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SECONDARY SCHOOL STUDENTS' COGNITIVE STRUCTURES AND MISCONCEPTIONS IN RESPIRATION TOPIC

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Abstract

Purpose of the study: This study aims to explore the cognitive structures and identify the misconceptions experienced by secondary school students in the respiration topic.

Methodology: This study is a qualitative study. The instruments used for data collection were the Word Association Test (WAT) and the Questionnaire of Writing Sentence (QWS). The data obtained were in word form. The breakpoint technique was used to analyze the data for WAT while the data for QWS were analyzed by category. Purposive sampling was applied in this study. A total of 23 forms four students comprising 12 boys and 11 girls participated in this study.

Main Findings: The result showed that the students' cognitive structures in the respiration topic were incomplete. The students were unable to form a comprehensive relationship for the given keywords, and there were also weak or incorrect associations. The misconceptions that had been identified are largely related to the keywords about cell respiration, anaerobic respiration, and breathing mechanism.

Applications of this study: This study provides insights into the students' cognitive structures and misconceptions about respiration. Thus, it will be useful for teachers in planning their teaching strategies so that they can improve the students' cognitive structures as well as avoid misconceptions.

Novelty: Most of the previous studies only focused on the identification of misconceptions without further investigation into the students' cognitive structures, especially on the respiration topic. Thus, this study investigates the cognitive structures and misconceptions specifically among secondary school students who have learned respiration in biology.

Keywords: *Cognitive Structure, Misconception, Respiration, Word Association Test (WAT), Questionnaire of Writing Sentence (QWS), Biology Education.*

INTRODUCTION

Meaningful learning is said to occur when students are able to establish a scientific connection between the concepts they have just learned and the concepts they had learned in their cognitive structure (Ausubel, 1968). Successful learning processes mean that the individual has a more complex network of knowledge in his or her cognitive structure and the process of remembering information is also easier because there is a strong connection between the concepts in the individual's mind (Bahar et al., 2006).

Cognitive structure refers to a structure that reflects the relationship between the concepts that students learned in their long-term memory (Kurt et al., 2013). The cognitive structure is one of the most important factors contributing to student mastery of a topic. Irnidayanti and Kurth (2019) argued that students' ability to form a strong hierarchy of cognitive structures will be the determining factor in the success of learning. According to Ceylan (2015), cognitive structures are important in ensuring meaningful learning, helping to shape the connection between ideas, and facilitating the process of retrieving information.

Tsai and Huang (2002) posited that studies of students' cognitive structures can help teachers to understand the misconceptions that students experience. This is because cognitive structures provide information about what students know and do not know (Kurt et al., 2013). When teachers are able to gain information about what students know and do not know, then teachers will be able to assess the extent to which students master a particular topic. Kurt et al. (2013) also suggested that teachers utilize the findings of the studies on students' cognitive structures when designing their teaching strategies so that the development of high-quality cognitive structures among students can be achieved.

Misconceptions related to biology concepts have been reported to be widespread among high school and university students (Bello, Bello, & Abimbola, 2016). Among the topics identified with many misconceptions are genetics, ecology, respiration, and photosynthesis (Taber, 2009). Misconceptions occur among students because each student has different ideas, knowledge levels, and experiences of different phenomena (Tekkaya, 2002). There are many factors that can contribute to this problem including teachers, parents, or textbooks themselves (Giuseppe & Fraser, 2012). In fact, the use of language that is difficult to understand in textbooks has also led to misconceptions among students (Soeparno, 2005).

Studies on misconceptions, particularly on respiration topics, have been extensively conducted. However, most previous studies focused only on the identification of students' misconceptions without further research to understand the cognitive structure of students experiencing the misconceptions (Ameyaw, 2016; Halim, Meerah, & Halim, 2009; Halim

& Meerah, 2014; Subayani, 2016; Svandova, 2014). Other than identification, many researchers also only focused on the attempt to overcome misconceptions in their research by using various approaches such as animation, learning portal, and learning through playing (Ismail & Halim, 2017; Stephen & Halim, 2017; Vebrianto, Rery, & Osman, 2016).

Kumandas, Ateskan, and Lane (2018) reported that 44% of studies on misconceptions in biology which were conducted from 2000 to 2014 are aimed at identifying misconceptions while only 19% studied cognitive structures. From the intensive literature search, the researchers did not discover any related study concerning cognitive structure which involves secondary school students on the topic of respiration.

Therefore, this study was conducted to delve deeper into the cognitive structures and misconceptions experienced by secondary school students on the respiration topic. Based on the literature, this topic was chosen as the target for this study because respiration has been identified as one of the difficult topics for students (Barman et al., 2006; Mohan, Chen, & Anderson, 2009; Wilson et al., 2006). The objectives of this study were as follows:

1. To study the cognitive structures of students on the topic of respiration.
2. To identify the misconceptions that students have on the topic of respiration.

LITERATURE REVIEW

Many previous studies showed students having difficulty learning and build cognitive structures about respiration and they also experienced misconceptions about this topic (Bahar, Johnstone, & Sutcliffe, 1999; Cimer, 2012; Haslam & Treagust, 1987; Tekkaya & Balci, 2003). This is because the students themselves are unable to grasp abstract concepts and make connections between what they are learning and their daily lives (Anagun et al., 2010; Dede Er et al., 2013; Tasdemir & Demirbas, 2010). Based on previous studies on cognitive structures, it was reported that students failed to form an association or have low strength of association for important words related to the concept and often established an insufficient association for a given keyword or concept (Ozarslan & Cetin, 2018; Uzun, Ozsoy, & Keles, 2010). Other than that, research carried out by Sikumbang, Rakhmawati, and Suwandi (2019) indicated that the information processing modes most students use are 'defining' and 'describing' only. Both modes are categorized as low-level cognitive rather than 'comparing' and 'formulating' which are categorized as high-level cognitive.

According to Smith, Disessa, Roschelle (1994), misconceptions are naive scientific explanations or incomplete scientific concepts and are shared by many other students. Misconceptions are students' understandings that are strongly held by them and often difficult to change (Dagdelen & Kosterelioglu, 2015). Bahar (2003) explained that misconceptions occurred when there is a significant discrepancy between students' existing understanding and the scientific consensus of a concept. Many argued that misconceptions are based on students' existing knowledge that deviates from the facts but misconceptions can also happen after the learning process in the classroom had occurred (Yenilmez & Tekkaya, 2006). There are five types of misconceptions that have been identified, which are preconceived notions, non-scientific beliefs, conceptual understandings, vernacular misconceptions, and factual misconceptions (Patil, Chavan, & Khandagale, 2019).

The misconception issue needs to be emphasized because the misconceptions that students experience during schooling will usually continue until they enter higher education institutions (Murni, 2013). Nevertheless, misconceptions are difficult to detect through the summative assessment often used by teachers because such assessments are developed to measure how well students are able to recall the facts they learned (Bransford, Brown, & Cockong, 2000). The aspect of misconception detection in students is also less emphasized by the teachers as the emphasis is only on the overall achievement in a given subject. Among the methods used in previous studies to identify misconceptions are multi-tier diagnostic tests, open-ended questions, multiple-choice questions, drawing methods, concept inventories, and word relationship tests (Patil, Chavan, & Khandagale, 2019).

There are many misconceptions about respiration that researchers have successfully documented based on past studies (Gunes et al., 2012; Keles & Kefeli, 2010; Kurt et al., 2013). Among them, students believed that plants undergo respiration through the process of photosynthesis and photosynthesis is a process of respiration that occurs during the day. They also believed plants undergo photosynthesis during the day and perform respiration at night (Gunes et al., 2012). Students also described respiration as a process of exchange of gas and plants performing respiration rather than photosynthesis when in a dark environment (Keles & Kefeli, 2010).

METHODOLOGY

This is a qualitative study using the survey research design. The sampling method used in this study was purposive sampling in which the criterion that has been determined as the sample must be among students who had studied the respiration topic in biology. This study involved 23 students consisting of 12 boys and 11 girls. All of these students attended the same class in one secondary school in Kajang. The students were chosen as the sample for this study since they met the criterion that has been determined earlier.

The instruments used in this study were the Word Association Test (WAT) and the Questionnaire of Writing Sentence (QWS) (Ozarslan & Cetin, 2018). WAT is a commonly used test for studying the cognitive structure of students and it has also been proven effective in identifying misconceptions (Kurt, 2013; Yucel & Ozkan, 2015; Zan, Zan, & Morgil, 2015). In this study, WAT was used to study students' cognitive structures while QWS aimed to identify students' misconceptions about respiration topics. In WAT, students were required to write 10 words that come to their mind when reading a given keyword. Students had to write 10 words in 60 seconds. There were 10 keywords provided in this WAT, namely cell respiration, aerobic respiration, anaerobic respiration, adenosine triphosphate (ATP), respiratory structure, compensation point, gaseous exchange, breathing mechanism, gas transportation, and glucose. All of these keywords were written in 10 different pages and each keyword was written 10 times on one page and followed by QWS at the bottom of the page. The purpose each keyword was written 10 times on one page was to avoid the risk of 'chain responses' where students provided answers based on their previous answers (Bahar, Johnstone, & Sutcliffe, 1999). For QWS, students were also given 60 seconds to write one sentence that comes to their mind when reading a given keyword.

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Cell respiration: ______________________________

Example sentence:

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Figure 1: Sample Page of the Instrument

For the data analysis process, students' answer sheets were numbered from 1 to 23. This number represented the student's name during the data analysis process to facilitate the researcher to identify the owner of the answer sheet (Kurt et al., 2013). For WAT, words written by students in the answer space were recorded and counted separately by each keyword. Words with the same meaning will only be counted once, while words that are irrelevant, unrelated to the topic, or appear only once will not be considered. Next, the breakpoint (BP) value was determined based on the highest frequency of the word that the student wrote for a keyword. The intervals of 3 to 5 that were lower than the highest recorded value will be used as BP (Bahar, Johnstone, & Sutcliffe, 1999). In this study, the highest frequency recorded was 23 and the interval used was 3. There were five BPs used, namely 20 to 23, 16 to 19, 12 to 15, 8 to 11, and 4 to 7. Words that were at the highest BP value were 20 to 23 which meant that the word has the strongest association with keywords in the student's cognitive structure (Ozarslan & Cetin, 2018).

The analysis for QWS was done according to categories in which students' written sentences were categorised into three categories: sentences containing scientific knowledge, sentences containing non-scientific or not in-depth knowledge, and sentences containing misconceptions (Ercan, Tasdere, & Ercan, 2010). Phrases that were not related to the topic of respiration were excluded from data analysis (Kurt, 2013).

FINDINGS AND DISCUSSION

Once the data analysis process was completed, the data were compiled and presented in tables and mind maps so that they are more systematic and easy to understand. The findings of this study had successfully answered and clarified the objectives.

The findings of the first objective of the students' cognitive structures were presented in the forms of tables and mind maps. Table 1 shows the total number of words students wrote as well as the highest word frequency by keyword. The keywords with the highest number of words were 'respiratory structure' with a total of 206 words while 'glucose' had the minimum number of words of only 60 words. The total number of words students wrote for all keywords was 1408 words. The word 'energy' was the word with the highest frequency written by students in response to four keywords, namely 'cell respiration', 'aerobic respiration', 'adenosine triphosphate (ATP)', and 'glucose'.

Table 1: Number of Words Written by Students and the Words with the Highest Frequency According to Keywords

Keywords	Total number of words written by students	Words with the highest frequency
Cell respiration	148	Energy (23)
Aerobic respiration	143	Energy (22)
Anaerobic respiration	180	Lactic acid (22)
Adenosine triphosphate (ATP)	96	Energy (20)
Respiratory structure	206	Lungs (23)
Compensation point	95	Light intensity (21)
Gaseous exchange	160	Oxygen (23), alveolus (23)
Breathing mechanism	170	Lungs (18)
Gas transportation	150	Oxygen (21), blood vessel (21)
Glucose	60	Energy (22)
Total	1408	

Next, mind maps were constructed to illustrate the students' cognitive structures on the topic of respiration based on the words written by students in the WAT. Five mind maps were constructed sequentially according to the BP values from the highest of 20-23 to the lowest BP of 4-7 (refer to Figure 2 until Figure 6).

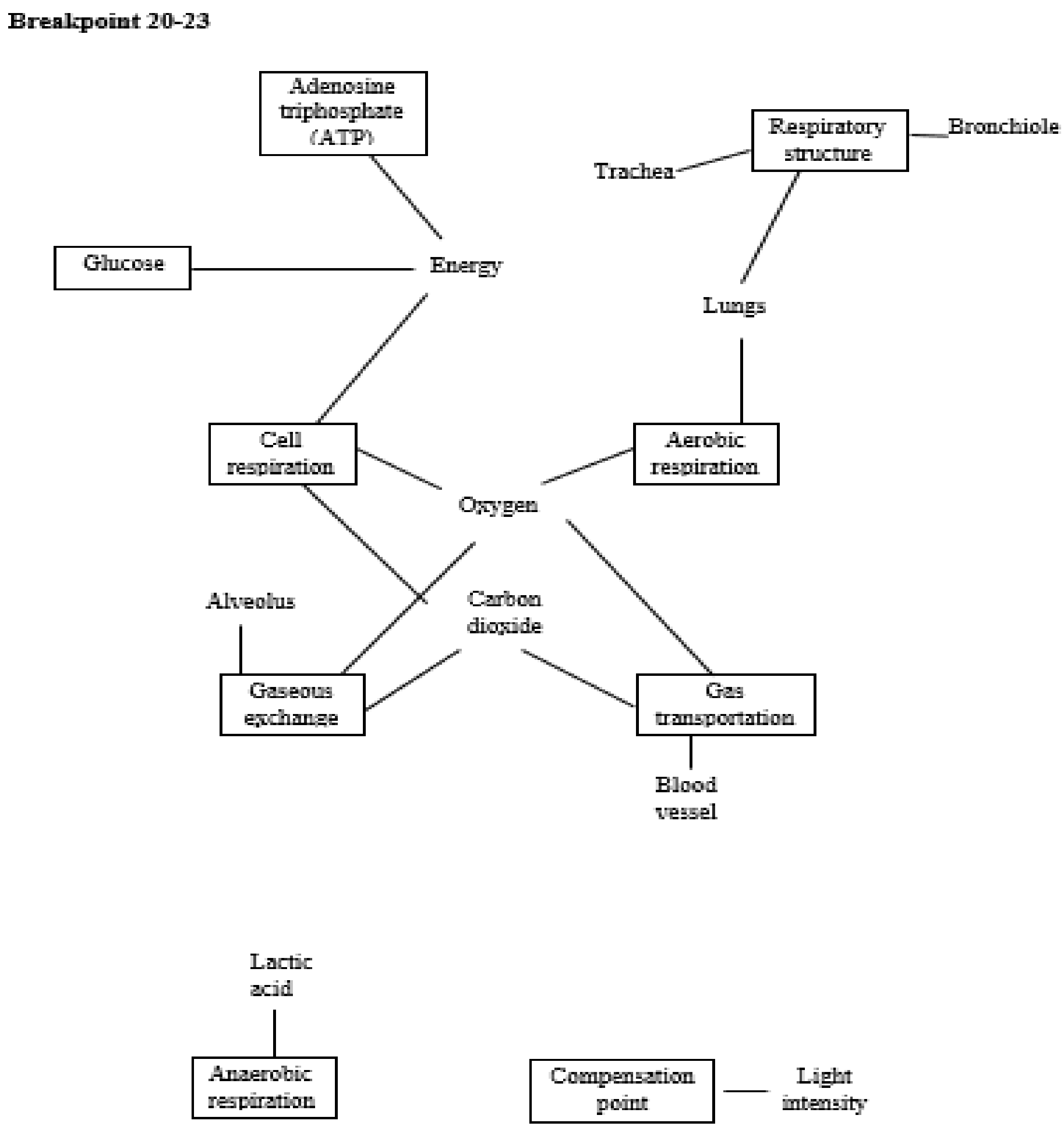

Figure 2: Mind Map According to BP 20-23

Breakpoint 16-19

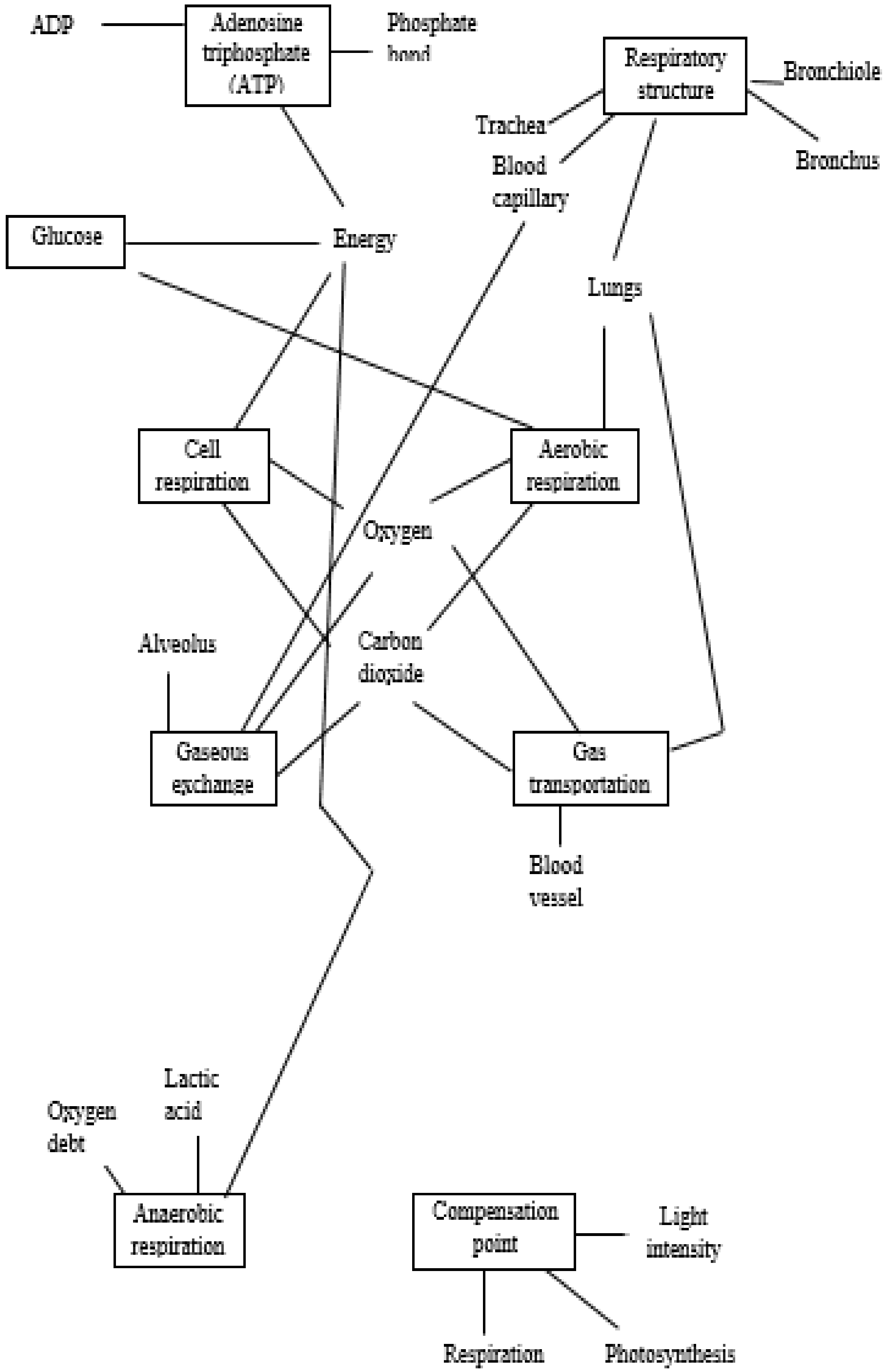

Figure 3: Mind Map According to BP 16-19

Breakpoint 12-15

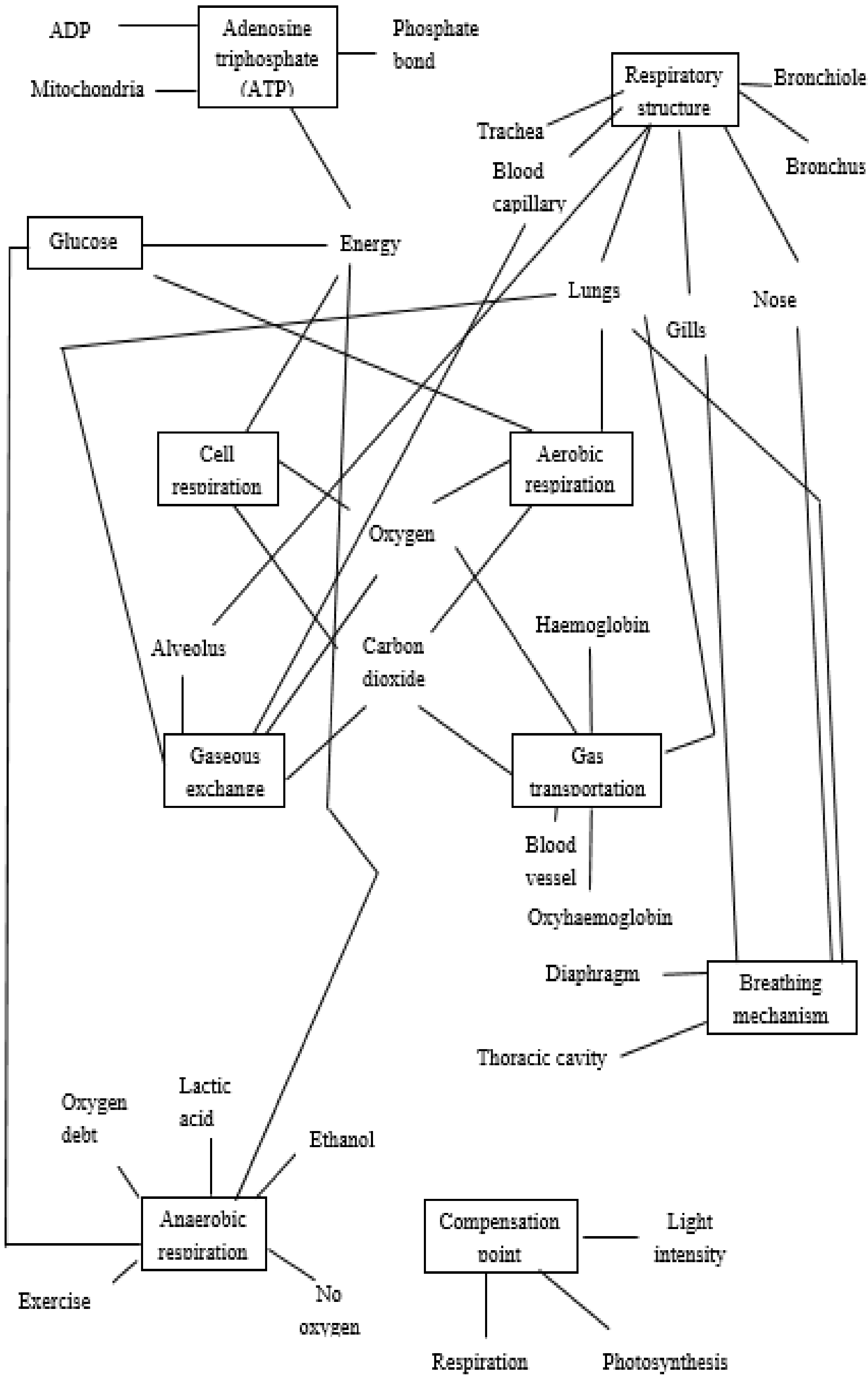

Figure 4: Mind Map According to BP 12-15

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Breakpoint 8-11

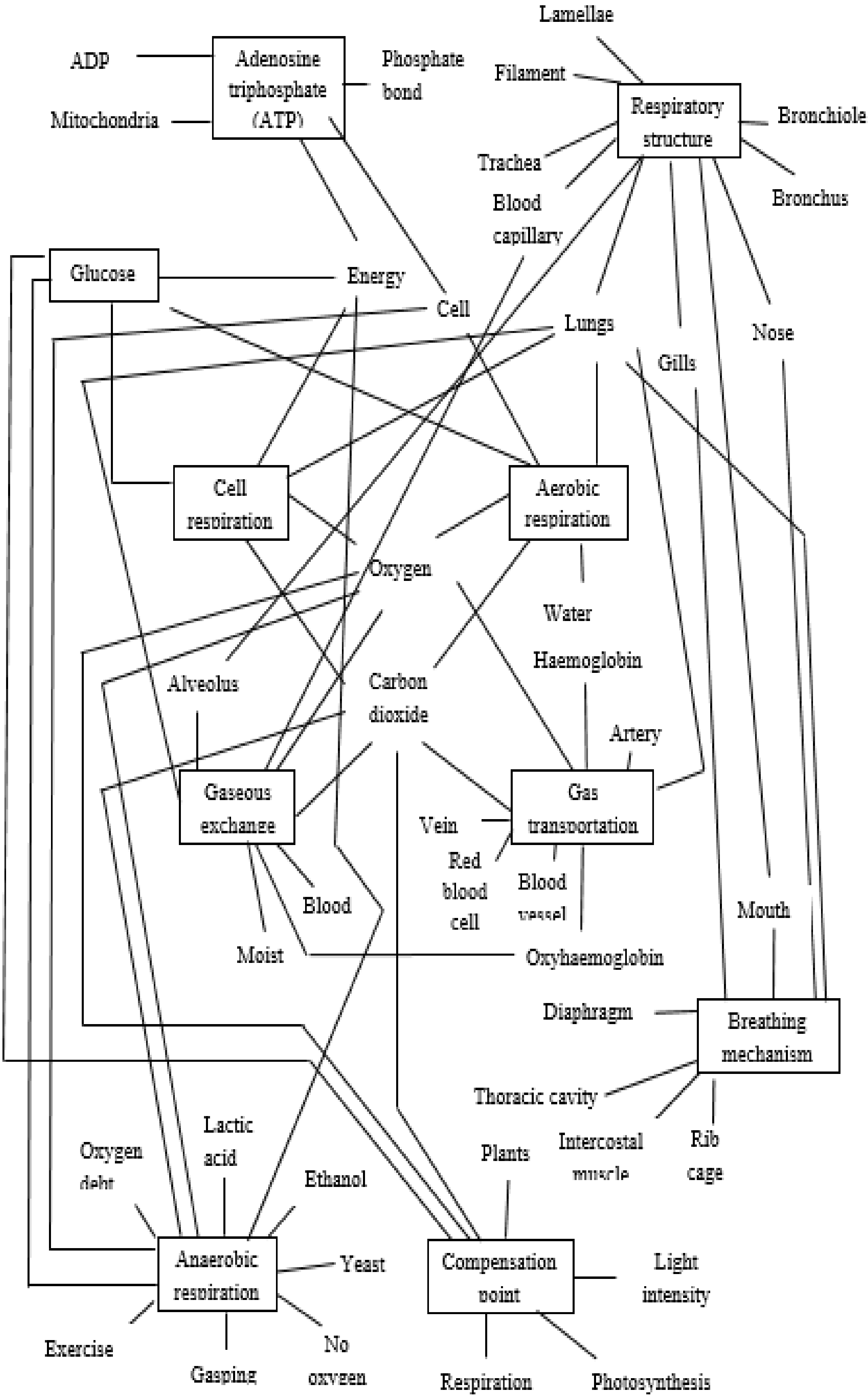

Figure 5: Mind Map According to BP 8-11

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Breakpoint 4-7

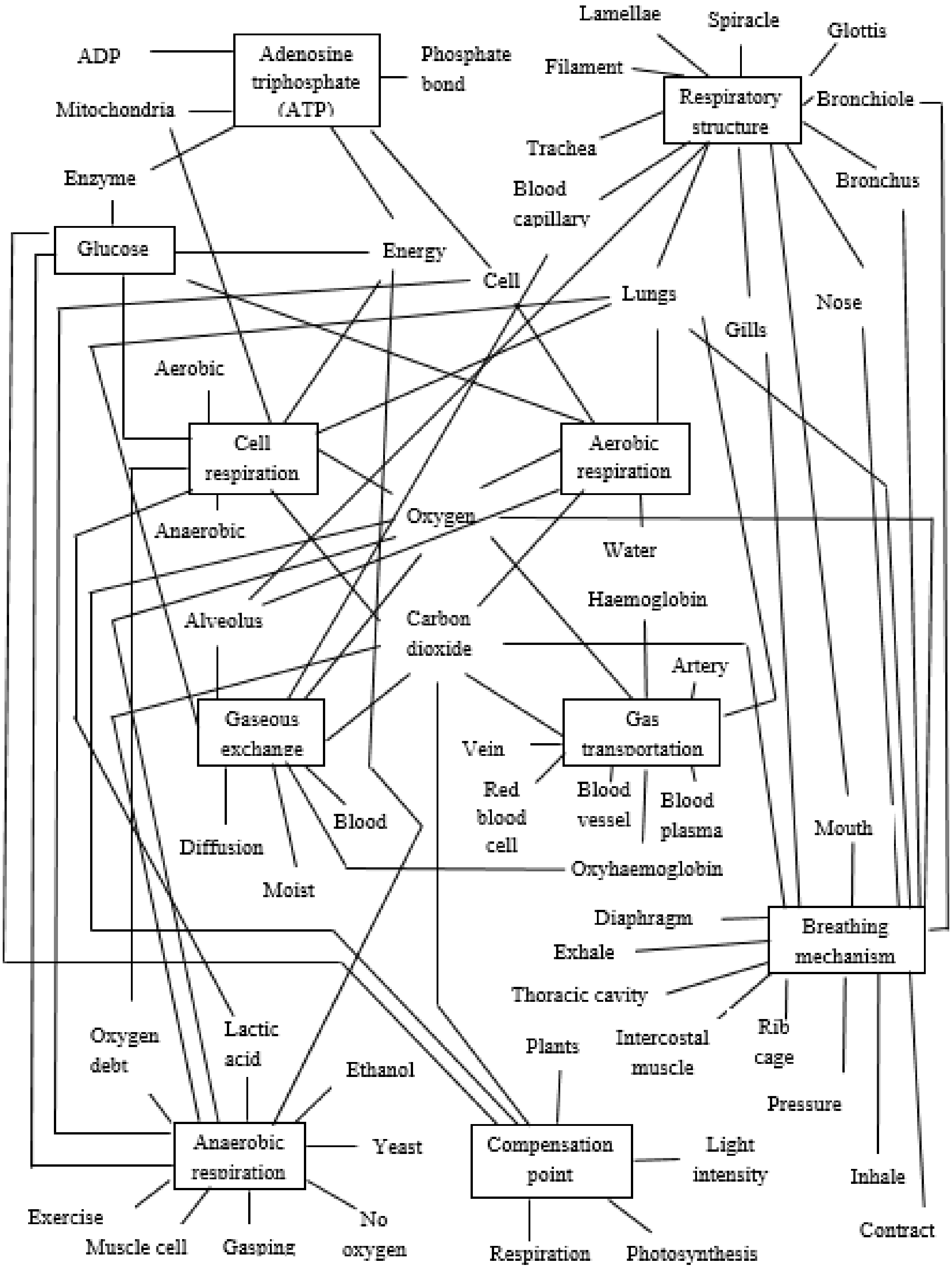

Figure 6: Mind Map According to BP 4-7

Based on the five mind maps generated (refer Figure 2 until Figure 6) from the BP values, the keywords that had the strongest association in the hierarchy of student cognitive structures, namely BP values of 20 to 23, were ‘cell respiration’, ‘aerobic respiration’, ‘anaerobic respiration’, ‘adenosine triphosphate (ATP)’, ‘respiratory structure’, ‘compensation point’, ‘gaseous exchange’, ‘gas transportation’, and ‘glucose’ (refer Figure 2). Only the keywords for the ‘breathing mechanism’ were in the third-highest hierarchy with BP values of 12 to 15 (refer Figure 4). The students were found to be able to establish a scientific and meaningful relationship to each keyword for BP values of 20-23 and able to provide scientific answers or terms such as lactic acid, oxygen, carbon dioxide, alveolus, and bronchial. This is contrary to the findings of Ozarslan and Cetin (2018) which found that most students write words related to their daily lives or past experiences for the highest cognitive hierarchy. Yucel and Ozkan (2015) also reported that students usually write examples of their experiences in daily life as an answer rather than writing scientific terms for a given keyword.

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However, for lower BP values of 8 to 11 (refer Figure 5) and 4 to 7 (refer Figure 6), students were found to exhibit inaccurate correlations in their cognitive structures. For example, for the 'breathing mechanism' keyword, the student answers mouth while for the 'gaseous exchange' keyword, the answer is oxyhemoglobin. Both of these answers were incorrect and irrelevant to the keywords. Bahar and Ozatli (2003) also reported similar findings in which students were found to form unrelated associations between DNA and ATP, RNA and ATP, energy and vitamins, minerals and vitamins, carbohydrates, and air, as well as water and energy. Although these unscientific associations occur in the hierarchy of relatively low cognitive structures, this indicates that students were still unable to master the topic of respiration as a whole. This indicated that there was an error in the students' cognitive structures, especially on the topic of respiration. Ozarslan and Cetin (2018) emphasized that the formation of perfect cognitive structures is essential to ensure meaningful learning, especially in biology education.

The students' cognitive structures were still incomplete and could be seen when the students failed to establish relationships between important concepts and the given keywords. For the 'cell respiration' keyword, students were unable to associate this keyword with important words such as cell. A study by Bahar and Ozatli (2003) on the topic of basic components of living things also found that students could not formulate the relationship between the keyword 'enzyme' and the word 'cofactor'. The students were not only unable to establish important relationships between some concepts, they were also found to have a poor cognitive structure for other concepts. For example, the word 'mitochondria' which was one of the major key points that teachers often emphasize for cell respiration only appeared in the lowest cognitive hierarchy of BP 4-7. The word 'yeast' only appeared for BP 8-11 although it was one of the most important words for 'anaerobic respiration' keyword. A similar finding was also found in the study by Ozarslan and Cetin (2018), in which they discovered that the relationship between the keyword 'enzyme' and the word 'protein' which is an important word related to 'enzyme', only appeared in the lowest hierarchy of cognitive structures among students.

This could be attributed to the nature of the word itself being abstract, thus making it difficult for students to make connections between the word and the given keywords (Yildirir & Demirkol, 2018). Often, students were more likely to remember and relate what they had learned to something that is visible and closely related to their daily lives. Thus, this study managed to reaffirm the findings documented by previous studies on cognitive structures which were mainly related to the students' inabilities to form the correct association, had low strength of association for important words related to the concept, established an incomplete association for a given keyword or concept as well as failed to understand abstract concepts.

Furthermore, students' knowledge about this topic only focused on human and animal respiration. This can be evidenced by the 'respiration structure' keyword in which none of the words written by the student were related to plants. All of the answers written by students were related to humans and animals such as lamellae, glottis, trachea, lungs, and bronchus. This indicated that students' mastery of the topic of respiration was still limited and incomplete. Kurt et al. (2013) also demonstrated in their study that students' knowledge of respiration topics was insufficient and much of their knowledge was incomplete, incorrect, and contained misconceptions.

Although plants do not have specialized organs for gaseous exchange compared to animals, plants have certain structures involved in the exchange of gases such as roots, stems, and leaves while the exchange of gases between plant cells and the environment occurs through stomata and lenticels. This finding is in line with the study conducted by Cokadar (2012), in which he found that students tend to have misconceptions about concepts related to plant respiration. This finding could be related to the arrangements of information in the biology textbook used by the students in which the subtopic for respiration in plants was separated from the subtopic for respiration in animals and humans. This might be the reason why students cannot link the idea that respiration involves plants as well.

Table 2 shows the number of sentences written by students according to category. The total number of sentences written by students was 213 out of 10 keywords. The categories with the most number of sentences were sentences containing scientific knowledge with 142 sentences (67%), followed by sentences containing misconceptions with 51 sentences (24%), and sentences containing non-scientific or not in-depth knowledge which comprised 20 sentences (9%). The keyword with the most sentences containing misconception was 'cell respiration' with a total of 10 sentences. The keywords that had the sentence with the least misconception were 'adenosine triphosphate (ATP)' and 'gas transportation' with just one sentence respectively.

Table 2: Number of Words by Category

Keywords	Sentences that contained scientific knowledge	Sentences that contained neither scientific nor in-depth knowledge	Sentences that contained misconceptions	Total number of sentences	No response or sentences not related to the topic
Cell respiration	9	4	10	23	-
Aerobic respiration	16	-	7	23	-

Anaerobic respiration	14	-	9	23	-
Adenosine triphosphate (ATP)	15	2	1	18	5
Respiratory structure	14	5	4	23	-
Compensation point	15	-	5	20	3
Gaseous exchange	20	-	2	23	-
Breathing mechanism	9	5	8	22	1
Gas transportation	20	2	1	23	-
Glucose	10	2	3	15	8
Total	142	20	51	213	17

Table 3: Example Sentences by Category

Keywords	**Sentences that contained scientific knowledge**	**Sentences that contained neither scientific nor in-depth knowledge**	**Sentences that contained misconceptions**
Cell respiration	Cell respiration is divided into two parts, namely aerobes and anaerobes.	Cell respiration is required by cells to function properly.	Cell respiration is a process involving the exchange of oxygen and carbon dioxide.
Aerobic respiration	Aerobic respiration produces energy, carbon dioxide, and water.	-	Inhaled oxygen contains glucose to be converted into energy for the human body.
Anaerobic respiration	Anaerobic respiration causes oxygen debt.	-	Anaerobic respiration is an incomplete respiration that converts oxygen and glucose to lactic acid and energy as well as glucose.
Adenosine triphosphate (ATP)	ATP is the end result of energy-based respiration.	ATP means adenosine triphosphate.	ATP is used during anaerobic respiration.
Respiratory structure	Respiratory structures are the lungs, mouth, nose, and trachea	Each organism has its own respiratory structure.	The human respiratory structure comprises the trachea, bronchus, bronchiole, lungs, alveolus, and heart.
Compensation point	The compensation point is when photosynthesis rates and respiration rates are the same.	-	The compensation point is when the product of respiration = the product of photosynthesis.
Gaseous exchange	The gaseous exchange takes place through simple diffusion.	-	Oxygen dissolves in oxygenated blood in the blood capillaries.
Breathing mechanism	When breathing in, the lungs expand, the rib cage goes up and the diaphragm relaxes and vice versa when breathing out.	A respiratory mechanism is required for every human being.	Fish's breathing mechanism is gills.
Gases transportation	Hemoglobin combines with oxygen to form oxyhemoglobin.	Gas transportation carrier gas for gas exchange.	Oxygen passes through the alveolus and into the blood capillaries to the body cells for air exchange.
Glucose	Glucose produces lactic acid and energy during anaerobic	The fruit cake contains a lot of glucose.	The process of respiration and photosynthesis

respiration	produces glucose

In addition to the mind maps, the weakness of the students' cognitive structures could also be seen in the written sentences in which the sentences contained ideas that deviated from the correct scientific knowledge. For the keyword 'cell respiration', the biggest misconception that students had was that they thought cell respiration was the process of exchanging oxygen and carbon dioxide. Students were still unable to distinguish between external and internal respiration (cell respiration). This indicated that the students' level of understanding of cell respiration was low or out of depth. According to Oztas and Oztas (2012), students thought that respiration was synonymous with breathing which refers to the process of exchange of oxygen and carbon dioxide. Harman (2012) in his study also concluded that students had an incomplete or wrong understanding of the definition and purpose of respiration.

The misconception about the 'breathing mechanism' keyword was that most students thought that breathing mechanism and respiratory structure were the same. Based on the written text, students submitted examples of respiratory structures such as gills, spiracles, and lungs as breathing mechanisms. Students were unable to distinguish between breathing mechanisms that referred to the process of breathing and respiratory structures that referred to the organs involved in respiration. This could be attributed to the abstract nature of a concept in which students often had difficulty understanding something that cannot be seen with the naked eye. According to Badenhorst et al. (2015), misconceptions often occurred when students needed to associate what they were learning with something they could not see. Previous studies had also shown that students had difficulty in understanding the abstract aspects of a concept in addition to failing to relate what they were learning to their daily lives (Anagun et al., 2010; Dede Er et al., 2013; Kurt et al., 2013; Tasdemir & Demirbas, 2010).

The results of this study benefit educators in which teachers can identify in a more detailed manner about which concepts or subtopics that are difficult to understand and potentially cause misconceptions among students. Furthermore, the findings of this study also help teachers to design appropriate learning strategies to enhance students' understanding and mastery of these topics while avoiding the issue of misconceptions.

CONCLUSION

In conclusion, based on the results of this study, the cognitive structures of secondary school students were still incomplete and needed to be improved. Students were still unable to form relationships between important concepts in the topic of respiration in their cognitive structures. There were also incorrect associations between the concepts which might be one of the contributing factors for misconceptions. The students also encountered misconceptions in all of the keywords, in which the highest number of misconceptions was for the 'cell respiration' keyword. Incomplete cognitive structures as well as the existence of misconceptions indicated that students' mastery of the topic of respiration was still at an unsatisfactory level.

LIMITATION AND STUDY FORWARD

This study is a qualitative study that only involved 23 students in one school. Thus, the findings are limited for this sample only and cannot be generalized to the whole population of students in Malaysia. For future studies, these WAT and WQS might be improved in terms of the use of different keywords. In addition, the texts written in WQS could also be studied in more detail in terms of information processing modes such as defining, explaining, describing, and comparing. This study could also be extended to higher education students such as matriculation or university.

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AUTHORS CONTRIBUTION

Author 1: Conceptualisation, writing the original draft.

Author 2: Conceptualisation, writing the original draft.

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