maintains the carbon dioxide and oxygen balance. A micrograph and drawing of the mitochondria show the structure thereof. The structure of the chloroplast is listed, along with a micrograph and drawing. The functions of both the chloroplasts and mitochondria are given. Study and Master Grade 10 mentions that the intercellular spaces between the parenchyma tissue allow gas exchange and that these gases are available for photosynthesis and respiration, making it explicit that plants respire. The textbook further mentions that the different tissues of the leaf are structurally adapted and function together to allow photosynthesis; there is, however, no mention of the tissues being adapted for respiration. The structural adaptations of the leaf for photosynthesis are listed. The functions of the different leaf tissues are also given, for example, the palisade mesophyll's arrangement and structure allows maximum absorption of sunlight for photosynthesis. In the section on the oxygen cycle, it is mentioned that photosynthesis is the main driver of this cycle. It is mentioned that photosynthesis is the main source of oxygen, and that respiration removes oxygen from the atmosphere (but not from oxygen-rich tissue that accumulated oxygen from photosynthesis). It is further mentioned that carbon dioxide is used during photosynthesis and that carbon dioxide is returned to the atmosphere through respiration. It might be possible that the focus on photosynthesis in plants and the lack of focus on respiration contributes to the idea that photosynthesis occurs in plants and respiration in

animals. In the section on nutrient cycles in Study and Master Grade 10, a figure shows the recycling in an ecosystem between producers, consumers, decomposers and the soil. There is, however, no explicit mention of the flow of matter from plants to animals and that animals depend on the carbon-based molecules that plants produce. In the section on energy flow, food chains, webs and pyramids are discussed.

Criterion 2: How are photosynthesis and respiration covered in the Grade 11 textbook? (In the same chapter or in different chapters?) To what extent does the chapter on photosynthesis refer to respiration? To what extent does the chapter on respiration refer to photosynthesis?

Photosynthesis is discussed in Unit 1 of the Study and Master Life Sciences Grade 11 textbook (Gebhardt et al., 2012b), hereafter only referred to as Study and Master Grade 11, and respiration is discussed in Unit 3; these two topics are thus separated from each other. The chapter on photosynthesis refers to respiration twice: once where the two metabolic pathways are listed and a second time where it is stated that the oxygen from photosynthesis is available for respiration and the carbon dioxide produced during respiration can be used in photosynthesis; here a link between photosynthesis and respiration is made. The chapter on respiration, however, does not mention photosynthesis; the links between photosynthesis and respiration, or the products of photosynthesis that are used in respiration are thus not mentioned explicitly in this chapter.

Criterion 3: How does the Grade 11 textbook refer to the structure of plant organs in relation to gas exchange of photosynthesis and respiration? How does the Grade 11 content link to the Grade 10 textbook where structures are discussed?

Study and Master Grade 11 refers to the structure of plant organs but does not explicitly refer to the structure in relation to gas exchange linked to photosynthesis and respiration. The textbook refers to the structure of the chloroplasts with no mention of gases, however, when giving the function of the chloroplasts it is mentioned that energy from light is trapped and that carbon dioxide and water is converted into chemical potential energy (here the gas carbon dioxide is mentioned). Three activities within the photosynthesis and respiration chapters in Study and Master Grade 11 require learners to explain ways in which the leaf, chloroplasts and spongy mesophyll are adapted for photosynthesis and also how the mitochondria are suited for their function. Here learners can refer to the structure of the plant organ / organelles in relation to the gas exchange linked to photosynthesis and respiration.

The Grade 11 content, where structure is discussed, in Study and Master Grade 11 links to that of Study and Master Grade 10. The structure of the chloroplast links to the discussion of the cell organelles in Grade 10. The structure of the leaf and the structural adaptations thereof link to the leaf and adaptations for photosynthesis as discussed in Study and Master Grade 10. Study and Master Grade 11 also refers to the structure of the mitochondrion and refers to the mitochondrion as the “powerhouse” which was also learnt in Grade 10.

Criterion 4: How does the Grade 11 textbook cover interrelated topics of photosynthesis and respiration for the learners to make the connections between these topics? (Refer to sub criteria 4.1–4.11 in Table 2 in Appendix A.)

The content as stated in criterion 4, in the table in Appendix A, is mostly covered by Study and Master Grade 11. The criteria were set based on what learners need to know about photosynthesis and respiration; Brown & Schwartz (2009), Raven et al. (2014) and Reece et al. (2011) were used to set the criteria. Study and Master Grade 11 states that the oxygen from photosynthesis is available for respiration and that the carbon dioxide from respiration is used in photosynthesis; there is, however, no mention of the cycling of matter and energy between the chloroplasts and mitochondria, and water and glucose are also not mentioned. The textbook mentions that water is split into hydrogen ions and oxygen gas during photosynthesis. It is further mentioned that hydrogen atoms combine with oxygen to form water during respiration (oxidative phosphorylation). The textbook mentions that glucose is broken down in the presence of oxygen during respiration; however, there is no mention that the glucose and oxygen comes from photosynthesis and is used by the mitochondria for cellular respiration. The textbook states that glucose is broken down (during respiration) to pyruvic acid during glycolysis and that the pyruvic acid enters Kreb’s cycle to release energised hydrogen atoms and carbon dioxide. A figure in the respiration chapter shows that alcohol and carbon dioxide are released during anaerobic respiration in plants. The textbook states that the carbon dioxide produced during respiration is used in photosynthesis. It is mentioned that chemical potential energy is found in glucose and that glucose is broken down during respiration and the energy captured in ATP molecules. There is, however, no direct mention of the chemical potential energy being used in respiration. It is mentioned that ATP is an energy carrier and provides energy for energy-consuming activities. Carbon dioxide and water are shown to be reactants for photosynthesis and products of respiration; it is stated that the carbon dioxide produced during respiration is used in photosynthesis, but there is no explicit mention that water from respiration is used in photosynthesis. The textbook mentions that the light-dependent phase of photosynthesis occurs only in the presence of light and that respiration take place in the presence of oxygen. The learners might thus make the connection

that photosynthesis and respiration occur simultaneously in light; this is, however, not explicitly stated. The textbook also does not mention that respiration occurs continuously, day and night.

Criterion 5: Does the Grade 11 textbook include the concepts / standards as set by the AAAS, ASPB and NGSS? (Refer to the concepts / standards as listed (5.1–5.14) in Table 2 in Appendix A.)

The concepts / standards as listed in criterion number 5 in Table 2 in Appendix A, were set up based on standards set by the AAAS, ASPB and NGSS. Study and Master Grade 11 does not explicitly state that water, inorganic elements, and light are needed by plants; however, by looking at the requirements listed for photosynthesis, learners might conclude that water and light are needed. The textbook does not explicitly mention that materials can be recycled and reused, but does, however, mention that the oxygen from photosynthesis is available for respiration and the carbon dioxide from respiration is used in photosynthesis. This textbook states that life depends on photosynthesis, because energy (and nutrients) are obtained from green plants (directly or indirectly). It is further mentioned that light energy is captured and converted into chemical potential energy. It is also mentioned that ATP is synthesised during photosynthesis and released during glycolysis of respiration. In the chapter on photosynthesis the equation shows that carbon dioxide, water and light energy serve as reactants / requirements of photosynthesis. Study and Master Grade 11 mentions that energy can be transformed from one form into another. It is further mentioned that light energy trapped by the chlorophyll is converted to chemical potential energy during photosynthesis. The textbook also mentions that work involves changing potential energy into kinetic energy and that energy is available to the cell by means of respiration. The textbook does not explicitly state that the continuous input of sunlight keeps the flow of energy in a food web going; it is, however, stated that organisms at the higher trophic levels obtain their energy from stored organic compounds in plants (directly or indirectly). It is further mentioned that a constant flow of energy is needed for survival. The textbook lacks an explanation of the flow of energy between the chloroplasts and mitochondria; however, it is mentioned that one form of energy is transformed into another, and that some energy is lost as heat. The textbook mentions that a constant level of oxygen and carbon dioxide is maintained by photosynthesis. Study and Master Grade 11 does not mention the production of other carbon-based molecules from the hydrocarbon backbones; however, the chemical formula shows that glucose contain carbon, hydrogen, and oxygen. There is no mention that animals depend on the carbon-based molecules that plants produce and that they access this through feeding. The flow of matter from plants to animals to supply animals with molecules for respiration is thus not described. The only reference made to the flow of matter and energy is the mention that the oxygen from photosynthesis is

used in respiration and that the carbon dioxide from respiration is used in photosynthesis. The textbook does not mention that the energy from photosynthesis and respiration is needed for growth and reproduction; however, it is mentioned that organisms perform activities that require energy, and that this energy is made available by means of respiration. The chapter on respiration discuss the process in terms of glycolysis, Kreb's cycle and oxidative phosphorylation, and here learners can conclude that bonds are broken, and new compounds are formed that transport energy. There is no mention of the fact that photosynthesis and respiration are an important part of the carbon cycle. The textbook does not mention that plants play a role in the cycling of nutrients, but it is mentioned that oxygen is a product of photosynthesis and the textbook states explicitly that respiration occurs in both plants and animals.

Criterion 6: How does the Grade 11 textbook stimulate research on the subject?

Study and Master Grade 11 contains practical activities for both photosynthesis and respiration, and these practical activities might lead to research on these topics. The practical activities in the respiration chapter, however, include a practical with germinating seeds and another with small animals. The textbook also includes an activity where the learners must design their own investigation.

Criterion 7: Is the purpose of the Grade 11 learning material constructed in a logical sequence to empower the learners as opposed to merely providing a lot of information? (understanding as opposed to memorising)

The unit on photosynthesis begins with the concept of energy, followed by the equation and the starch test. The practical activities testing the requirements and products precede the process and importance of photosynthesis. Thereafter the factors affecting the rate of photosynthesis are discussed. The unit ends with the role of ATP.

The respiration unit begins with the need for energy, followed by the equation and a discussion of aerobic and anaerobic respiration. The unit ends with a comparison between aerobic and anaerobic respiration.

Learners might memorise the facts, but the practical activities and the logical sequence of the content might contribute to the learners' understanding.

Criterion 8: How does the Grade 11 textbook content provide the learners with an understanding of how these topics fit into the larger environment, and the importance thereof?

Study and Master Grade 11 provides an understanding of how the topics of photosynthesis and respiration fit into the larger environment. The textbook mentions that photosynthesis is a source of energy within food chains. An activity also looks at the role of algae as food. The important role that photosynthesis plays in the composition of air is linked to global warming. The textbook mentions that photosynthesis plays an important role in maintaining oxygen and carbon dioxide levels. It is further mentioned that the oxygen from photosynthesis is available for respiration and the carbon dioxide from respiration and combustion of fuels is used in photosynthesis, which prevent carbon dioxide levels from rising too high. The textbook includes activities that require learners to explain how farmers can increase the crop yield in greenhouses, and also states ways in which farmers can enrich the air inside the greenhouse. In the chapter on respiration, alcoholic fermentation and exercise are discussed, as well as the role of anaerobic respiration in the industry.

Criterion 9: How does the Grade 11 textbook trigger the teacher to address preconceived ideas (misconceptions) on the topic?

Any misconceptions held by learners can perhaps be addressed by the teacher during the practical activities in Study and Master Grade 11, but whether this opportunity will be used will depend on the teacher. The textbook does not further support the teacher to address misconceptions.

Criterion 10: How does the content in the Grade 11 textbook address the misconceptions held by learners?

Learners might have misconceptions, as listed in Table 3 in Appendix B. Study and Master Grade 11 gives the correct facts; however, this textbook does not directly address misconceptions held by the learners. The textbook states that photosynthesis occurs in the green parts of a plant, mainly the leaf, which corrects the misconception that photosynthesis take place only in the leaves. The textbook could perhaps mention that photosynthesis occurs in the green parts of the plant and respiration occurs in all living parts. The textbook also states that respiration occurs in all plants and animal cells, except the erythrocytes; this corrects the misconception that plants do not have cellular respiration. The activities in the respiration chapter will lead to learners concluding that oxygen and glucose are needed for respiration and that carbon dioxide is released. This corrects the misconception that carbon dioxide is used in respiration and that glucose is the only reactant for respiration. It is important to note that the facts alone will not correct the misconceptions that learners might have regarding photosynthesis and respiration, and that misconceptions should ideally be addressed through a careful process of conceptual change (Posner et al., 1982), preferably by a skilled teacher.

Criterion 11: How does the content of the Grade 11 textbook enable the teacher to demonstrate skills or use the knowledge?

The practical activities found in Study and Master Grade 11 can enable teachers to demonstrate skills and use knowledge, but only if the teacher is competent or so inclined.

Criterion 12: How do the activities, experiments and diagrams (in the Grade 11 textbook) contribute to the learners' understanding of the topics?

Study and Master Grade 11 contains figures, activities and experiments that will contribute to the learners' understanding. The practical activities in both the photosynthesis and respiration chapters might help learners to better understand the topics. The textbook includes a micrograph for the chloroplasts and the mitochondria, which might help the learners better understand the structure thereof. Other figures, for example, are graphs that show the influence of carbon dioxide, temperature, and light intensity on the rate of photosynthesis.

Criterion 13: Is pre-requisite knowledge required to understand the Grade 11 textbook content?

Pre-requisite knowledge is needed to understand the content in Study and Master Grade 11. Study and Master Grade 10 lays down the foundation needed.

4.6.3. Textbook series 3: Solutions for all

Criterion 1: How does the Grade 10 textbook lay down the foundation needed in Grade 11? Mention chloroplast and mitochondria. Mention structure and function. Detail of gases (oxygen and carbon dioxide).

The Solutions for all Life Sciences is not available in a Grade 10 textbook. This criterion is thus not applicable to the Solutions for all series.

Criterion 2: How are photosynthesis and respiration covered in the Grade 11 textbook? (In the same chapter or in different chapters?) To what extent does the chapter on photosynthesis refer to respiration? To what extent does the chapter on respiration refer to photosynthesis?

Within the Solutions for all Life Sciences Grade 11 textbook (McKay et al., 2012a), hereafter only referred to as Solutions for all Grade 11, photosynthesis is discussed in Topic 4 and respiration is discussed in Topic 6; these two concepts are thus separated from each other. The chapter on photosynthesis refers to respiration a few times. It is mentioned in this chapter

that the glucose molecule (from photosynthesis) is used in respiration and that the energy in the glucose molecule is transferred to ATP molecules. This information implies that flow of matter and energy occurs. It is further mentioned that oxygen (released during photosynthesis) is needed for respiration. The chapter on respiration refers once to photosynthesis, where it is mentioned that plants convert energy from the sun into chemical energy (in the glucose molecule) during photosynthesis. It is also mentioned here that photosynthesis is anabolic compared to respiration, which is catabolic.

Criterion 3: How does the Grade 11 textbook refer to the structure of plant organs in relation to gas exchange of photosynthesis and respiration? How does the Grade 11 content link to the Grade 10 textbook where structures are discussed?

Solutions for all Grade 11 refers to the structure of plant organs, however there is limited mention of gas exchange in photosynthesis or respiration. The leaf as the main photosynthetic organ, with its adaptations, are discussed, but there is no explicit mention of gas exchange. In this textbook, learners need to complete a table by matching the adaptation of the leaf to the reason for the adaptation, for example the large air spaces between the cells of the spongy mesophyll allow for gaseous exchange. It is further mentioned that the spaces between the spongy mesophyll allow for the diffusion of carbon dioxide. The structure of the chloroplast is given, with no reference to gases. The textbook also mentions that the mitochondria are adapted for respiration and learners must list the adaptations; here learners might mention that the double membrane of the mitochondria is permeable and allows for the movement of substances (gases) in and out of the mitochondria.

The content of Solutions for all Grade 11 cannot be compared to that of a Grade 10 textbook, as the Solutions for all Life Sciences is not available in Grade 10. However, when comparing the Grade 11 content to that what is stated in the CAPS document (DBE, 2011) (as seen in Table 1 above) for Grade 10, one can see that the content in Solutions for all Grade 11 does link to the Grade 10 content as set out in the CAPS document (DBE, 2011). Solutions for all Grade 11 refers to the structure and adaptations of the leaf, as well as the structure of the chloroplasts and mitochondria, which links to what is discussed in Grade 10.

Criterion 4: How does the Grade 11 textbook cover interrelated topics of photosynthesis and respiration for the learners to make the connections between these topics? (Refer to sub criteria 4.1–4.11 in Table 2 in Appendix A.)

Solutions for all Grade 11 covers most of the content as stated in criterion 4 in the table in Appendix A. The criteria were set based on what learners need to know about photosynthesis

and respiration; Brown & Schwartz (2009), Raven et al. (2014) and Reece et al. (2011) were used to set the criteria. Solutions for all Grade 11 mentions that the glucose made by photosynthesis may be transported to other parts of the plant and that glucose is used by the cells of the plant for respiration. The textbook explicitly mentions that both plants and animals respire. It is further mentioned that carbon dioxide comes from the air and water from the soil; it is not mentioned that the carbon dioxide and water is produced during respiration and is available for photosynthesis. The textbook does mention that glucose is produced during photosynthesis and is used in respiration. It is also mentioned that oxygen is a product of photosynthesis, but there is no mention that the oxygen from photosynthesis can be used in respiration. It is mentioned that oxygen and glucose are needed for respiration and that carbon dioxide and water are products of respiration. The textbook, however, does not directly mention the cycling of matter between chloroplasts and mitochondria. The textbook mentions that the energy in the glucose molecule can be transferred to an ATP molecule during respiration. It is stated that water is split into oxygen and energy-rich hydrogen atoms during photosynthesis and that oxygen is given off as gas. The textbook further states that during respiration the hydrogen atoms combine with oxygen to form water (oxidative phosphorylation). It is mentioned that glucose (from photosynthesis) is used for respiration; however, there is no mention of the mitochondria. It is further mentioned that the glucose is broken down to pyruvic acid, and the pyruvic acid is further broken down during Kreb's cycle to release energy-rich hydrogen and carbon dioxide. The textbook mentions that during anaerobic respiration in plants, carbon dioxide is released. It is stated in the textbook that carbon dioxide is taken up from the air during photosynthesis and that carbon dioxide is released as a gas during respiration; there is, however, no direct mention of the carbon dioxide from respiration being used in photosynthesis. Glucose is referred to as an energy-rich molecule that is used in respiration, and it is further mentioned that the energy in the glucose molecule is transferred to the energy-rich ATP molecule during respiration. The textbook states that light energy is converted to chemical energy in glucose molecules by photosynthesis and this chemical energy is transferred to energy-rich ATP molecules during cellular respiration, thus describing the energy flows between processes. The textbook does state that light energy is used to make ATP during the light phase of photosynthesis and that this ATP is used in the dark phase of photosynthesis to produce glucose. The textbook further states that the ATP produced through respiration is used for various life processes, as ATP provides energy to the cells. It is not mentioned in the textbook that carbon dioxide and water produced during respiration can be used in photosynthesis, but only mentions that carbon dioxide and water are reactants of photosynthesis and products of respiration. The textbook mentions that the light phase of photosynthesis depends on light and that respiration (aerobic respiration) requires oxygen; the learners might make the connection that photosynthesis and

respiration occur simultaneously in light; however, they might not. The textbook does not mention that respiration occurs continuously, day and night.

Criterion 5: Does the Grade 11 textbook include the concepts / standards as set by the AAAS, ASPB and NGSS? (Refer to the concepts / standards as listed (5.1–5.14) in Table 2 in Appendix A.)

The concepts / standards as listed in criterion number 5 in Table 2 in Appendix A were set up based on standards set by the AAAS, ASPB and NGSS. Solutions for all Grade 11 lists water and sunlight as requirements for photosynthesis, but the textbook does not explicitly state that plants need water, inorganic elements, and light. The textbook does not explicitly state that material can be recycled and reused; however, it does state that the glucose from photosynthesis is used in respiration and that the chemical energy in the glucose molecule is transferred to the ATP molecule during respiration. The textbook states that during photosynthesis the energy from the sun is used to make glucose, which can be stored as starch. It is further stated that the energy in the glucose is transferred to ATP during respiration. It is also mentioned that glucose is the basic energy source for organisms and that glucose is used in respiration, which releases energy to sustain life (ATP provides energy to all living cells); this energy is used for various life processes. In the chapter on photosynthesis, the equation shows that light energy, carbon dioxide and water are requirements / reactants. Solutions for all Grade 11 states that light energy is used to produce glucose, which is an energy-rich molecule; the energy in the glucose is transferred to ATP during respiration. The textbook further mentions that the light energy is converted to chemical energy in glucose by means of photosynthesis and that it is the chemical energy that is transferred to the ATP molecules during respiration. The textbook does not explicitly state that the continuous input of sunlight keeps the flow of energy in a food web going; however, it is stated that glucose (produced during photosynthesis) is the basic energy source. The textbook lacks an explanation of energy flow between the mitochondria and chloroplasts. It does, however, mention that the energy in glucose (chemical energy) is transferred to ATP during respiration. It is mentioned in the textbook that oxygen is added to the atmosphere and that carbon dioxide is removed from the atmosphere by plants during the day. The production of other carbon-based molecules from hydrocarbon backbones is not mentioned in this textbook; however, the chemical formula shows that glucose contains carbon, hydrogen, and oxygen; furthermore, in an activity the learners are asked where the carbon, hydrogen, and oxygen atoms, that form part of glucose, end up at the end of respiration. The textbook, however, does not mention that animals depend on the carbon-based molecules that plants produce. The flow of matter from plants to animals for respiration is not described. This textbook does not make any

reference to the flow of matter and energy; however, it is stated that glucose is used in respiration and that the energy from the glucose is transferred to ATP. It is stated in the textbook that the energy from the ATP molecules (from respiration) is available for life processes, such as growth and movement. In the respiration chapter, respiration is discussed in terms of glycolysis, Kreb's cycle and oxidative phosphorylation; learners could deduce from this that bonds break and new compounds form. The textbook does not mention that photosynthesis and respiration are important parts of the carbon cycle. No reference is made to the role plants play in the cycling of nutrients; however, the textbook does mention that oxygen is added to the atmosphere.

Criterion 6: How does the Grade 11 textbook stimulate research on the subject?

Solutions for all Grade 11 has practical activities in both the photosynthesis and respiration chapters, which might trigger the learners' interest and lead to research on these topics. Germinating seeds and insects (small animals) are used in the practical activities in the respiration chapter; no other plants are included. The textbook also includes the history of photosynthesis and an enrichment activity.

Criterion 7: Is the purpose of the Grade 11 learning material constructed in a logical sequence to empower the learners as opposed to merely providing a lot of information? (understanding as opposed to memorising)

The topic of photosynthesis begins with a section on what the learners should already know, which is followed by an overview of photosynthesis. A detailed description of photosynthesis follows, as well as the history of the discovery of photosynthesis. The investigations (practical activities) precede the discussion of the importance of photosynthesis, factors affecting the rate of photosynthesis and improving crop yields. The section on photosynthesis ends with the role of ATP.

The topic of cellular respiration starts off with what the learners should already know. Aerobic respiration is then discussed, followed by the practical activities. Anaerobic respiration is then discussed, followed by a comparison between aerobic and anaerobic respiration.

Learners might memorise the facts, but the practical activities and the logical sequence of the content might contribute to the learners' understanding.

Criterion 8: How does the Grade 11 textbook content provide the learners with an understanding of how these topics fits into the larger environment, and the importance thereof?

Solutions for all Grade 11 provides learners with the understanding of how photosynthesis and respiration fits into the larger environment. The textbook lists the importance of photosynthesis, where the carbon dioxide levels link to global warming. It is mentioned that plants and animals need oxygen for respiration and that oxygen is released into the atmosphere by photosynthesising plants. It is further mentioned that carbon dioxide is given off during respiration. It is mentioned that plants release carbon dioxide at night and animals release carbon dioxide continually, but that the carbon dioxide in the atmosphere is kept constant as it is removed by photosynthesis during the day. Factors influencing the rate of photosynthesis, which is important when growing crops to provide food to people, are discussed. In the respiration chapter anaerobic respiration in humans (exercising) is discussed. The role of anaerobic respiration in industry is also discussed.

Criterion 9: How does the Grade 11 textbook trigger the teacher to address preconceived ideas (misconceptions) on the topic?

The practical activities within Solutions for all Grade 11 are available for the teacher to address misconceptions, but whether this opportunity will be used will depend on the teacher. The textbook, however, does not support the teacher to address misconceptions.

Criterion 10: How does the content in the Grade 11 textbook address the misconceptions held by learners?

The misconceptions as listed in Table 3 in Appendix B and other misconceptions might be held by learners. Solutions for all Grade 11 gives the correct facts regarding photosynthesis and respiration; however, the textbook does not address misconceptions directly. The textbook mentions that the energy from sunlight is used to make food and release oxygen during photosynthesis, in contrast to the misconception that sunlight is converted to food during photosynthesis. The textbook states that respiration occurs in both plants and animals, which corrects the misconception that plants do not have cellular respiration. The textbook also mentions that carbon dioxide is released during respiration, in contrast to the misconception that carbon dioxide is used during respiration. It is important to note that although the textbook gives the correct facts, this is not sufficient to correct the misconceptions that learners might have, and that misconceptions should ideally be addressed through a careful process of conceptual change (Posner et al., 1982), preferably by a skilled teacher.

Criterion 11: How does the content of the Grade 11 textbook enable the teacher to demonstrate skills or use the knowledge?

The teacher can demonstrate skills and knowledge when explaining or completing the practical activities in Solutions for all Grade 11, but only if the teacher is competent or so inclined.

Criterion 12: How do the activities, experiments and diagrams (in the Grade 11 textbook) contribute to the learners' understanding of the topics?

The experiments, activities and figures in Solutions for all Grade 11 should help learners to have a better understanding of the topics of photosynthesis and respiration. The figures in this textbook, for example, show the structure of the leaf, and the structure of the chloroplasts and mitochondria. Other figures in the textbook show the light and dark phases of photosynthesis and the formation and breakdown of ATP. Graphs showing the influence of light intensity, carbon dioxide and temperature on photosynthesis are also included. This textbook includes a table with a comparison between aerobic and anaerobic respiration.

Criterion 13: Is pre-requisite knowledge required to understand the Grade 11 textbook content?

The solutions for all Life Sciences is not available in a Grade 10 textbook. This criterion is thus not applicable to the solutions for all series.

4.6.4. General findings in all three textbook series

Criterion 1: How do the Grade 10 textbooks lay down the foundation needed in Grade 11? Mention chloroplast and mitochondria. Mention structure and function. Detail of gases (oxygen and carbon dioxide).

Both Understanding Life Sciences Grade 10 and Study and Master Grade 10 lay down a good foundation for photosynthesis and respiration. A good link is made between the structure of the leaf and the function of photosynthesis and respiration. The content, of both Understanding Life Sciences Grade 10 and Study and Master Grade 10, aligns with what is stated in the CAPS document (DBE, 2011), as seen in Table 1 above. The flow of matter and energy in both Understanding Life Sciences Grade 10 and Study and Master Grade 10 is mentioned; however, there is no explicit mention of the flow between plants and animals and that the plants supply the molecules needed by animals for respiration.

Criterion 2: How are photosynthesis and respiration covered in the Grade 11 textbooks? (In the same chapter or in different chapters?) To what extent does the chapter on photosynthesis refer to respiration? To what extent does the chapter on respiration refer to photosynthesis?

Photosynthesis and respiration are covered under the same strand (Strand two: Life processes in plants and animals); however, they are discussed as two separate topics / units within all three of the Grade 11 textbooks. In both Understanding Life Sciences Grade 11 and Solutions for all Grade 11 the photosynthesis chapter refers to the respiration chapter and vice versa. In Study and Master Grade 11 only the chapter on photosynthesis refers to respiration.

Criterion 3: How do the Grade 11 textbooks refer to the structure of plant organs in relation to gas exchange of photosynthesis and respiration? How does the Grade 11 content link to the Grade 10 textbooks where structures are discussed?

When looking at all three textbook series, it is evident that the Grade 11 textbooks refer to the structure of plant organs and to an extent refer to these organs in relation to gas exchange in photosynthesis and respiration. Understanding Life Sciences Grade 11 and Study and Master Grade 11 link to the Grade 10 content where structures are discussed. The Solutions for all Grade 11 content link to the Grade 10 content as stated in the CAPS document, however, no conclusion can be made about the Solutions for all Grade 10 textbook, as this textbook is not available. The structure of the leaf, chloroplasts and mitochondria are all mentioned in both the Grade 10 and Grade 11 textbooks that were analysed.

Criterion 4: How do the Grade 11 textbooks cover interrelated topics of photosynthesis and respiration for the learners to make the connections between these topics? (Refer to sub criteria 4.1–4.11 in Table 2 in Appendix A.)

Most of the content, as stated in criterion 4 in Table 2 in Appendix A, is covered by the textbooks; however, the textbooks could make the relationship between photosynthesis and respiration clearer. The learners can make use of the content to make the connections, but it might be beneficial if the textbooks made the connections between photosynthesis and respiration explicit. Understanding Life Sciences Grade 11 includes a sketch showing the cycling of matter between the chloroplasts and mitochondria, but this is not explicitly mentioned in the text.

The discussion of the light and dark phases of photosynthesis within Understanding Life Sciences Grade 11 and Study and Master Grade 11 might lead to a misconception that the dark phase occurs at night. It is important that the textbooks, like Solutions for all Grade 11, state that the dark phase relies on the products of the light phase and that the dark phase occurs during the day, as long as the light phase produces ATP and hydrogen atoms; the dark phase does not occur at night because the light phase cannot occur at night.

Solutions for all Grade 11 mentions that oxygen is obtained through breathing, which links to the fact that animals are mostly used as examples when explaining topics such as respiration. None of the textbooks mentions that oxygen is obtained through gas exchange in plants. This could contribute to the development of the misconception that only animals respire. The textbook does not mention the fact that oxygen from photosynthesis can be used in respiration.

Criterion 5: Do the Grade 11 textbooks include the concepts / standards as set by the AAAS, ASPB and NGSS? (Refer to the concepts / standards as listed (5.1–5.14) in Table 2 in Appendix A.)

The concepts / standards as listed in criterion number 5 in Table 2 in Appendix A were set up based on standards set by the AAAS, ASPB and NGSS. Some of these concepts are not explicitly mentioned in the textbooks, but could have been covered in other grades, for example, the concept that states that plants need water, other inorganic elements, and light. All three textbooks could make the cycling of matter and energy clearer. The role that photosynthesis and respiration play in the carbon cycle, and even the oxygen cycle, is absent in all three textbooks. All three textbooks also lack a description of the flow of matter from plants to animals. It is not mentioned that animals depend on the carbon-based molecules produced by plants.

Criterion 6: How do the Grade 11 textbooks stimulate research on the subject?

All three Grade 11 textbooks include practical activities on photosynthesis and respiration. These activities might lead to research on the topics of photosynthesis and respiration. Understanding Life Sciences Grade 11 and Solutions for all Grade 11 includes a section on the history of photosynthesis, which might trigger the learners' interest to do further research. Study and Master Grade 11 has an activity in which learners must design their own investigation, which might also lead to research on the topic.

Criterion 7: Is the purpose of the Grade 11 learning material constructed in a logical sequence to empower the learners as opposed to just providing a lot of information? (understanding as opposed to memorising)

In all three Grade 11 textbooks the material is constructed logically to help learners understand; however, the two related topics (photosynthesis and respiration) are separated into different chapters and links between the two processes are not always made clear.

Criterion 8: How does the Grade 11 textbook content provide the learners with an understanding of how these topics fit into the larger environment, and the importance thereof?

An understanding of how photosynthesis and respiration fit into the larger environment, and the importance thereof is covered in all three Grade 11 textbooks. All three textbooks list the importance of photosynthesis, including the control of carbon dioxide levels; this links to global warming. The role of respiration in sports and exercise is mentioned in all three textbooks. Anaerobic respiration and the role it plays in industry (biotechnology) is discussed in all three textbooks. This is consistent with the requirements in the CAPS document (DBE, 2011). What is not covered by the textbooks is the importance of respiration in plants to the ecosystem.

Criterion 9: How do the Grade 11 textbooks trigger the teachers to address preconceived ideas (misconceptions) on the topic?

The practical activities within the Grade 11 textbooks might trigger teachers to address preconceived ideas (misconceptions) about photosynthesis and respiration, but whether this opportunity will be used will depend on the teacher. The textbooks do not support teachers to address misconceptions.

Criterion 10: How does the content in the Grade 11 textbooks address the misconceptions held by learners?

All three Grade 11 textbooks give the correct facts, which address the misconceptions as listed in Table 3 in Appendix B, as well as any other misconceptions that learners might have. This alone, however, is not enough to help learners correct the misconceptions that they might have. Misconceptions should ideally be addressed through a careful process of conceptual change (Posner et al., 1982), preferably by a skilled teacher. Conceptual change is learning that changes one's existing conception. The process of conceptual change results in a paradigm shift, changing one's prior thinking; however, conceptual change takes time (*Conceptual Change*, n.d.). The textbooks do not address misconceptions directly. It might be helpful if the processes of photosynthesis and respiration could be addressed more comprehensively. It is also important to mention here that even the teacher's guides do not give any guidance with regards to misconceptions and how to correct them (Gebhardt et al., 2012c; Isaac et al., 2012b; McKay et al., 2012b).

Criterion 11: How does the content of the Grade 11 textbooks enable the teachers to demonstrate skills or use the knowledge?

The practical activities in all three Grade 11 textbooks enable teachers to demonstrate skills and use knowledge, but whether this happens depends on the teacher.

Criterion 12: How do the activities, experiments and diagrams (in the Grade 11 textbooks) contribute to the learners' understanding of the topics?

The diagrams, experiments, and activities in the three Grade 11 textbooks will contribute to the learners' understanding of photosynthesis and respiration. All three textbooks include practical activities, which might help learners to better understand the topics. The figures in the textbooks all contribute to the knowledge about photosynthesis and respiration.

Criterion 13: Is pre-requisite knowledge required to understand the Grade 11 textbook content?

Pre-requisite knowledge is required to understand the content in the Grade 11 textbooks. The foundation laid down in Understanding Life Sciences Grade 10 and Study and Master Grade 10 is sufficient to understand the content in the Grade 11 textbooks.

4.7. Conclusion

It is evident that the content of the textbooks aligns with what is stated in the CAPS document (DBE, 2011). Most of the standards set by the AAAS, ASPB and NGSS are covered by the textbooks. Some of these concepts are not explicitly mentioned in the textbook but could have been covered in other grades. The textbooks explain the concepts of photosynthesis and respiration; however, the two topics are separated into different chapters or sections. The textbooks provide a basic description of each process. The processes are written in a formulaic way, assuming that there is a standard way of presenting the content. There appears to be an assumption that if the content is mentioned once, learners will learn. All three textbooks are written in a similar, standard way where the facts are given, but the bigger picture is not attended to. There is no overarching discussion that both energy and matter will flow through the system. This limits the way that learners can understand the relationship between organisms and the environment. The relationship between photosynthesis and respiration could be made more clearly within the textbooks. The textbooks also do not address misconceptions directly. As seen from the literature, teachers and learners rely heavily on textbooks and for this reason the textbooks should be more than just facts.

4.8. Chapter overview

The purpose of this chapter was to discuss the data analysis and present the research findings. In this chapter the data was summarised for each of the criteria as listed in Table 2

in Appendix A, and the general findings were given. The results of this study could highlight potential problems and challenges related to how textbooks relate the concepts of photosynthesis and respiration and could contribute to further research and the design of quality curriculum materials. In the next chapter (Chapter 5) the findings that emerged in this study will be discussed.

Chapter 5: Discussion

5.1. Introduction

The purpose of this study was to analyse Grade 10 and 11 Life Sciences textbooks to determine how the textbooks represent the relationship between concepts of photosynthesis and respiration. The textbooks were analysed to determine whether the content of photosynthesis and respiration presented within the textbooks is in accordance with the CAPS document (DBE, 2011) and how the content compares to the standards set by the AAAS, ASPB and NGSS. Common misconceptions regarding photosynthesis and respiration were identified and the textbooks were investigated for the extent to which these misconceptions are addressed in South African Life Sciences textbooks. During the textbook analysis, how plants were included in the general presentation of respiration, so that learners do not develop the misconception that plants photosynthesise, but do not respire, was also assessed.

This chapter will start out with a brief discussion of the conceptual framework followed by a discussion of the general findings that emerged from the collection and analysis of the data in relation to the main themes of the study. Other studies and available literature will be used in the discussion to interpret and compare the findings.

5.2. Conceptual framework

The conceptual framework for this study (Figure 3 in Chapter 2) has been developed from the literature, as there is no existing framework in the literature. The relationship between textbook content and learner knowledge and how this relationship influences the learners' understanding of interrelated concepts of photosynthesis and respiration is shown. During the textbook analysis, how the textbooks link the interrelated concepts of photosynthesis and respiration in terms of the flow of matter and energy, and between structure and function, was assessed. The textbook content thus influences the learners' knowledge, pre-conceptions or misconceptions.

5.3. Discussion of general findings in all three textbook series

5.3.1. Foundation laid down by the Grade 10 textbooks and the link made to the Grade 10 textbook where structures are discussed

This study found that the Grade 10 textbooks, Understanding Life Sciences Grade 10 and Study and Master Grade 10, lay down a good foundation for photosynthesis and respiration. The content in the Grade 10 textbook also aligns with what is stated in the CAPS document (DBE, 2011). The content as prescribed by the CAPS document can be seen in Table 1 in

Chapter 4. The link between photosynthesis and respiration is made explicit in the Understanding Life Sciences Grade 10 textbook in the sections where the carbon and oxygen cycles are discussed. It is important for a textbook to make the connections between topics explicit as it seems as if learners are not able to do so by themselves (Roseman et al., 2010).

The Study and Master Grade 10 textbook draws the learners' attention to different forms of energy that flow through organisms by mentioning that light energy is converted to chemical potential energy during the process of photosynthesis. The concept of the flow of energy and matter is important for learners to understand topics such as photosynthesis and respiration. Bergan-Roller et al. (2018) stated that learners find topics such as respiration difficult and that this might be due to the fact that learners do not understand topics such as matter and energy transformation and conservation. When ignoring the flow of matter and energy the learners can come to the conclusion that the interrelated topics, photosynthesis and respiration, are opposite reactions; this is not the case as these two processes combine to supply energy to organisms (Brown & Schwartz, 2009). It is thus important that the textbooks make the flow of matter and energy clear.

A satisfactory link is made between the structure of the leaf and the function of photosynthesis and respiration. Even though the function of the leaf and plant tissue in both photosynthesis and respiration is mentioned, it is important to mention here that the focus of the leaf and plant tissue in the Grade 10 textbooks and the function these have in photosynthesis might contribute to the idea that photosynthesis occurs in plants and respiration in animals. The misconception that plants photosynthesise and do not have cellular respiration was mentioned by several studies (Al khawaldeh & Al Olaimat, 2010; Amir & Tamir, 1990; Jayanti & Sri Rahayu, 2019; Keleş & Kefeli, 2010; Parker et al., 2012; Uno, 2009).

The structure of the chloroplasts and mitochondria is given in the Grade 11 textbooks, Understanding Life Sciences Grade 11, Study and Master Grade 11 and Solutions for all Grade 11, which links to the discussion of the cell organelles in the Grade 10 textbooks. The adaptation of the leaf for photosynthesis is also touched on in all three Grade 11 textbooks, which also links to the structure of the leaf discussed in the Grade 10 textbooks. Again this is in accordance with the CAPS document (DBE, 2011). It is important to mention here that the structure of the plant organs in relation to gas exchange in photosynthesis and respiration is only referred to, to a limited extent. There is a greater focus on the structure and function relationship in photosynthesis in plants, compared with respiration. It is important that the textbook makes the structure and function clear. An understanding of the structure is needed in order to understand the function (Michael, 2021); thus an understanding of the structure of

the leaf and of cell organelles is needed to understand the processes of photosynthesis and respiration.

5.3.2. How photosynthesis and respiration are covered in the Grade 11 textbooks (in the same or different chapters); the construction of the learning material and the link made between the interrelated topics of photosynthesis and respiration

It was found that in all three Grade 11 textbooks (Understanding Life Sciences Grade 11, Study and Master Grade 11 and Solutions for all Grade 11) the topics of photosynthesis and respiration form part of the same strand (Strand 2: Life processes in plants and animals), which is in accordance with the CAPS document (DBE, 2011). The two interrelated topics, however, are separated into two different units (sections or chapters). Learners will thus struggle to make the connections between the two interrelated topics unless a textbook refers to the link explicitly. In the textbooks studied, some links are made, but the links between the interrelated topics of photosynthesis and respiration could be made more explicitly. Abrie (2015), Stern and Roseman (2004) and Lin and Hu (2003) also found that textbooks often separate concepts which hinders learners from forming an interconnected understanding of related concepts.

Due to the complex nature of biology it is important to understand how the different concepts relate to one another (Lin & Hu, 2003). It is important that textbooks make the connections between related topics explicit, because, as mentioned previously, learners often cannot make the connections themselves (Roseman et al., 2010). Lin and Hu (2003) found that learners understood concepts when looking at them individually, but struggled to comprehend the inter-relationship between concepts. This might be due to the fact that textbooks separate the topics into different sections or chapters (Lin & Hu, 2003; Stern & Roseman, 2004) It is however worth mentioning that separate chapters will be acceptable if the interrelationships are explicitly described. In the South African context, the extent to which learners understand interrelationships between topics to form a holistic understanding of biological phenomena is unknown. It will be fruitful to study learner understanding in this context.

In this study it was found that there is limited mention of respiration in the photosynthesis chapters and limited mention of photosynthesis in the respiration chapters. An exception occurs where the cycling of matter between the chloroplasts and mitochondria is shown in the Understanding Life Sciences Grade 11 textbook, in the respiration chapter. In the Study and Master Grade 11 textbook the chapter on photosynthesis states that the oxygen from photosynthesis is available for respiration and the carbon dioxide produced during respiration can be used in photosynthesis; here the link between photosynthesis and respiration is made.

It is, however, important that this link is made more explicit throughout the textbooks, for example in the Study and Master Grade 11 textbook the chapter on respiration does not mention photosynthesis and thus the link between photosynthesis and respiration, or the products of photosynthesis that are used in respiration are not made explicit in this chapter. In the Solutions for all Grade 11 textbook the information given in the chapter on photosynthesis implies that flow of energy and matter occurs; however, again the link between photosynthesis and respiration should be made more explicit.

In all three Grade 11 textbooks the content is constructed in a logical manner and although a lot of facts are mentioned, only certain aspects are discussed briefly. As a result, learners may learn to study a lot of facts from the textbook but do not necessary understand where it all fits in. The textbook must empower learners, and not merely provide a lot of information. Learners need to understand the content and not just memorise the facts; the fact that the topics are separated into different chapters or sections makes it difficult for the learners to make the connections between the two topics. It is important to mention here that the textbooks provide a basic description of each process. All three Grade 11 textbooks describe the processes in a formulaic way, apparently assuming that there is a standard way of presenting the content. All three textbooks are written in a similar, standard way where facts are given, but the bigger picture of the flow of matter and energy and the relationship between organisms and the environment is not attended to.

The present study found that most of the content, as stated in criteria 4.1–4.11 in Table 2 in Appendix A, is covered by the Grade 11 textbooks. The facts are given within the textbooks; however, the textbooks do not make the connection between photosynthesis and respiration explicit. One can argue that the learners can use the content to make certain connections between photosynthesis and respiration; however, as previously mentioned learners struggle to make the connections if the textbooks do not do so explicitly (Roseman et al., 2010). For example, in the Solutions for all Grade 11 textbook it is mentioned that the light phase of photosynthesis depends on light and that respiration (aerobic respiration) requires oxygen; the learners might make the connection that oxygen is produced during the light phase and that respiration requires oxygen and thus both respiration and photosynthesis occur simultaneously in light. However, because the textbook does not state this explicitly the learners might not be able to come to this conclusion. It is noticeable that none of the Grade 11 textbooks mentioned that respiration occurs continuously day and night.

The Grade 11 textbooks do not consistently spell out the flow of matter and energy, and learners can thus form the view that molecules are grabbed from the air and that there is no flow of elements such as carbon. The Grade 11 textbooks do not make the statement that

animals depend on the carbon-based molecules that plants produce and that they access this through feeding. The flow of matter from plants to animals are not described and thus it is also not mentioned that matter flows from plants to animals in order to supply molecules for respiration in animals. In order to understand the relationship between topics such as photosynthesis and respiration, learners need to have an understanding of the flow of matter and energy. Wilson et al. (2006) found that learners will better understand topics, such as photosynthesis and respiration, if they are able to trace matter within and between biological systems. Barman et al. (2003) found that the process of photosynthesis and how energy is passed through the ecosystem is unclear to learners. Stern and Roseman (2004) also found that textbooks fail to make the connections between concepts and that the instructional material focuses on the process of photosynthesis and respiration, failing to include the idea that substances are transformed into other substances. The link between photosynthesis and respiration should be understood in terms of the flow of matter and energy, and learners should understand the importance of the processes in their daily lives. For this reason, it is important that textbooks make the link between related concepts clear.

5.3.3. The inclusion of the concepts / standards as set by the AAAS, ASPB and NGSS

The study found that most of the concepts / standards, as listed at criteria 5.1–5.14 in Table 2 in Appendix A, are covered by the textbooks. Some of the concepts are not explicitly mentioned in the textbooks but could have been dealt with in earlier grades. All three textbooks could make the cycling of matter and energy clearer, as well as the relationship between photosynthesis and respiration. According to the AAAS (2009a), the transfer of energy and matter links organisms to one another and the environment. The knowledge of this relationship between organisms and their environment is gained across grade levels. From Grades 9 to 12 it is mentioned that learners should be able to link the flow of energy and conservation of matter. They should understand that energy is stored in molecules produced during photosynthesis and released during oxidation (AAAS, 2009a). It is noticeable that the role that photosynthesis and respiration play in the carbon cycle, and even the oxygen cycle, is absent in all three textbooks.

5.3.4. The contribution of activities, experiments and diagrams to the learners' understanding of photosynthesis and respiration, learners' interest, and plant blindness

The study found that activities, experiments and diagrams within all three Grade 11 textbooks will contribute to the learners' understanding of photosynthesis and respiration. The practical activities, as well as diagrams and figures, in both the photosynthesis and respiration chapters

/ sections might trigger the learners' interest and lead to further research on the topics of photosynthesis and respiration. Learners are not inherently interested in plants and the topics related to the plant sciences (Balas & Momsen, 2014; Link-Pérez & Schussler, 2013; Uno, 2009); it is therefore important that textbook make these topics as interesting as possible.

Textbooks have an influence on the learners' worldview and their understanding of how concepts apply to one another (Natarajan et al., 2002). School curricula and instruction do not adequately facilitate learners' knowledge about plants (Link-Pérez & Schussler, 2013). It was found in this study that the textbooks focus on photosynthesis in plants and less so on respiration in plants, which might contribute to the idea that photosynthesis occurs in plants and respiration in animals. The textbooks studied only mention once that respiration occurs in both plants and animals, but thereafter there is no further mention of respiration in plants. The chapter on respiration in all three Grade 11 textbook uses germinating seeds in a practical activity. Here it is worth mentioning that learners tend to see seeds as non-living objects, however, they know that seeds become plants (Naude, 2016). Plants are seen as static and lifeless (Lindemann-Matthies, 2005) and this results in the idea that plants do not respire (Al khawaldeh & Al Olaimat, 2010; Amir & Tamir, 1990; Jayanti & Sri Rahayu, 2019; Keleş & Kefeli, 2010; Parker et al., 2012; Uno, 2009). If learners do not think seeds are living, testing seeds for respiration might confuse them. Learners might also not make the link that seeds are plant reproductive organs. Using seeds in the practical activities might be a bad idea in the absence of a conversation about living and non-living things and the role of seeds in plant reproduction. Teachers might also not be aware that this is a problem for learners, and the potential for confusion and misconceptions increase. The textbooks should thus use more plant examples in the respiration chapter as well. Other studies also found that textbooks contain less plant content than animal content and that animals are usually used as examples in the discussion of topics such as respiration (Abrie, 2015; Balas & Momsen, 2014; Link-Pérez & Schussler, 2013; Uno, 2009).

Plant blindness is the inability to notice and appreciate plants, as well as the inability to recognise the importance thereof in the biosphere (Allen, 2003; Brownlee et al., 2023; Jose et al., 2019; Parsley, 2020). Plant blindness amongst learners might be due to the fact that plants are underrepresented in textbooks (Jose et al., 2019; Parsley, 2020). Textbooks must therefore include plant examples and make these sections interesting in order to gain the attention of the learners. It was found by other studies that learners tend to show more interest in plants when the examples used can be linked to their everyday life, for example medicinal plants (Lampert et al., 2019). As mentioned before, the practical activities within the textbook might trigger the learners' interest. It was found by Allen (2003) and Jose et al. (2019), that

when doing practical activities that include plants, as well as textbooks that consider plants important, issues with plant blindness may be mitigated. The textbooks that have been studied need to use more plant examples, especially in, for example, the respiration section. This will then show learners that respiration also occurs in plants, and not just animals. The relationship between photosynthesis and respiration in plants is more complex compared to that in animals and an equal focus on plants might result in learners better appreciating plants and the role they play in the ecosystem.

5.3.5. How the Grade 11 textbooks' content provides the learners with an understanding of how the topics of photosynthesis and respiration fit into the larger environment, and the importance thereof

The study found that all three Grade 11 textbooks, Understanding Life Sciences Grade 11, Study and Master Grade 11 and Solutions for all Grade 11, touched on how photosynthesis and respiration fit into the larger environment, and the importance thereof. The textbooks list the importance of photosynthesis, for example in the control of carbon dioxide levels; this links to the topic of global warming. The role of respiration in sports and exercise is mentioned, as well as the role that anaerobic respiration plays in the industry and biotechnology. The textbooks lack a discussion on the role of respiration in plants and how this influences the environment, for example by regulating the levels of oxygen and carbon dioxide in the environment. This content within the textbooks is consistent with the requirements in the CAPS document (DBE, 2011). It is important to note that while the facts are given in the textbooks, the textbooks do not have an overarching discussion of how energy and matter flow through the system, which limits the way learners understand the relationship between organisms and the environment. It was found that learners better understand topics such as photosynthesis and respiration, as well as the cycling of carbon through the ecosystem, if they are able to trace matter within and between biological systems (Wilson et al., 2006). A better understanding of energy and matter transformation and conservation is thus needed. Researchers also state that for learners to better understand global issues such as food supply and energy flow, they need an in-depth understanding of concepts such as photosynthesis and respiration (Lumpe & Staver, 1995).

Photosynthesis and respiration are 'complicated active processes' due to their intangibility and their manifestation on several ecological levels, each with their own characteristics. Some of their properties only exist at the higher levels of structure and are referred to as emergent. The emergent interactions between these ecological levels, as well as within a level, can be regarded as a nested system with the different levels as subsystems (Brown & Schwartz, 2009). In plants, various elements or raw materials are brought together into compartments

which make up the organism. Plants are biological systems in their own right and are also elements of a nested system in the global ecosystem. Interaction of the organism within the ecological system has an impact on the global environment (Brown & Schwartz, 2009).

5.3.6. Misconceptions and the textbooks

The study found that the textbooks do not address misconceptions directly. In their study in Mafraq, Jordan, Al khawaldeh and Al Olaimat (2010) also mentioned that misconceptions are not addressed by textbooks or in the classroom. Correct facts are given in the textbooks, which remedy the misconceptions as listed in Table 3 in Appendix B, as well as any other misconceptions that learners might have; however, the facts alone are not enough to correct any misconceptions that learners might have. If misconceptions make sense to learners, they are difficult to change (Kumandaş et al., 2019). Coley and Tanner (2015) also stated that misconceptions are persistent and retained unless addressed explicitly. Kumandaş et al. (2019) mentioned that meaningful learning is compromised by misconceptions. They further state that meaningful learning takes place when the learners are able to make connections between prior knowledge and new knowledge (Kumandaş et al., 2019). Misconceptions should ideally be addressed through a careful process of conceptual change (Posner et al., 1982), preferably be a skilled teacher. A constructivist approach, where learners are actively involved in the construction of knowledge, is required for teaching for conceptual understanding. Merely telling learners about their incorrect understanding or conception will not lead to conceptual change. Research shows that the conceptual change model is effective in addressing misconceptions and improving conceptual understanding (Addido et al., 2022).

While conducting the textbook analysis, it was noted that the discussion of the light and dark phases of photosynthesis might lead to a misconception. Understanding Life Sciences Grade 11 and Study and Master Grade 11 discusses the light and dark phases in such a way that learners (and possibly even teachers) might conclude that the dark phase occurs at night. These textbooks should, like Solutions for all Grade 11 does, state that the dark phase relies on the products of the light phase and that the dark phase occur during the day, as long as the light phase produces ATP and hydrogen atoms; the dark phase does not occur at night because the light phase cannot occur as night. Several enzymes are regulated by light (Storey, 1989) and thus the process of photosynthesis (light and dark phase) occurs in light. The textbooks should therefore make some concepts clearer and be more explicit. It was found by other studies that mistakes within textbooks can cause misconceptions (Abrie, 2015), and even though these three textbooks give the correct facts, certain concepts must be stated explicitly as the learners will perhaps not be able to draw the correct conclusion. Khine (2013) and Liu and Khine (2016) stated that any inconsistency or omissions within the textbooks can

lead to misconceptions amongst learners. Cañal (1999) and Sanders and Cramer (1992) also stated that misconceptions might be due to the information provided in textbooks. This is supported by Parker et al. (2012) and Stern and Roseman (2004) who stated that textbooks contribute to the formation of misconceptions. Storey (1989) also found that textbooks contained a number of errors and misconceptions.

Misconceptions might be dealt with by the teacher during the practical activities and normal lessons, but whether this opportunity will be used will depend on the teacher. It is also important to mention that none of the Grade 11 Teacher's Guides gives any guidance as how to address misconceptions that learners might have (Gebhardt et al., 2012c; Isaac et al., 2012b; McKay et al., 2012b). Teachers need to be aware of misconceptions and how to address them (Kumandaş et al., 2019). As previously mentioned, skilled teachers will have to address misconceptions through a process of conceptual change. It is also important that teachers are aware of the learners' prior knowledge and for this reason teaching materials should guide the teacher in terms of the possible misconceptions and prior knowledge that learners have (Stern & Roseman, 2004). Yenilmez and Tekkaya (2006) also stated that teachers' awareness of misconceptions might improve teaching and learning. It was, however, found that teaching materials rarely alert teachers to misconceptions and how to address them (Stern & Roseman, 2004). Roseman et al. (2010) also found that textbooks did not support teachers in teaching, as these textbooks did not make connections between the related concepts. It might thus be beneficial if the processes of photosynthesis and respiration are addressed more comprehensively, and the necessary links are made between the interrelated concepts of photosynthesis and respiration.

5.3.7. How the content of the Grade 11 textbooks enables teachers to demonstrate skills and knowledge

The practical activities in all three Grade 11 textbook series will enable teachers to demonstrate skill and use knowledge, but only if the teacher is competent or so inclined. It is important to note here that teachers rely on textbooks (Ngwenya & Arek-Bawa, 2019; Sunday, 2014) and seldom go beyond textbooks (Johnston, 2018; Natarajan et al., 2002; Uno, 2009). It is for this reason that textbooks should provide the necessary content and support for teachers to teach interrelated topics such as photosynthesis and respiration. It was, however, found by other studies that textbooks did not support teachers in teaching, as they did not form connections between related topics (Roseman et al., 2010). The textbooks determine what topics are taught and also how these topics are taught (Johnston, 2018; Ngwenya & Arek-Bawa, 2019; Stern & Roseman, 2004); it is thus important that the textbooks provide support when it comes to teaching and learning. It is generally agreed upon that textbooks are the

main conveyor of the curriculum and play a central role in education (Bittar, 2022). O'Keeffe and O'Donoghue (2015) mentioned that good teaching might compensate for shortfalls in a textbook; however, evidence suggests that this is not the case. Teachers have insufficient training in botany and thus plant biology is not taught as it should be (Abrie, 2015; Brownlee et al., 2023; Hershey, 1993). Teachers themselves might hold misconceptions (Coley & Tanner, 2015) and might even have little knowledge about topics related to the plant sciences and are not as confident in teaching these topics. Textbook should therefore be more than just a compilation of facts.

5.4. Conclusion

Plant blindness and the learners' lack of interest in plants makes it difficult to teach Botany, including the processes that occur in plants, such as photosynthesis and respiration. However, teaching about plants is important due to the fundamental role that plants play in the ecosystem (Lampert et al., 2019). Plant blindness may result in learners having insufficient understanding of important environmental and conservation issues (Pany et al., 2019). It is thus important that textbooks make concepts such as photosynthesis and respiration, both of which occur in plants, clear. Plants play an important role in the carbon cycle and knowledge about the cycling of carbon is important to understand issues such as global warming (Pany et al., 2019). Even the oxygen in the atmosphere is due to plants' biological processes (Sanders, 2019).

The sequencing of the subject matter within the textbook provides teachers with the insight to decide about the depth of coverage of the content; teachers strictly follow what is offered in the textbooks (Ngwenya & Arek-Bawa, 2019). The quality of textbooks is thus important, as it impacts teaching and learning (Schizas et al., 2018). Support to the learners and teachers during the learning and teaching process must be provided by textbooks in order to be considered suitable. In addition a quality textbook will enable learners to achieve the learning outcomes they are supposed to reach by guiding them towards gaining skills and understanding (Ngwenya & Arek-Bawa, 2019). The textbooks must thus represent scientific information accurately, to be effective (Schizas et al., 2018).

One key strength of a textbook is that it can be used at school and at home (O'Keeffe & O'Donoghue, 2015), and it is therefore important that the textbook makes the needed connections between interrelated topics, such as photosynthesis and respiration, so that the learners are able to understand the topics when reading the textbook in the absence of a teacher.

This study found that although the textbooks are structured in a logical way, they lack a combined explanation of photosynthesis and respiration. All the information provided explains the two topics and provides an understanding of each, which aligns with what is stated in the curriculum. However, an understanding of the relationship between the two interrelated topics of photosynthesis and respiration is lacking. The textbooks do not sufficiently clarify the fact that these processes both occur in plants and that they have links with each other. The textbooks provide a basic description of the two processes, but learners need to understand the bigger picture in terms of energy and matter flow through the system.

5.5. Chapter overview

The purpose of this chapter was to discuss the general findings of this study in relation to previous international and South African studies. The next chapter (Chapter 6) will conclude the study with brief conclusions regarding the research questions. The chapter will give some final thoughts and end with a section on limitations and recommendations.

Chapter 6: Conclusion

6.1. Introduction

This is the final chapter of this study and gives brief conclusions for each of the research questions. The chapter concludes with a discussion regarding the limitations of this study, as well as suggestions for possible future endeavours.

6.2. Conclusions for each of the research questions

Secondary question 1: How does the content of photosynthesis and respiration within the textbooks align with what is stated in the CAPS document?

This study found that the content within the photosynthesis and respiration chapters is consistent with what is stated in the CAPS document (DBE, 2011). The requirements of the CAPS document can be seen in Table 1 in Chapter 4. All the textbook series are CAPS compliant, and I could not find any deviation regarding the information provided by the textbooks. The two topics are also discussed under the same strand (Strand 2: Life Processes in plants and animals), as prescribed by the CAPS curriculum. The textbooks are also written with the content following the order listed in the CAPS document.

Secondary question 2: How do textbooks present the relationship between photosynthesis and respiration?

It was found that the relationship between photosynthesis and respiration is not made explicit within any of the textbooks. While in certain sections of the photosynthesis and respiration chapters a link is made, the textbooks do not attend to the bigger picture of where these processes fit into the ecosystem. There is no overarching discussion of how both energy and matter flow through the system, which limits the way that learners may understand the relationship between organisms and the environment.

Secondary question 3: How do textbooks and the CAPS document align with the scientific consensus according to the AAAS, ASPB and NGSS?

The study found that most of the concepts / standards, as listed at criteria 5.1–5.14 in Table 2 in Appendix A, are covered by the textbooks (and the textbooks are aligned with the CAPS document; for this reason the concepts / standards are then also mostly covered by the CAPS curriculum). Some of the concepts are not explicitly mentioned in the textbooks but could have been dealt with in earlier grades; the CAPS document for lower grades and textbooks of lower grades would have to be consulted to confirm this. All three textbooks could make the cycling

of matter and energy clearer, as well as the relationship between photosynthesis and respiration. It is also important to mention that none of the textbooks mention the role that photosynthesis and respiration play in the carbon cycle, or even in the oxygen cycle.

Secondary question 4: How are misconceptions addressed in the textbooks?

It was found that none of the textbooks deal with misconceptions directly. The correct facts are given; however, this is not sufficient to correct misconceptions that learners might have. Misconceptions should ideally be addressed through a careful process of conceptual change (Posner et al., 1982), preferably by a skilled teacher. The textbooks need to discuss the processes of photosynthesis and respiration more comprehensively and make the links between the interrelated concepts much clearer, especially as they relate to plants.

Primary question: How do South African Grade 10 and 11 Life Sciences textbooks represent the interrelated concepts of photosynthesis and respiration, especially as they relate to plants?

It is evident that the content of the textbooks aligns with what is stated in the CAPS document (DBE, 2011). Most of the standards set by the AAAS, ASPB and NGSS are covered by the textbooks; however, the concepts are not necessarily mentioned explicitly and could be discussed more comprehensively.

The study found that the Grade 10 textbooks do lay down the foundation needed to understand the content of photosynthesis and respiration in Grade 11. In the Understanding Life Sciences Grade 10 textbook a link is made between photosynthesis and respiration. The Study and Master Grade 10 textbook draws the learners' attention to different forms of energy that flow through organisms. In the Grade 10 textbooks, a good link is made between the structure of the leaf and the function of photosynthesis and respiration. The structure of the chloroplasts and mitochondria, as well as the structure of the leaf, is discussed in the Grade 10 textbooks and link to what is given in the Grade 11 textbooks. It is important to mention here that the structure of the plant organs in relation to gas exchange of photosynthesis and respiration is referred to only in a limited way.

The topics of photosynthesis and respiration are separated into different sections within the Grade 11 textbooks, even though the two topics fall under the same strand (as prescribed by the CAPS curriculum). The textbooks give brief discussions of the topics of photosynthesis and respiration with limited or no reference to one another. The textbooks are also written in a standard way where facts are given, but there is no overarching discussion of how both energy and matter flow through the system. The relationship between photosynthesis and

respiration could be made more clearly within the textbooks. The textbooks also do not address misconceptions directly.

The topics or concepts in the Grade 11 textbooks are based on the assumption that learners have a sound knowledge of the Grade 10 related content. This might not necessarily be correct. A brief overview of the Grade 10 topics, and how they fit in, would then be advisable. Only the Solutions for all Grade 11 textbook introduces the various topics with a small introduction of previous grade content. Due to the complex nature of biology (Lin & Hu, 2003) it is important to make links between interrelated topics, and a review on some of the more important topics or concepts might also assist the learner in forming a clearer understanding of photosynthesis and respiration and related concepts or topics.

6.3. Limitations

Interest in textbooks is not new, with research on textbooks having been conducted in different countries for different purposes (Bittar, 2022). However, it is important to note that literature in relation to this study is limited. Much of the literature is at least a few years old, with recent literature being scarce. This confirms that a study such as the current one is filling a gap that exists in the literature.

The research was not supplemented by interviews with learners or teachers, or classroom observations. However, textbooks in their own right are tools for providing public information or knowledge in a written format, on a particular topic or subject, as required by society relevant to a specific time or period (Morgan & Henning, 2013). This study also focused only on printed textbooks used in schools in South Africa and that are available in bookstores. It is acknowledged that interactive sites, e-books and similar media are increasingly utilised for educational purposes. In view of this, the electronic-based media should be considered when tools are being designed for text analysis (Morgan & Henning, 2013). Analysing other forms of media could be a topic for future research.

This study included only three textbook series (Grade 10 and Grade 11), in which only the content linked to photosynthesis and respiration was analysed. It is possible that different results could be found regarding the quality of Life Sciences textbooks in South Africa, if a larger sample size is used, and if other chapters or topics are analysed. There is thus room for further research.

Another possible limitation is the potential loss of information about topics that are not emphasised in the textbooks or that are presented in scattered, fragmented manner throughout the textbooks and even over two or more grades.

6.4. Suggestions / Recommendations

Textbook analysis is essential, as textbooks are a dominant classroom resource (O'Keeffe & O'Donoghue, 2015). Textbooks, as core educational materials, support learners' learning process and influence learners' academic achievement; textbooks should therefore be written in such way to enable learners to be independent in their learning process (Peti-Stantić et al., 2021).

The authors, compilers and editors of textbooks must make sure that the textbook fulfils the aims of the curriculum and meets the needs of the learners (Baig et al., 2021). Teachers rely on textbooks when teaching and the textbooks become the implemented curriculum (Ngwenya & Arek-Bawa, 2019; Zhang et al., 2020). This study found that the textbooks align with what is stated in the CAPS document (DBE, 2011); however, the relationship between photosynthesis and respiration must be made more explicit. Certain topics cannot be taught in isolation, and need to be integrated and taught simultaneously to strengthen the development of conceptual understanding (Ngwenya & Arek-Bawa, 2019).

It is also worth mentioning that textbook developers should address plant blindness by ensuring that equal numbers of animal and plant examples are given, especially when it comes to major themes within biology (Brownlee et al., 2023). An equal focus on both plants and animals will help learners understand that processes such as respiration occurs in both plants and animals. Learners need to understand the important role that plants play in the ecosystem.

Further research could include participants (learners) to assess their understanding of topics such as photosynthesis and respiration when using the textbooks; studies including learners could also touch more on misconceptions, and whether the textbooks contribute to any misconceptions learners have or form regarding the topics they study. As mentioned previously, learning material other than textbooks could also be included in a study on the representation of related topics such as photosynthesis and respiration.

6.5. Conclusion

Plants are biological systems in their own right and are also elements of a nested system in the global ecosystem. Interaction of the organism within the ecological system has an impact on the global environment. Learners can find it difficult to view plants as a system due to the fact that the concepts are compartmentalised; it is for this reason that learners need to understand that the processes of photosynthesis and respiration occur simultaneously in the presence of light (Brown & Schwartz, 2009). The processes of photosynthesis and respiration play important roles in understanding many aspects of living systems. Furthermore, these

processes are essential in the cycling of matter and energy flow through ecosystems (Yenilmez & Tekkaya, 2006). It is thus important that textbooks make the connections between interrelated concepts such as photosynthesis and respiration.

This study found that even though the textbooks are structured in a logical way, they lack a combined explanation of photosynthesis and respiration. All the information provided explains the two topics and provides an understanding of each, which aligns with what is stated in the curriculum. However, an understanding of the relationship between the two interrelated topics of photosynthesis and respiration is lacking. The occurrence of both these processes in plants is not consistently supported in the way that the textbooks portray them, especially respiration. The textbooks provide a basic description of the two processes, but learners need to understand the bigger picture in terms of energy and matter flow through the ecosystem.

There is a lack of textbook research / analysis in South Africa (Ngwenya & Arek-Bawa, 2019), particularly in Life Sciences. This study thus contributes to the knowledge by addressing the gap in the existing literature.

At the end of the study, I understood how textbooks portrayed the topics of photosynthesis and respiration and whether connections between these related topics were made. I also established how the textbooks and CAPS document compared to the standards as set by the AAAS, ASPB and NGSS.

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Appendix A

The following table was used to analyse the textbooks:

Table 2: Criteria for analysing Grade 10 and 11 Life Sciences textbook series.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
1. How does the Grade 10 textbook lay down the foundation needed in Grade 11? 1.1. Mention chloroplast and mitochondria.	p.15 Palisade cells containing chloroplasts for photosynthesis. p.77 Mitochondria in animals and plants. Mitochondria is the site of respiration. Mitochondria referred to as “power-stations”. Structure of mitochondria given. Chloroplasts have chlorophyll for photosynthesis	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
1.2. Mention structure and function. 1.3. Detail of gases (oxygen and carbon dioxide).	and found only in plants. Structure of chloroplast given. No mention of gas. p.101 Chlorenchyma contain chlorophyll for photosynthesis. p.121 Function of leaves = photosynthesis. Leaves allow gas exchange for photosynthesis and respiration. No link between spaces and gas made. p.123 Upper and lower epidermis have chloroplasts. p.124 Palisade mesophyll have chloroplasts. p.127 Leaf adapted for photosynthesis and gas exchange. Adaptations for absorption of light and CO_2 is listed.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.128 List adaptations for gaseous exchange. O_2 and CO_2 mentioned. Mention that air spaces and thin walls are for diffusion. p.137 Stems holds leaves in such a way to receive sunlight for photosynthesis. Stems contain chlorophyll for photosynthesis. p.139 Cuticle is transparent for sunlight to penetrate for photosynthesis. p.140 Mention that spaces between parenchyma cells allow for the transport of water and gases. p.247 Chlorophyll captures energy from sunlight during photosynthesis. p.252 Water is split during photosynthesis. Water is a product during respiration.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.254 Carbon used during photosynthesis and released by the breakdown of organic compounds during respiration. Mention that the carbon from carbon dioxide forms part of glucose and then other organic compounds during photosynthesis. Figure 3.3.4 (carbon cycle) shows photosynthesis using CO_2 and respiration releasing CO_2 which is available again for photosynthesis. p.255 Oxygen is used during respiration and released during photosynthesis. Figure 3.3.5 (oxygen cycle) shows O_2 released during photosynthesis and available for respiration; respiration releasing CO_2 which is available for photosynthesis. p.5 Increased surface area for maximum respiration due to folded inner membrane of mitochondrion.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.66 Mitochondria in both plants and animals. Surface of inner membrane covered with granules that contain enzymes for aerobic respiration. p.67 Mitochondria site of aerobic respiration. Mention that energy is released by breaking down of food in the presence of oxygen. Energy stored as ATP. ATP referred to as energy carrier in cell. More mitochondria = more active cell. Only mention oxygen, no other gases mentioned. p.69 Plastids (chloroplasts) only found in plants. Mention that stroma contains enzymes for the dark phase of photosynthesis. Thylakoids contain chlorophyll and other photosynthetic pigments. Mention that chlorophyll absorbs sunlight for photosynthesis.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.70 Chloroplasts site of photosynthesis. Chlorophyll traps light energy, used to convert CO_2 and water into chemical potential energy (found in food). CO_2 used and O_2 released. Photosynthesis maintains CO_2 and O_2 balance. p.97 Parenchyma tissue have intercellular spaces for circulation of gases (CO_2 and O_2). Gases in the spaces available for photosynthesis and respiration. Spaces also allow water to pass through. Chlorenchyma cells = Parenchyma cells containing chloroplasts. p.98 Collenchyma cells often contain chloroplasts. p.100 Epidermal cells transparent for light to penetrate for photosynthesis. Guard cells have chloroplasts. Guard cells regulate gas exchange.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.119 Main function of leaf = Photosynthesis. p.120 Stomata allow CO_2 into leaf and O_2 out during photosynthesis. Palisade mesophyll contains chlorophyll. Palisade mesophyll's longitudinal arrangement ensure exposure to sunlight to maximise photosynthesis. Palisade mesophyll cells have thin walls for diffusion of gases. Spongy mesophyll also contains chloroplasts. Spongy mesophyll has intercellular spaces that store gases (CO_2 and O_2) which can diffuse into and out of the chloroplasts. H_2O absorbed from the soil and carried to mesophyll via xylem and is used for photosynthesis. p.121 Leaf adaptations for photosynthesis listed. Adaptation for maximum absorption of sunlight and gas exchange (CO_2 and O_2) mentioned.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.130 Cuticle transparent, allowing light through for photosynthesis. Stomata for gas exchange. Parenchyma cells have intercellular spaces for gas exchange. p.234 Light provides energy for photosynthesis. p.246 Photosynthesis and respiration in balance with each other (CO_2 and O_2 balance). p.253 Main driver of oxygen cycle is photosynthesis. p.254 Main source of oxygen is photosynthesis. Oxygen lost from atmosphere via respiration. Carbon dioxide used by photosynthesis for synthesis of organic compounds. Carbon dioxide returns to atmosphere through respiration.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.266 Sun provides continuous flow of energy. Solutions for all Life Sciences is not available in Grade 10.	
2. How are photosynthesis and respiration covered in the Grade 11 textbook? (In the same chapter or in different chapters?)	Photosynthesis and respiration are covered under the same strand; however, they are discussed as two separate topics. Photosynthesis and respiration are covered under the same strand; however, they are discussed as two separate units. Photosynthesis and respiration are covered under the same strand; however, they are discussed as two separate topics.	Strand two: Life Processes in plants and animals. Topic 2.1 = Photosynthesis. Topic 2.3 = Respiration Strand two: Life processes in plants and animals. Unit 1 = Photosynthesis. Unit 3 = Respiration. Strand two: Life processes in plants and animals. Topic 4 = Photosynthesis. Topic 6 = Respiration.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
2.1. To what extent does the chapter on photosynthesis refer to respiration?	p.134 Oxygen released during photosynthesis is used to release energy during respiration. p.145 Photosynthesis and respiration mentioned. No mention of gases. p.154 O_2 from photosynthesis available for respiration. CO_2 produced during respiration used in photosynthesis. p.121 Mention that glucose is the energy-rich molecule used in respiration. Refer to topic 6 where respiration is discussed. p.122 Glucose (product of photosynthesis) used in respiration. p.125 During cellular respiration the energy in the glucose is transferred to ATP molecules. Refer to topic 6 where respiration is discussed.	No other mention of respiration in photosynthesis chapter.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.134 Oxygen needed for respiration. Refer to topic 6 where respiration is discussed. Carbon dioxide is a product of respiration. Glucose is used in the process of cellular respiration to release energy. p.140 ATP produced through respiration. Refer to topic 6.	
2.2. To what extent does the chapter on respiration refer to photosynthesis?	p.182 Flow chart linking photosynthesis to respiration. Reference made to the manufacturing of starch during photosynthesis. p.186 Activity 2.3.1 – Photosynthesis and respiration regarded as "opposite processes". p.200 Activity 2.3.10 – Cycling of matter between chloroplast and mitochondria.	p.182 Flow chart does not show flow of matter between photosynthesis and respiration.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.202 Activity 2.3.12 – Glucose from photosynthesis broken down during respiration. No mention of photosynthesis. p.183 Mention that plants convert energy from the sun into chemical energy (in glucose molecules) during photosynthesis. Mention that photosynthesis is anabolic.	
3.1. How does the Grade 11 textbook refer to the structure of plant organs in relation to gas exchange of photosynthesis and respiration?	p.125 Double membrane of chloroplast = Permeable to water and CO_2. p.131 Spongy mesophyll = Airspaces for gas exchange (CO_2 and O_2). Mesophyll thin walls for entry of CO_2 and water. Stoma = Exchange of gases (CO_2 and O_2).	(p.131) Link to Grade 10 structure of the leaf.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.184 Outer membrane of mitochondria permeable to O_2 and pyruvic acid. p.152 Refers to the structure of chloroplast. But no mention of gases. p.153 The function of chloroplast is given. There it is mentioned that chlorophyll traps energy from light to convert CO_2 and H_2O into chemical potential energy. p.156 Activity 10 – Learner required to explain ways in which leaves are adapted for photosynthesis and also how chloroplasts are suited for photosynthesis. p.157 Activity 11 – Learners have to explain how spongy mesophyll is adapted for photosynthesis.	(p.152) Link to Grade 10 – Structure of the chloroplast. (p.156) Link to leaf discussed in Grade 10.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
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	p.195 Activity 3 – Learners need to explain how mitochondrion is suited for its function. p.119 Mention that a leaf is an organ and the main function is photosynthesis. Refer to the adaptations of the structure of the leaf, but no mention of gases. p.120 Table 4.1 – Learners have to match the reason for the adaptation to the adaptation of the leaf. Here there is mention of the air spaces allowing gaseous exchange. p.121 Mention that CO_2 enters through the stomata and diffuse through the leaf via air spaces between the spongy mesophyll. p.122 Figure 4.2 – Structure of the chloroplast. No mention of gases.	(p.195) Link to Grade 10 – Structure of mitochondria.

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	p.183 Mention that mitochondria are adapted for respiration. Learners have to study figure 6.1 and list adaptations.	(p.183) Here learners might mention that the double membrane is permeable to allow movement of substances in and out of the mitochondrion.
3.2. How does the Grade 11 content link to the Grade 10 textbook where structures are discussed?	p.125 Structure of chloroplast link to Grade 10 discussion of the cell organelles. p.131 Structure of the leaf also studied in Grade 10. p.184 Sketch of mitochondrion links to the discussion of the cell organelles in Grade 10. p.152 Structure of chloroplasts links to Grade 10 discussion of the cell organelles.	

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	p.156 Activity 10 – Structural adaptation of the leaf studied in Grade 10. p.157 Activity 11 – Structure of the leaf studied in Grade 10. p.195 Refer to mitochondria as “powerhouse” – as learnt in Grade 10. Activity 3 – Structure of mitochondrion links to the discussion of cell organelles in Grade 10. p.119-120 Structure and adaptations of the leaf studied in Grade 10. p.122 Structure of the chloroplast link to Grade 10 discussion of the cell organelles. p.183 Structure and adaptations of the mitochondria link to Grade 10 discussion of the cell organelles.	

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	p.197 Questions on cellular respiration – Question 3 link to the structure of the mitochondria also discussed in Grade 10 (cell organelles).	
4. How does the Grade 11 textbook cover interrelated topics of photosynthesis and respiration for the learners to make the connections between these topics? How is the following represented in the textbook (Brown & Schwartz, 2009; Raven et al., 2014; Reece et al., 2011):		

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4.1. Water, oxygen, carbon dioxide and glucose cycle between the chloroplast (site of photosynthesis) and the mitochondrion (site of cellular respiration).	p. 200 Activity 2.3.10 – Sketch showing cycling of matter between the chloroplast and mitochondrion. p.154 Mention that oxygen from photosynthesis is available for respiration and the carbon dioxide from respiration is used in photosynthesis. p.121 Glucose made by photosynthesis may be transported to other parts of the plant. Glucose is used by the cells of the plant in the process of respiration. p.121 Mention that CO_2 comes from the air and H_2O from the soil. No mention that these can come from respiration. p.122 Glucose is a product of photosynthesis and is used in respiration.	(p.154) No mention of the chloroplast and mitochondrion. No mention of water and glucose. (p.121+122) No direct mention of the cycling of matter between the chloroplast and mitochondrion. (p.121) The requirements for photosynthesis are listed. No mention that CO_2 and H_2O from respiration are available for photosynthesis.

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	p.122 Mention that O_2 is a product of photosynthesis, but no mention that this oxygen can be used in respiration. p.125 Mention that the energy in glucose molecule can be transferred to ATP molecule during respiration. p.134 The importance of photosynthesis is listed. Mention that O_2 is needed for respiration. It also mentions that CO_2 is a product of respiration and glucose used for respiration. p.138 Mention that energy in glucose (produced during photosynthesis) is transferred to ATP molecules during respiration. p.184 CO_2 and H_2O released during respiration.	(p.134) No mention of cycling between mitochondrion and chloroplast. (p.138) No mention of cycling between chloroplast and mitochondrion. (p.184) Not mentioned that CO_2 and H_2O can be used in photosynthesis.

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4.2. Water is broken down during photosynthesis to form oxygen.	p.126 Water is split into high-energy H atoms and O_2. O_2 released into atmosphere. p.151 Water is split into H ions and O_2 gas. p.124 H_2O is split into O_2 and energy-rich H-atoms. O_2 given off as gas. p.125 Figure 4.4 shows water being broken into oxygen gas and energy-rich hydrogen atoms.	Figure 2.18 = Schematic representation of photosynthesis.
4.3. In respiration oxygen combines with hydrogen to form water.	p.186 Mention that H combine to O_2 to form H_2O. p.197 Hydrogen atoms combine with oxygen to form water.	(p.186) It is mentioned that this occurs during oxidative phosphorylation. (p.197) Mentioned at oxidative phosphorylation.

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	p.184 Hydrogen atoms combine with oxygen to form water. H-atoms lose energy and combine with O_2 to from H_2O. p.185 Figure 6.2 shows H-atoms and O_2 gas enter oxidative phosphorylation and H_2O released.	(p.184) Mentioned at oxidative phosphorylation.
4.4. Oxygen and organic molecules, produced during photosynthesis, are used by the mitochondria for cellular respiration.	p.182 Glucose broken down during cellular respiration. Oxygen required for cellular respiration. p.200 Activity 2.3.10 – Sketch shows O_2 and $C_6H_{12}O_6$ used by mitochondria. p.154 Oxygen given off during photosynthesis used in respiration.	No mention of mitochondria (p.182) No mention of the mitochondria.

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	p.195 Glucose broken down in the presence of O_2 during respiration. Glucose = the major fuel source for respiration. p.196 Glucose broken down during glycolysis. p.121 Glucose used in cellular respiration. p.122 Glucose (product of photosynthesis) used for respiration. p.125 Energy in glucose molecule transferred to ATP molecule during respiration. p.184 Glucose (in the presence of oxygen) is broken down during respiration. Glucose broken down during glycolysis.	No mention of the mitochondria.

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4.5. Glucose is converted to carbon dioxide during respiration.	p.182 Figure 2.3.1 shows CO_2 released as by-product. p.185–186 Figure 2.3.4 – Glucose broken down to pyruvic acid during glycolysis, the pyruvic acid enters Kreb's cycle and H-atoms and CO_2 released. p.190 During anaerobic respiration, in plants, pyruvic acid is broken down to ethanol and CO_2. p.198 Compare aerobic and anaerobic respiration. Mention that both processes need glucose and, in plants, CO_2 is released. p.195 Glucose broken down in the presence of O_2 to form CO_2 and H_2O.	This also stated in paragraph p.182.

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	p.196–197 Glucose broken down to pyruvic acid during glycolysis, the pyruvic acid (in the presence of O_2) enters Kreb's cycle and energised H-atoms and CO_2 are released. p.196 Figure 2.3.2 – Alcohol and CO_2 released during anaerobic respiration in plants. p.200 Pyruvic acid converted to alcohol and CO_2 in a plant during anaerobic respiration. p.204 Compare aerobic and anaerobic respiration. Mention that glucose is needed and carbon dioxide is released (during anaerobic respiration CO_2 only released in plants). p.184 CO_2 is a product of respiration. Glucose broken down to pyruvic acid during glycolysis, energy-rich hydrogen given off. The pyruvic acid	

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	is broken down during Kreb's cycle, energy-rich hydrogen and CO_2 released. p.185 Figure 6.2 shows glucose entering glycolysis and CO_2 given off at Kreb's cycle. p.191 Alcoholic fermentation – Equation shows glucose broken down and CO_2 being released. Comparison between aerobic and anaerobic respiration shows glucose as a requirement and CO_2 being released (in plants).	
4.6. The carbon dioxide, from respiration, is used in photosynthesis.	p.126 Figure 2.18 – CO_2 from atmosphere. p.200 Activity 2.3.10 – Diagram shows CO_2 from mitochondria used in chloroplast.	No direct mention of CO_2 from respiration being used in photosynthesis.

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	p.134 Respiration releases CO_2 into atmosphere and during photosynthesis CO_2 used. p.154 CO_2 produced during respiration is used in photosynthesis. p.121 CO_2 from air. p.184 CO_2 given off as gas (in Kreb's cycle).	No mention of the CO_2 from respiration used in photosynthesis.
4.7. The chemical energy from the glucose molecule, produced in photosynthesis, is used in respiration to make ATP.	p.127 Refer to energy-rich carbohydrates. p.182 Refer to the glucose being broken down to release energy in the form of ATP. p.183 Figure 2.3.3 – Shows energy from glucose breakdown used in ADP/ATP cycle.	Not explicitly mentioned that chemical energy from glucose, made during photosynthesis, is used in respiration to make ATP.

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	p.185+190 Refers to energy-rich compounds such as glucose. p.153 Chemical potential energy found in food, such as glucose. p.194 Energy made available to cells due to respiration. p.195 Glucose (a fuel molecule) is broken down during respiration and energy is captured in ATP molecules. Glucose the major fuel source for respiration. p.196 Glucose broken down to form ATP during glycolysis. p.121 Refer to glucose as an energy-rich molecule used in respiration. p.125 Energy in the glucose molecules can be transferred to energy-rich ATP molecules during respiration.	No mention of the chemical potential energy being used in respiration.

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	p.183 Light energy is converted to chemical energy in glucose molecules by photosynthesis and this chemical energy is transferred to energy-rich ATP molecules during cellular respiration.	
4.8. ATP provides energy for photosynthesis.	p.126 Light energy from the sun used to form ATP. p.183 Figure 2.3.2 shows energy from ATP available for other processes. p.202 Activity 2.3.12 – Explaining how glucose from photosynthesis is broken down to release energy. p.159 ATP = energy carrier, providing energy for energy-consuming activities. Used during the formation of polysaccharides.	Not explicitly stated that ATP, from respiration, is used in photosynthesis. Not explicitly mentioned that the ATP, produced in respiration, is used for photosynthesis.

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	p.124 Light energy use to make ATP during the light phase of photosynthesis, ATP used in the dark phase to produce glucose. p.140 ATP produced through respiration used for various life processes. ATP = energy carrier. p.183 ATP provides energy to cells.	Not mentioned that the ATP produced during respiration is used in photosynthesis.
4.9. The carbon dioxide and water, produced during respiration, serve as raw materials for photosynthesis.	p.114+125 CO_2 and H_2O are reactants in the equation of photosynthesis. p.182 H_2O and CO_2 serve as raw materials in photosynthesis. H_2O and CO_2 released as by-products during respiration.	Not explicitly stated that CO_2 and H_2O produced during respiration (in plants) can be used in photosynthesis.

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	p.186 CO_2 released during Kreb's cycle. H_2O forms during oxidative phosphorylation. p.200 Activity 2.3.10 – Diagram shows CO_2 and H_2O cycle between the mitochondria and chloroplast. p.146 CO_2 and H_2O are reactants in the equation of photosynthesis. p.154 CO_2 produced during respiration, used in photosynthesis. p.195 CO_2 and H_2O are products in the equation of respiration. p.197 CO_2 released during Kreb's cycle and H_2O produced during oxidative phosphorylation.	Not explicitly mentioned that CO_2 and H_2O produced during respiration (in plants) can be used in photosynthesis.

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	p.121 + 124 CO_2 and H_2O are reactants in the equation of photosynthesis. p.184 CO_2 and H_2O are products in the equation of respiration. CO_2 released during Kreb's cycle and H_2O produced during oxidative phosphorylation. p.185 Figure 6.2 shows CO_2 and H_2O being produced during respiration.	Not stated that CO_2 and H_2O produced during respiration (in plants) can be used in photosynthesis.
4.10. Photosynthesis and respiration occur simultaneously in light.	p.126 Discuss light-dependent phase of photosynthesis. No reference to both processes. p.184 Aerobic respiration dependent on O_2.	Will learners be able to make the connection that O_2 is produced during the light-dependent phase of photosynthesis and thus respiration also occurs in light?

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	p.153 The light-dependent phase (light phase) of photosynthesis occurs only in the presence of light. The light-independent phase (dark phase) can occur in the presence of light or without light. p.195 Respiration (in most organisms) take place in the presence of oxygen = aerobic respiration. These organisms need a continues supply of O_2 to undergo aerobic respiration. p.124 The light phase of photosynthesis depends on light, the dark phase of photosynthesis relies on the products of the light phase and does not need light. The dark phase occurs during the day, as long as the light phase produces ATP and H-atoms. Dark phase does not occur at night, because light phase cannot occur at night.	Will learners be able to make the connection that O_2 (needed for aerobic respiration) is produced during the light-dependent phase of photosynthesis and thus respiration also occurs in light? The way in which the light and dark phase are discussed might confuse learners and learners might think that the dark phase occurs at night. Will learners be able to make the connection that O_2 is produced during the light-dependent phase of photosynthesis

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	p.184 Aerobic respiration takes place in the presence of O_2. Stated that O_2 obtained through breathing. No reference made to the fact that O_2 from photosynthesis can be used in respiration.	and thus respiration (using O_2) also occurs in light? p.184 O_2 obtained through breathing – link to the fact that animals mostly used as examples when explaining topics.
4.11. Respiration occurs continuously day and night.	No reference made. No reference made. No reference made.	
5. Does the Grade 11 textbook include the following concepts / standards:		

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5.1. Plants need water, other inorganic elements and light (AAAS, 1993; ASPB, 2022).	Not stated explicitly. Not stated explicitly. Not explicitly stated.	Learners might conclude that water and light are needed as these are requirements for photosynthesis. Learners might conclude that water and light are needed as these are requirements for photosynthesis (p.146). Learners might conclude that water and light are needed as these are requirements for photosynthesis (p.121).
5.2. Materials can be recycled and reused (AAAS, 1993; ASPB, 2022; NSTA, 2014).	Not explicitly stated. p.200 Activity 2.3.10 – Diagram shows cycling between the chloroplast and mitochondrion.	

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	Not explicitly stated. p.154 O_2 from photosynthesis used in respiration and CO_2 from respiration used in photosynthesis. Not explicitly stated. p.121 + 122 Glucose (from photosynthesis) used in respiration. p.183 Chemical energy in glucose molecule transferred to ATP molecule during respiration.	
5.3. Energy is needed for life and growth. Photosynthesis and respiration provide most of the energy (AAAS, 1993; ASPB, 2022; NSTA, 2014).	p.126 Light energy used to form ATP and release high-energy hydrogen atoms during photosynthesis. p.127 Energy-rich carbohydrates form; the ATP and high-energy hydrogen atoms provide energy for this process. p.134 Importance of photosynthesis = Provide food/energy for organisms in higher trophic levels.	

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	p.182 Energy released during respiration in the form of ATP. p.183 20% of energy used to form ATP during respiration. ATP available for various processes. p.184 Mitochondria site of respiration. The number of mitochondria indicates the amount of energy required. p.185 Diagram shows ATP produced during respiration. p.153 Light energy captured and converted to chemical potential energy in food (glucose). p.153 Life depends on photosynthesis, because energy (and nutrients) obtained from green plants (directly or indirectly).	

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	p.159 ATP (energy carrier) synthesised during photosynthesis. p.195 Energy captured in ATP molecule during respiration. p.196 Energy released during glycolysis to form ATP. p.197 Energy from energised hydrogen given off to form ATP during oxidative phosphorylation. p.121 Photosynthesis uses energy from the sun to make glucose. Refer to glucose as an energy-rich molecule. Glucose converted to starch (a much larger energy-rich molecule) which stores energy. p.122 Energy in glucose comes from sunlight energy.	

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	p.124 ATP (energy-rich molecules) made during light phase of photosynthesis. Water is split to produce energy-rich H-atoms. Glucose gets energy from the energy-rich ATP and H-atoms produced in light phase of photosynthesis. p.125 Energy in glucose transferred to ATP during respiration. Excess glucose converted to starch and stored (this energy can be used later). p.134 Importance of photosynthesis = trapping energy (production of food). Glucose basic energy source for organisms. Glucose used for cellular respiration, which releases energy to sustain life. p.140 ATP produced during cellular respiration and used for various life processes. ATP = energy carrier.	

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	p.183 Energy comes directly or indirectly from sun. During photosynthesis energy from sun converted to chemical energy within glucose. Chemical energy transferred to ATP molecules during respiration. ATP provides energy to all living cells. p.184 Energy released as ATP when glucose broken down. This energy used for various life processes. p.185 One glucose molecule produces 38 ATP molecules (aerobic respiration). This energy used for life processes such as growth, movement and transporting substances across cell membrane.	

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5.4. Energy in light, carbon dioxide and water is used by plants to make sugars (AAAS, 1993).	p.114+125 Equation of photosynthesis. CO_2, H_2O and light energy serve as reactants. p.126–127 Process of photosynthesis – light and dark phases. p.146 Equation of photosynthesis. CO_2, H_2O and light energy serve as reactants / requirements. p.121+124 Equation of photosynthesis. CO_2, H_2O and light energy serve as reactants / requirements. p.124 Process of photosynthesis – light and dark phase.	

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5.5. In living things energy can change from one form to another (AAAS, 1993). E.g., during photosynthesis light energy is converted to chemical energy (NSTA, 2014).	Not explicitly stated. p.114+125 Light energy use to form glucose. p.125 Light energy use to manufacture food such as starch. p.126 Light energy used to form ATP and high-energy H-atoms. p.127 Energy-rich carbohydrates form during photosynthesis. (ATP and high-energy H-atoms provide the energy.) p.182 Glucose broken down to release energy in the form of ATP. p.183 20% of energy given off during respiration is used to make ATP, the rest is released as heat.	

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	p.185 Glucose broken down, energised H-atoms and energy released. The energy is used to form ATP. p.186 Energy from H-atoms used to form ATP. p.145 Law of energy – energy can be transformed from one form into another. p.146 Light energy used to produce food (glucose). p.153 Light energy trapped by chlorophyll and converted to chemical potential energy during photosynthesis. p.159 ATP used to form polysaccharides such as starch.	

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Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.194 Work involves changing potential energy into kinetic energy. Energy available to cell by means of respiration. p.195 Glucose broken down to release ATP molecules. p.197 Energised H-atoms used to form ATP. p.121 Light energy used to produce glucose (energy-rich molecule). Glucose converted to starch and stored in plant. p.124 Some light energy used to make ATP during light phase of photosynthesis. Glucose gets energy from ATP and energy-rich H-atoms during dark phase of photosynthesis. p.125 Energy in glucose transferred to ATP during respiration.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
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	p.140 ATP used to synthesis macromolecules. p.183 Light energy converted to chemical energy in glucose by means of photosynthesis. The chemical energy is transferred to ATP molecules during respiration. ATP provides energy for living cells. p.184 Energy released when glucose broken down. Breakdown of glucose releases energy-rich H-atoms. Energy in H-atoms used to form ATP.	
5.6. Continuous input of sunlight (energy) keeps the flow of energy in a food web going (AAAS, 1993).	Not explicitly mentioned. Not explicitly stated.	

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	p.153 Life depends on photosynthesis because organisms obtain their nutrient, and therefore energy, from plants (directly or indirectly). Organisms at higher trophic levels obtain energy from stored organic compounds in plants (directly or indirectly). p.194 Constand flow of energy needed for survival. Not stated explicitly. p.134 The glucose produced during photosynthesis is the basic energy source.	
5.7. Energy is transferred from one system to another and energy is released (NSTA, 2014).	p.183 Figure 2.3.2 – ADP/ATP cycle. Energy from glucose breakdown forms ATP, ATP is then available for other processes. Energy (not used in the production of ATP) released as heat.	Textbooks lack explanation of energy flow between the mitochondrion and chloroplast.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
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	p.145 One form of energy is transformed into another, and some energy is lost as heat. p.125 Energy in glucose transferred to ATP during respiration. p.183 Chemical energy transferred to energy-rich ATP molecules during respiration. p.184 Energy released as ATP when glucose is broken down.	Textbooks lack explanation of the flow of energy between the mitochondrion and chloroplast. Textbooks lack explanation of energy flow between the mitochondrion and chloroplast.

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
5.8. The removal of carbon dioxide from the atmosphere by plants during the process of photosynthesis alters the earth's atmosphere by releasing oxygen (AAAS, 1993).	p.134 Importance of photosynthesis = control carbon dioxide and oxygen levels in the atmosphere. p.154 Photosynthesis maintains a constant global level of oxygen and carbon dioxide. p.121 CO_2 comes from air. p.122 O_2 released into air. p.134 O_2 added (by plants) to atmosphere during the day. CO_2 removed (by plants) from atmosphere during the day.	

Criteria for analysing Grade 10 and 11 Life Sciences textbook series		
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5.9. The sugar molecules formed during photosynthesis contain carbon, hydrogen and oxygen and these hydrocarbon backbones are used to make other carbon-based molecules (NSTA, 2014).	p.114 Chemical formula shows glucose contains carbon, hydrogen and oxygen. Production of other carbon-based molecules from the hydrocarbon backbones not mentioned. p.146 Chemical formula shows glucose contains carbon, hydrogen and oxygen. Production of other carbon-based molecules from the hydrocarbon backbones not mentioned. p.121 Chemical formula shows glucose contains carbon, hydrogen and oxygen.	

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	p.185 Activity 1, question 5 – Ask learners where the carbon, hydrogen and oxygen atoms that form part of glucose end up at the end of respiration. Production of other carbon-based molecules from the hydrocarbon backbones not mentioned.	
5.10. The flow of matter and energy allows for the recombination of chemical elements to form different products (NSTA, 2014).	p.200 Activity 2.3.10 – Diagram shows flow of matter between mitochondrion and chloroplast. No other reference made to the flow of matter and energy. p.154 O_2 from photosynthesis used in respiration and CO_2 from respiration (in plant) used in photosynthesis. (Flow of matter)	

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	No other reference made to the flow of matter and energy. p.121 + 122 Glucose (produced in photosynthesis) used in respiration. p.125 Energy in glucose transferred to ATP during respiration. p.183 Light energy converted to chemical energy (during photosynthesis), which is transferred to ATP during respiration. No other reference made to the flow of matter and energy.	
5.11. Plants respire and use the energy for growth and reproduction (ASPB, 2022).	p.183 Uses of energy listed – growth, movement, cell division, maintaining body temperature and active transport.	

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	p.194 Organisms perform activities that require energy, which is made available by means of respiration. No mention of growth and reproduction. p.185 During respiration one glucose molecule produces 38 ATP molecules. This energy used for life processes, such as growth and movement.	
5.12. During respiration, bonds in food molecules (glucose) and oxygen are broken and new compounds are formed that transport energy (NSTA, 2014).	p.185–186 Process of respiration – Glycolysis, Kreb's cycle and oxidative phosphorylation. Figure 2.3.4 summarise aerobic respiration. p.196–197 Process of respiration – Glycolysis, Kreb's cycle and oxidative phosphorylation.	

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	p.184–185 Process of respiration – Glycolysis, Kreb's cycle and oxidative phosphorylation. Figure 6.2 summarise aerobic respiration.	
5.13. Photosynthesis and respiration are an important part of the carbon cycle (NSTA, 2014).	No mention. No mention. No mention.	
5.14. Plants play an important role in the cycling of nutrients and the addition of oxygen (ASPB, 2022).	No reference made to cycling of nutrients. p.134 Mentions addition of oxygen to the atmosphere. No reference made to the cycling of nutrients. p.146 Oxygen is a product of photosynthesis.	

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	p.154 Photosynthesis plays a role in maintaining oxygen and carbon dioxide levels. No reference made to the cycling of nutrients. p.122 Oxygen given off as by-product of photosynthesis. (Figure 4.3 p.123 – shows O_2 being released.) p.125 Figure 4.4 – shows O_2 being given off. p.134 Oxygen released. Oxygen added to atmosphere during day.	
6. How does the Grade 11 textbook stimulate research on the subject?	p.112–113 Deals with the history of photosynthesis. p.115–124, 187–188, 191–192 – Practical activities.	This might trigger learners' interest which can lead to research.

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	p.147–152, 154–159, 195–202 – Practical activities. p.198 Activity 6 – Learners design own investigation. p.126 Deals with the history of photosynthesis. p.127–133, 186–189, 196 – Practical activities. p.192 Enrichment activity.	This might lead to research on the topic. This might trigger interest and lead to research.
7. Is the purpose of the Grade 11 learning material constructed in a logical sequence to empower the learners as opposed to merely providing a lot of	The photosynthesis chapter starts off with history, followed by the equation and the starch test. Practical activities testing the requirements of photosynthesis precede the more detailed process.	Material constructed logically to help learners understand; however, topics are separated into two different sections.

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information? (Understanding as opposed to memorising)	The respiration chapter starts off with the uses of energy, followed by aerobic and anaerobic respiration. Aerobic and anaerobic respiration are then compared. The unit on photosynthesis starts with the concept of energy, followed by the equation and the starch test. The practical activities testing the requirements and products precede the process and importance of photosynthesis. Thereafter the factors affecting the rate of photosynthesis are discussed. The unit ends with the role of ATP. The respiration unit starts off with the need for energy, followed by the equation and a discussion on aerobic and anaerobic respiration. The unit ends with a comparison between aerobic and anaerobic respiration.	Material constructed logically to help the learners understand; however, the topics are separated into two different units.

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	The topic of photosynthesis starts off with a section on what the learners should already know, this is then followed by an overview of photosynthesis. A detailed description follows, as well as the history of the discovery of photosynthesis. The investigations (practical activities) precede the discussion of the importance of photosynthesis, factors affecting the rate of photosynthesis and improving crop yields. The section on photosynthesis ends with the role of ATP. The topic of cellular respiration starts off with what the learners should already know. Aerobic respiration is then discussed, followed by the practical activities. Anaerobic respiration is then discussed, followed by a comparison between aerobic and anaerobic respiration.	Material constructed logically to help the learners understand; however, the topics are separated into two different sections.

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Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
8. How does the Grade 11 textbook content provides the learners with an understanding of how these topics fit into the larger environment, and the importance thereof?	p.108 Figure 2.1 illustrates the relationship amongst life processes. p.134 Lists the biological importance of photosynthesis. p.192–194 Anaerobic respiration in micro-organisms and commercial value (biotechnology). p.198 Activity 2.3.8 – The article might help learners to link Life Sciences to everyday life. p.201–202 Activity 2.3.11 deals with respiration and sport. p.153 Photosynthesis as a source of energy within food chains (importance of photosynthesis). p.153 Activity 7 – The role of algae as food.	Control of CO_2 levels links to global warming.

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	p.154 Photosynthesis and the composition of air (importance of photosynthesis). p.156 Activity 10. Question 6 – Learners need to explain how farmers can increase the yield of crops grown in greenhouses. p.158 The role of CO_2 enrichment, and optimum light and temperature in greenhouses. p.159 Activity 13 – Learners need to state ways in which farmers could enrich the air inside the greenhouse. They need to explain how an increase in CO_2 levels can lead to an increase in the production of tomatoes.	CO_2 levels in the atmosphere link to global warming.

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	p.200 Anaerobic respiration. Mention alcoholic fermentation and exercise. p.201–202 Activity 9 – Process of fermentation. p.202 The role of anaerobic respiration in industry. (p.202–204 Activity 10 & 11) p.134 List the importance of photosynthesis. CO_2 levels link to global warming. p.138 Improving crop yields. Factors influencing the rate of photosynthesis important when growing crops that provide food for people.	

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	p.193 Anaerobic respiration in humans (exercising). p.194–195 Role of anaerobic respiration in industry (biotechnology).	
9. How does the Grade 11 textbook trigger the teachers to address preconceived ideas (misconceptions) on the topic?	Misconceptions might be dealt with by teachers during practical activities. Misconceptions can perhaps be addressed during practical activities. Misconceptions might be dealt with during practical activities.	
10. How does the content in the Grade 11 textbook address the misconceptions held by learners?	p.113 Activity 2.1.1 Question 2 allows learners to think about what contributes to the growth of a plant. (This is not only water.) Question 3 allows learners to think about what the soil provides. Question 4 – learners think about the mass increase.	

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	p.186 Activity 2.3.1 – Photosynthesis and respiration regarded as 'opposite processes'. p.146 Mention that photosynthesis occurs in the green parts of a plant, mainly the leaf.	The answers to this activity might help learners understand where the requirements/ reactants come from and what happens to the products that form. *SEE TABLE ON MISCONCEPTIONS. The facts in the textbook might help learners overcome these misconceptions. The textbook, however, does not directly address misconceptions. It might be helpful if a section correcting misconceptions is available.

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Criteria	**Textbooks** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**	**Comments / Examples** **Understanding Life Sciences Grade 10** **Understanding Life Sciences Grade 11** **Study & Master Life Sciences Grade 10** **Study & Master Life Sciences Grade 11** **Solutions for all Life Sciences Grade 11**
	p.153 Mentions that the dark phase of photosynthesis occurs in the presence of light, or without light. p.159 Activity 13 – Learners must suggest a reason why additional CO_2 is only given off during the day. p.195 Mentions that respiration occurs in all plant and animal cells, except the erythrocytes. Mention that aerobic respiration need oxygen and anaerobic respiration does not. p.197–198 Activities 4 – 6. Learners might conclude that oxygen and glucose are needed for respiration and that carbon dioxide is released.	Learners might realise that the light-dependent phase of photosynthesis occurs only in daytime and the light-independent phase can only occur if the products of the light dependent phase are available. *SEE TABLE ON MISCONCEPTIONS. The facts in the textbook might help learners overcome these misconceptions. The textbook, however, does not directly

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	p.121 Mentions that the energy from sunlight is used to make food and releases oxygen during photosynthesis. p.124 The light phase depends on light, but the dark phase depends on the products of the light phase. The dark phase occurs during the day, as long as the light phase produces ATP and H-atoms. The dark phase does not occur at night, because the light phase does not occur at night.	address misconceptions. It might be helpful if a section correcting misconceptions is available. Learners might realise that the light-dependent phase of photosynthesis occurs only in daytime and the light-independent phase can only occur if the products of the light dependent phase are available. Thus photosynthesis occurs during the day.

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	p.184 Respiration occurs in both plants and animals. p.184 Aerobic respiration occurs in the presence of oxygen and anaerobic respiration occurs without oxygen. p.184 Energy released when glucose is broken down during respiration (in the presence of oxygen). Glucose is broken down during glycolysis. p.184 CO_2 released during aerobic respiration. p.191 CO_2 released during anaerobic respiration in plants (alcoholic fermentation).	Learners might realise that both glucose and oxygen are reactants in respiration. *SEE TABLE ON MISCONCEPTIONS. The facts in the textbook might help learners overcome these misconceptions. The textbook, however, does not directly address misconceptions. It might be helpful

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		if a section correcting misconceptions is available.
11. How does the content of the Grade 11 textbook enable the teachers to demonstrate skills or use the knowledge?	The teacher can demonstrate knowledge and skills during practical activities. During practical activities, teachers can demonstrate knowledge and skills. The teacher can demonstrate skills and knowledge during practicals.	
12. How do the activities, experiments and diagrams (in the Grade 11 textbook) contribute to the learners' understanding of the topics?	Practical activities in both the photosynthesis and respiration topics might help learners understand concepts better. p.126 Figure 2.1.8 explains the process of photosynthesis.	

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	p.185 Figure 2.3.4 Summarises aerobic respiration. p.190 Figure 2.3.5 Summarises anaerobic respiration. p.200 Activity 2.3.10 – Diagram shows the flow of matter. The practical activities in both the unit on photosynthesis and the unit on respiration might help learners understand the topics better. p.152 The micrograph might add to the learners' understanding of the structure of the chloroplast. p.155 Figure 2.1.9 – Graph shows the influence of CO_2 concentration on the rate of photosynthesis.	

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	p.156 Figure 2.1.11 – Graph shows the influence of temperature on the rate of photosynthesis. p.156 Figure 2.1.12 – Graph shows the influence of light intensity on the rate of photosynthesis. p.195 Figure 2.3.1 The micrograph of the mitochondrion might add to learners' understanding of the structure. p.196 Figure 2.3.2 Summarise aerobic and anaerobic respiration. Practical activities in both the photosynthesis and respiration topics might help learners understand concepts better.	

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	p.119 Figure 4.1 Shows the structure of the leaf and a micrograph of a chloroplast. p.122 Figure 4.2 – Structure of the chloroplast. p.123 Figure 4.3 – Summarises photosynthesis. p.125 Figure 4.4 – Shows the light and dark phases of photosynthesis. p.135 Figure 4.12 a and b – Graphs showing the influence of light intensity and the influence of CO_2 levels on the rate of photosynthesis. p.136 Figure 4.12 c – Graph showing the influence of temperature on the rate of photosynthesis. p.140 Figure 4.16 – Formation and breakdown of ATP.	

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	p.183 Figure 6.1 – Sketch of mitochondrion. p.185 Figure 6.2 – Summarises aerobic respiration. p.191 Table 6.1 – Compares aerobic and anaerobic respiration.	
13. Is pre-requisite knowledge required to understand the Grade 11 textbook content?	Yes, the foundation as laid down by the Grade 10 textbook (listed at number 1 of this table) is needed to understand the content. Yes, the foundation as laid down by the Grade 10 textbook (listed at number 1 of this table) is needed to understand the content. Yes, the foundation laid down in Grade 10, according to the CAPS document, is needed to understand the content.	

Appendix B

The following table shows misconceptions as stated in the literature: Limitations in the literature review might mean that the list is incomplete and that some misconceptions are not listed here.

Table 3: Misconceptions as stated in the literature.

Misconceptions
Plants photosynthesise but do not have cellular respiration (Al khawaldeh & Al Olaimat, 2010; Amir & Tamir, 1990; Jayanti & Sri Rahayu, 2019; Keleş & Kefeli, 2010; Parker et al., 2012; Uno, 2009).
Only flowering plants are true plants (Barman et al., 2003).
Plants need food in a similar way to people (Barman et al., 2003). Plants take in food from the outside in the same way as animals and humans (Cañal, 1999; Ekici et al., 2007; Keleş & Kefeli, 2010).
Carbon dioxide is used instead of oxygen during the fermentation reactions (Al khawaldeh & Al Olaimat, 2010).
Carbon dioxide is used during respiration (Jayanti & Sri Rahayu, 2019) when the plant does not photosynthesise (Keleş & Kefeli, 2010).
Glucose is the only reactant used in respiration (Al khawaldeh & Al Olaimat, 2010).
Plants breathe like animals or humans (Barman et al., 2003; Cañal, 1999; Jayanti & Sri Rahayu, 2019; Lin & Hu, 2003; Sanders & Cramer, 1992; Svandova, 2014; Yenilmez & Tekkaya, 2006).

Plants only respire at night when photosynthesis does not occur (Al khawaldeh & Al Olaimat, 2010; Jayanti & Sri Rahayu, 2019; Keleş & Kefeli, 2010; Svandova, 2014).
Oxygen is used during anaerobic respiration (Al khawaldeh & Al Olaimat, 2010).
Plants produce oxygen at the end of respiration and animals produce carbon dioxide (Al khawaldeh & Al Olaimat, 2010; Jayanti & Sri Rahayu, 2019).
Plants produce oxygen during the day and absorbs oxygen at night (Jayanti & Sri Rahayu, 2019).
Carbon dioxide is released as a product during aerobic and anaerobic respiration (Al khawaldeh & Al Olaimat, 2010).
Carbon dioxide is used during glycolysis to form ATP (Al khawaldeh & Al Olaimat, 2010).
At the end of photosynthesis energy is produced (Al khawaldeh & Al Olaimat, 2010).
Mass of a plant increases due to the uptake of water and inorganic matter from the soil (this is the food for the plant) (Cañal, 1999; Keleş & Kefeli, 2010; Svandova, 2014).
Plants get their food or energy from the soil (Wernecke et al., 2018).
The food for plants is sunlight (Keleş & Kefeli, 2010).
Carbon dioxide is food for the plant (Keleş & Kefeli, 2010).
Sunlight is converted to food during photosynthesis (Ekici et al., 2007; Keleş & Kefeli, 2010).
Carbon dioxide is converted to oxygen during photosynthesis (Keleş & Kefeli, 2010).
Plants do not use oxygen (Keleş & Kefeli, 2010).

Photosynthesis is the respiration of plants (Ekici et al., 2007; Keleş & Kefeli, 2010; Svandova, 2014).
Photosynthesis and respiration takes place only in the leaves (Lim & Poo, 2021; Svandova, 2014).
Photosynthesis and respiration are the same process, they only occur at different times and places within the plant (Jayanti & Sri Rahayu, 2019; Svandova, 2014).
Plants produce oxygen during the day, as well as at night (photosynthesis occurs day and night) (Svandova, 2014).
The release of oxygen is the main purpose of photosynthesis (Svandova, 2014).
Respiration is the reverse of photosynthesis (Jayanti & Sri Rahayu, 2019).
Respiration in plants needs sunlight (Jayanti & Sri Rahayu, 2019).
In plants respiration does not produce energy (Jayanti & Sri Rahayu, 2019).
Chlorophyll is needed in plants for respiration (Jayanti & Sri Rahayu, 2019).
During the process of photosynthesis energy is produced (Ekici et al., 2007).
Photosynthesis is a gas exchange process (Ekici et al., 2007).
Chlorophyll is produced during photosynthesis (Ekici et al., 2007).