ASIA PACIFIC JOURNAL
OF EDUCATORS AND EDUCATION

Volume 36, Number 1, 2021
https://doi.org/10.21315/apjee2021.36.1.9

Research Article:

A Diagnosis of Students' Misconceptions of Photosynthesis and Plant Respiration

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ABSTRACT

This study aims to identify common misconceptions about photosynthesis and plant respiration among Form Four (Grade 10) students by developing two-tier multiple-choice test questions. This descriptive survey research was carried out using a quantitative approach, with 500 study samples. The items in Photosynthesis and Plant Respiration Diagnostic Test (PRDT) was designed in two parts; Part One tested the students' knowledge of concepts, and Part Two tested the students' understanding and reasoning. Rasch analysis was used to obtain the option probability curves for each item. The option probability curves present a visual image of the distribution of correct answers and misconceptions across the spectrum of student knowledge. The findings showed that students had 43 common misconceptions, which can be categorised into the inability to trace matter, energy as well as scale and location. The findings brought significant implications on the progress of the teaching and learning of Biology.

Keywords: Misconception, photosynthesis, plant respiration, two-tier multiple-choice questions test, option probability curves

Received: 27 Aug 2020; **Accepted:** 10 Jul 2021; **Published:** 25 Aug 2021

To cite this article: Lim, H. L., & Poo, Y. P. (2021). A diagnosis of students' misconceptions of photosysthesis and plant respiration. *Asia Pacific Journal of Educators and Education, 36*(1), 155–176. https://doi.org/10.21315/apjee2021.36.1.9

INTRODUCTION

Biology subject at the secondary or high school level provides students with knowledge and skills in science and technology, enabling them to solve problems and make decisions in everyday life based on scientific attitudes and noble values across the spectrum of disciplines within the subject. Photosynthesis and respiration, for instance, has become a core scientific topic in Biology that plays a critical role in environmental issues. It facilitates the students to understand the balance between oxygen and carbon dioxide in the environment. Photosynthesis produces the oxygen to replenish the ones used up by living organisms during the process of respiration. On the other hand, carbon dioxide is produced during the process of respiration that necessitate plants to perform photosynthesis. This topic, which is included in the Biology curriculum at secondary or high school levels in many countries (Köse, 2008), focuses on the concept of photosynthesis and plant respiration, as well as the differences between photosynthesis and plant respiration from various aspects.

However, several misconceptions in the learning of this topic have been identified. Throughout the years, misconceptions about photosynthesis and plant respiration are well documented (Treagust & Haslam, 1986; Amir & Tamir, 1990; Marmaroti & Galanopoulou, 2007; Köse, 2008; Cullinane & Liston, 2011; Svandova, 2014; Galvin et al., 2015). For instance, Marmaroti and Galanopoulou (2007) revealed that most Greek students aged 13 found that photosynthesis is a very difficult Biology topic because of the conflicting information they obtain about photosynthesis and respiration. They understand photosynthesis is an integral constituent of processes that are taking place in the green parts of plants, primarily in the leaves. However, they do not understand the function and presence of chlorophyll, even though they know that chlorophyll is a necessary constituent of photosynthesis. Svandova (2014) found that many lower secondary students do not even understand the fundamental concept that photosynthesis and plant respiration have mutually connected physiological functions. Jayanti and Rahayu (2019) found similar misconceptions about photosynthesis and respiration, indicating that misunderstandings regarding these topics were not properly resolved. Similar results found that misconceptions about photosynthesis and respiration in plants still exist among junior high school students, leading to the conclusion that photosynthesis and respiration are the most frequently investigated misconception in science learning (Anjarsari, 2018).

Parker et al. (2012) claimed that even undergraduates still lack both a basic understanding of the role of photosynthesis in plant metabolism and the ability to reason with scientific principles when learning new content. In short, a significant source of confusion for students is the basic concept of photosynthesis and respiration in a plant and the relationship between them. Many students believe that plants do not respire at all; they misunderstand that photosynthesis is like respiration in a plant (Amir & Tamir, 1990; Köse, 2008). Students believe that photosynthesis provides the plant with energy directly without going through the respiration process (Tekkaya, 2002; Köse, 2008).

Misconceptions in photosynthesis and respiration in plants will prevent students' meaningful and permanent learning; it seriously impacts students' future learning. Such misconceptions hinders students from learning more advanced concepts. Furthermore, when students' initial understanding is not carefully resolved, they may fail to grasp new concepts and information presented in the classroom and simply learn for the purpose of passing a test and thus, relate and apply their misconceptions outside the classroom.

There are a few diagnostic tools available abroad to diagnose students' misconceptions about photosynthesis and respiration in a plant, as mentioned earlier. For example, Svandova (2014) developed a research tool using modified tools developed earlier by Treagust and Haslam (1986), with some modifications for the Czech environment. Köse (2008) used a drawing method as a diagnostic tool to diagnose students' misconceptions of these concepts. All these studies relied solely on the percentage method to analyse the types of misconceptions.

This method has limitations compared to the misconception analysis based on Option Probability Curves (OPC) through the Rasch model. The use of the OPC curve to identify the types of misconceptions made by students is based on the student's level of ability. This analysis method is more straightforward and systematic compared to the percentage methods used by the previous studies. This means that the OPC curve has advantages in terms of identifying student misconceptions. It should also be noted that the type of misconceptions faced by high ability students might be different from low ability students (Chang & Lo, 2015; Herrmann & DeBoer, 2011b; 2016; Khong & Lim, 2019). Besides, the OPC curve analysis in the Rasch Model has a higher degree of reliability compared to the percentage method (Herrmann & DeBoer, 2011a, 2016; Chang & Lo, 2015) because students' misconceptions in OPC curve is analysed based on their ability level rather than an average or percentage.

Research Objectives

This study aims to identify misconceptions about photosynthesis and plant respiration held by secondary students using Photosynthesis and Plant Respiration Diagnostic Test (PRDT). OPC was used to identify the types of misconceptions made by students, based on their ability level.

Common Misconceptions in Photosynthesis and Plant Respiration

A diagnostic test helps to identify misconceptions in students' understanding. Based on the literature review, there are considerable misconceptions about photosynthesis and plant respiration. All the misconceptions were detected through diagnostic test and could be grouped into three categories: misconceptions connected to the inability to trace matter, misconceptions connected to the inability to trace energy, and misconceptions connected the inability to trace scale and location (Parker et al., 2012). Misconceptions connected to the inability to trace matter included failure to identify matter that changed

in photosynthesis and respiration, inability to distinguish matter and energy, inability to trace atoms and failure to conserve matter. Misconceptions connected to not tracing energy included failure to identify the form of energy in transformation, the nature of energy, conserve energy and identify the process that transfers energy in photosynthesis and plant respiration. Lastly, the misconception of not tracing scale and location included not knowing and failure to explain the structure of the system involved in photosynthesis and plant respiration. Table 1 shows a summary on how misconceptions about these topics are categorised based on the biological scope in photosynthesis and plant respiration.

Table 1. The scope of common misconceptions in photosynthesis and plant respiration

Type of misconceptions	Scope
Misconceptions connected to not tracing matter	• Identifying the matter that changes, that is, the inputs and outputs of a system or the reactants and products of a reaction or set of reactions • Distinguishing matter from energy • Tracing atoms • Conserving matter
Misconceptions connected to not tracing energy	• Identifying the energy that is transformed or transferred and the forms of energy involved • Describing the nature of the transformations or transfers • Conserving energy • Identifying processes that transfer or transform information
Misconceptions connected to not keeping track of scale and location	• Knowing the structure of the systems in which the relevant processes are taking place and how they facilitate the function • Selecting the appropriate level/scale in which to reason

Note: Adapted from Parker et al. (2012)

Theoretical Framework

It was important to study how concepts were formed in learners' minds before the identification of misconceptions could be accomplished. Hence, this framework is about how the conceptual understanding is formed, followed by the categorisation of misconceptions as the results of a diagnostic test.

Piaget's Cognitive Development Theory (McLeod, 2015) and Ausubel's Assimilation Learning Theory (Novak, 1993) can be used to explain the process of constructing knowledge. According to Piaget (McLeod, 2015), learners construct their understanding and new knowledge through experiencing things and reflecting on these experiences. Learners' adaptation to the environment is controlled through mental organisations called schema. Schemas are building blocks of knowledge that learner can use to represent the world and designate an appropriate action. However, for understanding to occur, the content of learning must be potentially meaningful, and the learners must relate it in a meaningful way to their prior knowledge.

Ausubel's Assimilation Learning Theory (Novak, 1993) was applied to define what meaningful learning is. In the process of meaningful learning, assimilation occurs when learners plugged new knowledge into an existing schema, whereas accommodation occurrs when learners reconceptualise new knowledge in order to understand. It can be concluded that students gained conceptual understanding about photosynthesis and plant respiration only after they have undergone meaningful learning about these topics. However, the process of assimilation and accommodation in meaningful learning are sometimes affected by learners' cognitive construal, which leads to wrong conceptual understanding, referred to as misconception.

The Biology Thinking Development Model (Coley & Tanner, 2012) explains how cognitive construal affected meaningful learning and leads to biological misconceptions. According to the model, there were three types of construal, namely teleological thinking, essentialist thinking and anthropocentric thinking. Connections between each of these cognitive construals has relevance in understanding misconceptions commonly encountered in Biology classrooms.

The first type of cognitive construal is teleological thinking, which is widespread cognitive construal that is useful in helping us make sense of many aspects of the world around us through causal reasoning. However, this natural form of explanation is often extended inappropriately in the domain of Biology. Students at all levels commonly explain biological structures and processes by reference to their supposed purpose, goal or function. But not all biological concepts can be linked through causal reasoning. The second type of cognitive construal, called essentialist thinking, refers to a set of assumptions that people make about concepts. A core property or feature of a biological structure, species or system determines its overt features and identity through assumptions. If students make the wrong assumptions, then misconceptions can occur. The third type of cognitive construal, anthropocentric thinking, is the tendency to reason about unfamiliar biological species or processes by analogy to humans. Trying to understand an unfamiliar idea or situation by comparing it to humans is wrong as this leads to misconceptions.

The application of theories and models in this research brought a clearer picture of how misconceptions were formed among students. Students' understanding needs to be further analysed to detect whether there are any misconceptions. The main concern of this research is to identify the misconceptions among students, but not to further analyse how cognitive construal affected each misconception found. Knowing that the connections between each of three cognitive construals have some relevance in understanding misconceptions commonly encountered in Biology classrooms, researchers can design and develop a more appropriate instrument to diagnose the misconceptions about photosynthesis and plant respiration among students. Without an understanding and ability to apply these principles, students would not have the foundation to build a more elaborate and detailed understanding. Therefore, the use of the diagnostic test in identifying misconceptions is essential.

METHODOLOGY

In this study, a quantitative approach with a descriptive survey design was used to investigate secondary school students' common misconceptions about photosynthesis and plant respiration (Note: The average age of the students is 16 years old). The function of the survey was to collect data to describe a population that is way too large to be observed directly. There were 31 secondary schools in the East-West District, Pulau Pinang, Malaysia, whereby data collection from the whole population would be difficult. Therefore, 15 schools were selected through random sampling from these 31 schools to sample the study participants. The sample comprised 500 students from the selected 15 schools. In every school, the sample included all students from average-performing classes and low-performance classes that were randomly taken. Fifty percent (50%) of the respondents were from average-performance classes, and another 50% were from low-performance classes. This is because students in high-performance classes normally score well in the examination, meaning their understanding of scientific concepts is better compared to those who are not performing well in the examination.

The PRDT is a two-tier diagnostic test consisting of 18 items developed by the researcher. Analysis was performed on the PRDT instrument as a whole; the reliability of the item was 0.99, while the separation of item was 8.47. In this study, the researcher determined the construct validity of PRDT by focusing on the analysis of unidimensionality, fit statistic, item map and differential item functioning (DIF). As a result, the item's PRDT reliability was reported at 0.99.

The test items were prepared based on learning objectives and outcomes, propositional statements and from students' responses in the open-ended pre-test questions. The two-tier diagnostic test in the form of a multiple-choice test consisted of two tiers or parts. The first tier of each item consisted of content knowledge questions designed to assess the students' knowledge about photosynthesis and plant respiration and has two choices, "Yes" and "No". The second tier of each multiple-choice item contained the reasons for selecting the responses to the first tier and a set of four choices that were possible reasons for the answers given to the first part. The reasons consisted of the designated correct answers together with the distractors identified by open-ended pre-test questions, and some were based on literature reviews. The distributions of items according to dimensions of PRDT are shown in Table 2.

Table 2. Distribution of PRDT items based on different dimensions

Dimension (Misconception)	Item no.		Total item
	Photosynthesis	Respiration in plant	
Not tracing matter	1a, 1b, 2a, 2b, 5a, 5b	3a, 3b, 4a, 4b, 6a, 6b	12
Not tracing energy	7a, 7b, 9a, 9b, 11a, 11b	8a, 8b, 10a, 10b, 12a, 12b	12
Not tracing scale and location	13a, 13b, 15a, 15b, 18a*, 18b*	14a, 14b, 16a, 16b,17a, 17b, 18a*, 18b*	12

Note: * covered both content photosynthesis and respiration in plant

Data collected from the PRDT instrument was analysed quantitatively using the Rasch Model. In the dichotomous Rasch Model, the probability that a student would respond to an item correctly is determined by the difference in the student's overall performance level and the difficulty of the item, according to the following equation:

$$\ln\left(\frac{P_{ni}}{1 - P_{ni}}\right) = B_n - D_i$$

P_{ni} is the probability that student n of overall performance level B_n will respond correctly to item i with a difficulty of D_i (Bond & Fox, 2015). In Rasch measurement, individuals' ability and items' difficulty are estimated simultaneously (Gavin et al., 2015). They can be compared on a common scale, called a logit scale, based on the chance that each individual would answer each item correctly (Gavin et al., 2015).

WINSTEPS (Linacre, 2012) was used to estimate the students' understanding of the topic and the item's level of difficulties. A person having a greater ability than another should have the greater probability of solving any item of the type in question, and similarly, one item being more difficult than another one means that for any person, the probability of solving the second item correctly is the greater one.

WINSTEPS was used to obtain option probability curves for each item (Linacre, 2012). The option probability curves generated during Rasch modelling present a visual image of the distribution of correct answers and misconceptions across the spectrum of student knowledge. Therefore, to represent the data more accurately and provide additional information about the misconceptions students have, each answer choice was analysed separately. The four curves, one for each answer choice, show the probability that students who have a particular level of understanding of this topic will choose that answer choice. Typically, students whose understanding of the topic is low, would be drawn to a specific misconception, and students whose understanding of the topic is higher would be drawn to other misconceptions (Herrmann & DeBoer, 2011a). The option probability curves were created by plotting the proportion of students who selected a given answer choice (y-axis) across the range of students' ability measures at each time point (x-axis), which means the y axis values indicated the relative popularity of each answer choice for students with different levels of ability (x-axis). Hence, major misconceptions of students about the topic of photosynthesis and respiration in plants can be determined by analysing the curves.

FINDINGS

Analysis of Items Designed to Diagnose Misconceptions Related to Not Tracing Matter

Item 1 was designed to check students' knowledge and understanding of the substances required for photosynthesis. For Item 1a, the probability curve revealed that the correct answer "Yes" is the most popular choice among students with low ability and high ability. This result can be seen by examining the proportion of students who selected the option "Yes" across the range of ability measures. The plot for Item 1a indicates the option choice "Yes" becomes increasingly frequent as the students' ability measures increased from 1.0 logits to 6.0 logits. Hence, this provides evidence that Item 1a is functioning as expected (Wind & Gale, 2015). Only a small portion of low ability students at 1.0 logits choose the option "No" for this item, with the probability 0.3, which is very low compared to the probability of selecting the option "Yes". Figure 1(a) illustrates the option probability curve for Item 1a.

For Item 1b, students with low ability at around 1.0 logits are likely to choose options (A), (B) and (C), which are distractors that represent misconceptions related to substances required in photosynthesis. In contrast, high ability students from 1.0 logits to 2.0 logits tend to choose option (D), which is the correct option. Specifically, the plots suggested that the misconceptions associated with option A (photosynthesis can take place without water) and option (C) (oxygen and water are required in photosynthesis) are prominent among students with low ability, and the probability of students selecting these options decreases when the students' ability increases. Misconception represented by option (B) (oxygen is needed to produce carbon dioxide), is not obvious in this item, as the probability of students selected this option is low compared to options (A) and (C). Hence, options (A) and (C) have been identified to indicate strong misconceptions of low-ability students. Figure 1(b) illustrates the option probability curve for Item 1b.

Item 3 is designed to check students' knowledge and understanding of the substances required for plant respiration. For Item 3a, low-ability students tend to select the wrong option, "No". As the students' ability increases, the probability curve reveals that the correct answer, "Yes" is chosen by the students. This result can be seen by examining the proportion of students who selected the option "Yes" across the range of ability measures. The plot for Item 3a indicates the option choice "Yes" becomes increasingly frequent as the students' ability measures increase from 0.0 logits to 4.0 logits. Hence, this provides evidence that Item 3a is functioning as expected (Wind & Gale, 2015). Figure 2(a) illustrates the option probability curve for Item 3a.

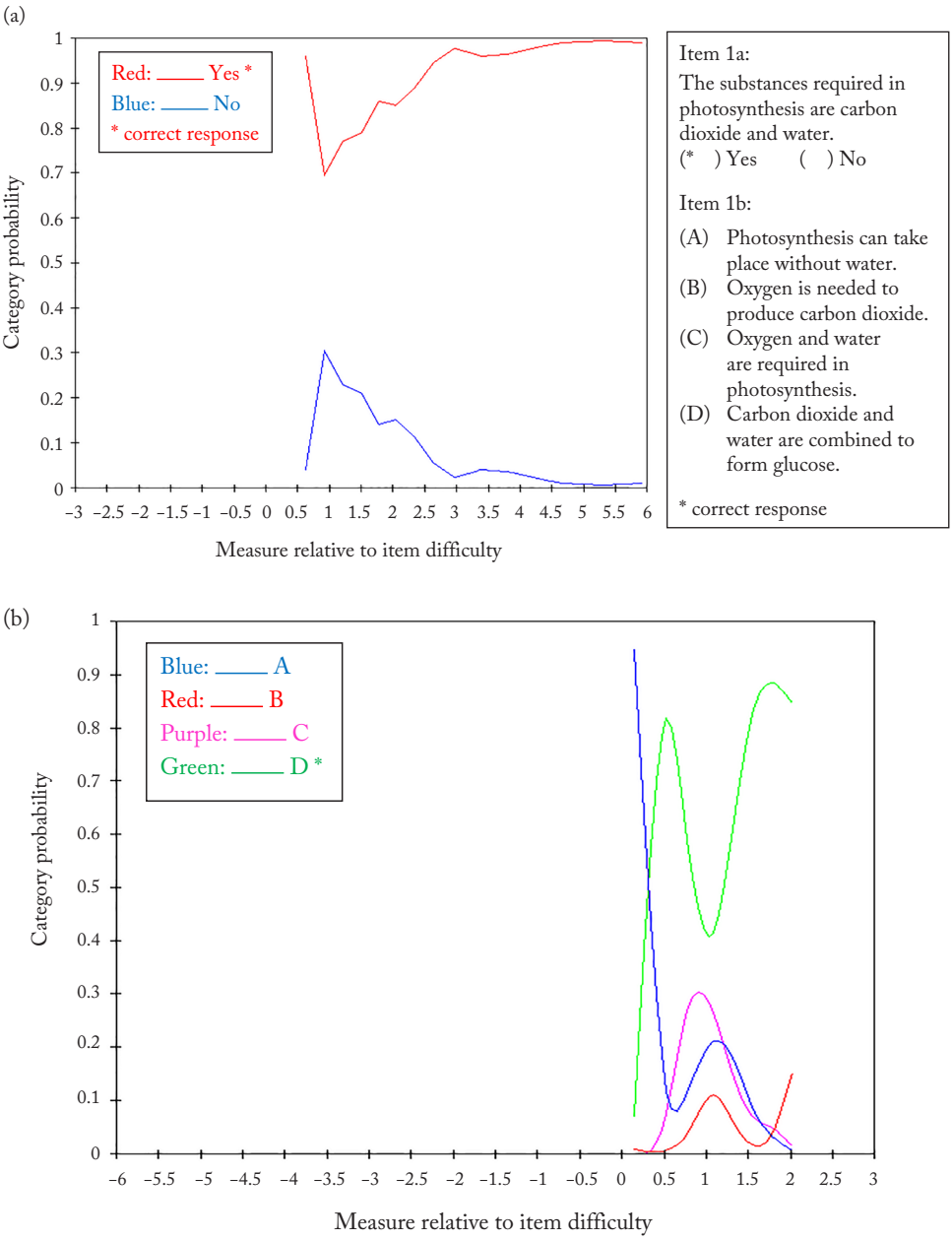


Figure 1. (a) Option probability curve for Item 1a and (b) Option probability curve for Item 1b

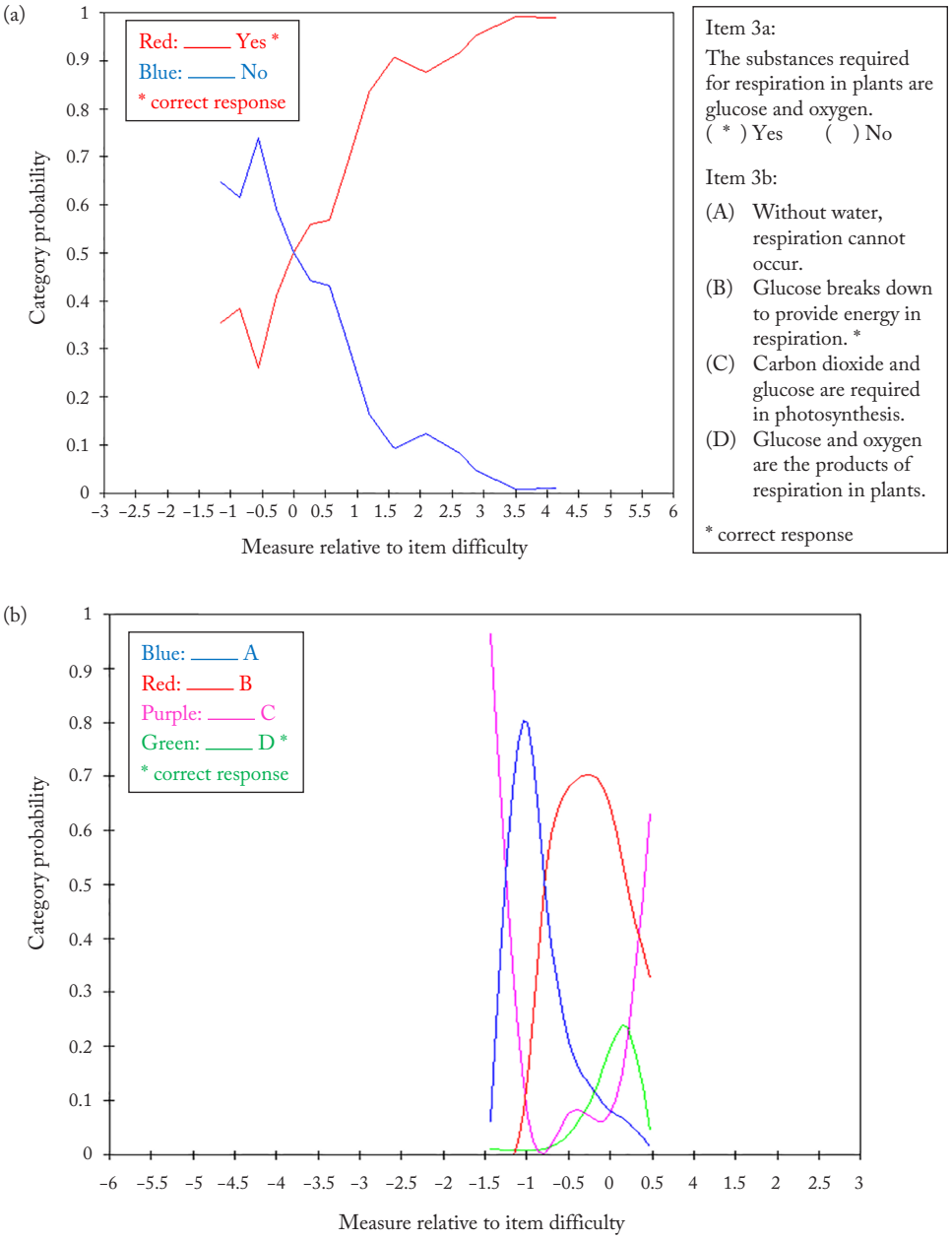


Figure 2. (a) Option probability curve for Item 3a and (b) Option probability curve for Item 3b

For Item 3b, the majority of high-ability students choose the correct answer (B). Students with low ability from -1.5 logits to -1.5 logits are likely to choose option (A) with misconceptions that plant respiration cannot occur without water. In comparison, some high-ability students at 0.0 logits to 0.5 logits tend to choose option (D) with the misconception that glucose and oxygen are the products of plant respiration. Options (A), (C) and (D) are distractors that represent misconceptions related to the substances required for respiration in a plant. However, option (C) (carbon dioxide and glucose are required in photosynthesis) is not a strong distractor, as the probability of students selecting option (C) is very low. Therefore, it is suggested that the misconceptions associated with options (A) and (D) are prominent. Low-ability students have strong misconceptions represented by option (A), whereas high-ability students have a strong misconception represented by option (D). Figure 2(b) illustrates the option probability curve for Item 3b. Table 3 shows a summary of misconceptions detected from the distractor analysis of Items 1 to 6.

Table 3. A summary of misconceptions related to not tracing matter

Item	Dimension		Misconception detected
	Photo.	Resp.	
1b	•		1. Photosynthesis can take place without water. 2. Oxygen and water are required in photosynthesis.
2b	•		3. Glucose is the raw material in photosynthesis. 4. The only product of photosynthesis is glucose. 5. Water and oxygen is produced from photosynthesis.
3b		•	6. Without water, respiration cannot occur. 7. Glucose and oxygen are the products of respiration in plants.
4b		•	8. Oxygen is given off from respiration of plants. 9. The only product of respiration is carbon dioxide.
5b	•		10. Water is not needed in photosynthesis. 11. Water molecule is the product of photosynthesis. 12. Water is needed to combine with oxygen to form glucose.
6b		•	13. Without water, respiration cannot occur. 14. Water molecules are broken down to form energy.

Analysis of Items Designed to Diagnose Misconceptions Related to Not Tracing Energy

Item 7 is designed to check students' knowledge and understanding of the anabolic process. For Item 7a, the probability curve reveals that students with high ability from 1.0 logits to 3.0 logits tend to choose the option "Yes", which is the wrong answer. The probability of students selecting the correct answer "No" decreases with the increase in the students' ability. Low-ability students at -2.5 logits to 1.0 logits are likely to choose the correct option "No". Hence, this provides evidence that Item 7a may not function as expected (Wind & Gale, 2015). Figure 3(a) illustrates the option probability curve for Item 7a.

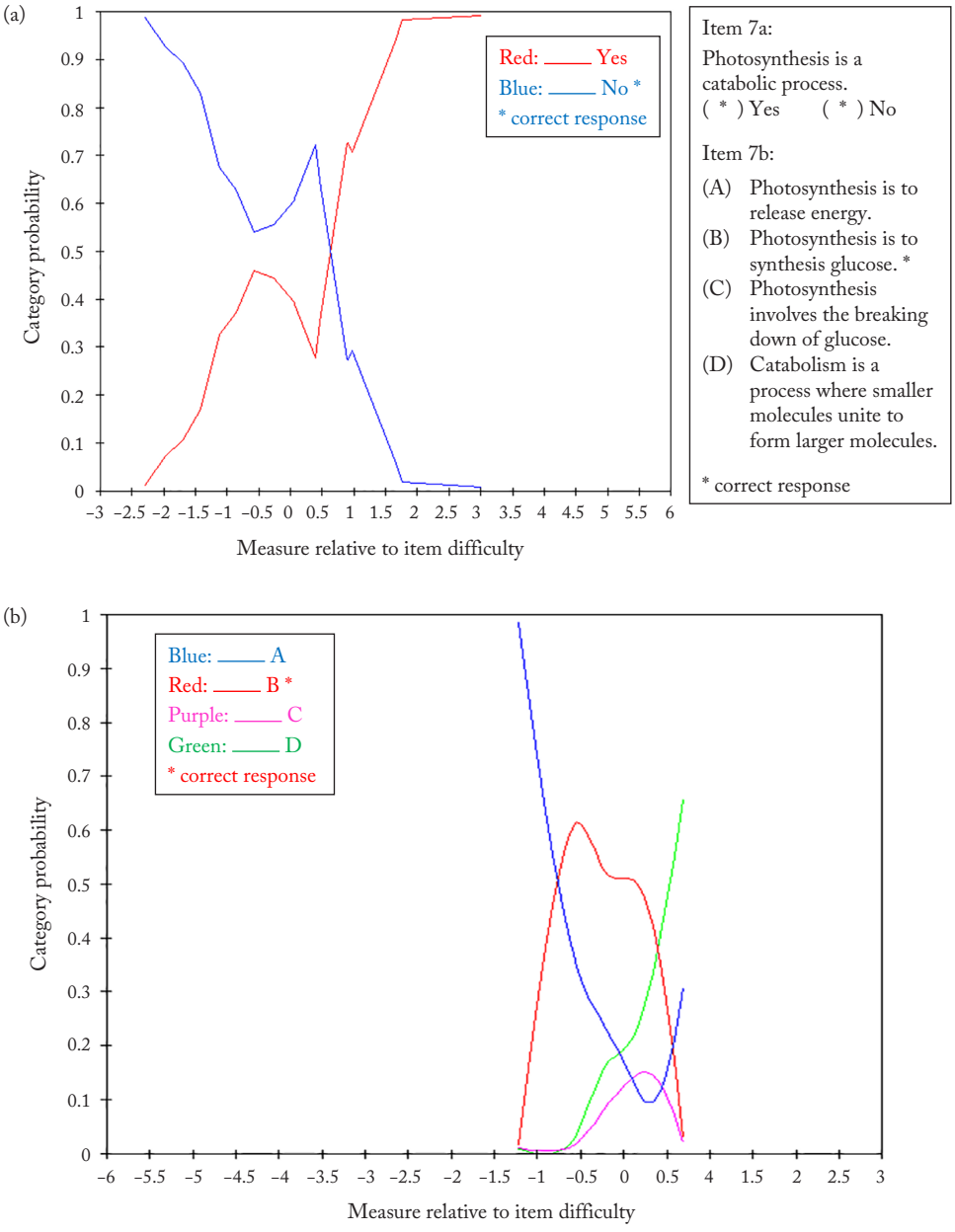
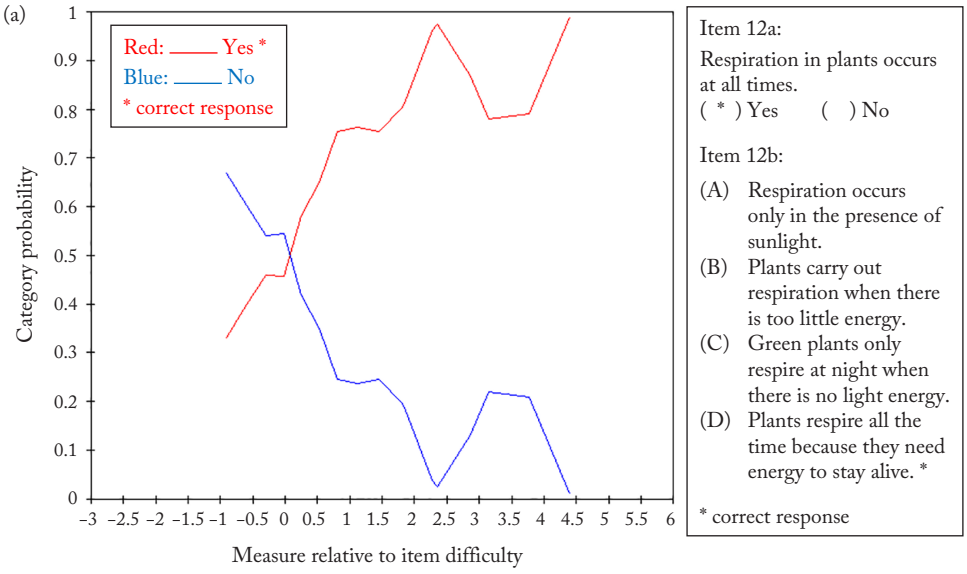


Figure 3. (a) Option probability curve for Item 7a and (b) Option probability curve for Item 7b

For Item 7b, the majority of high ability students select the correct answer, (B). This is shown by the curve for option (B), where the probability of high-ability students at –0.5 logits to 0.5 logits selecting the correct answer is high. However, the curves for options (C) and (D) show a peak at –0.5 logits to 0.5 logits, respectively. These revealed that high-ability students have misconceptions associated with both option (C), photosynthesis involves the breaking down of glucose and option (D), catabolism is a process where smaller molecules unite to form larger molecules. On the other hand, low-ability students have a misconception associated with another distractor, which is option (A), photosynthesis is to release energy, as shown in the curve where the probability of low-ability students at –1.0 logits to –0.5 logits selecting option (A) is high. Figure 3(b) illustrates the option probability curve for Item 7b.

Item 12 is designed to detect students' knowledge and understanding about when plant respiration occurs. For Item 12a, the probability curve reveals that the correct answer, "Yes", is the most popular choice among students with high ability. This result can be seen by examining the proportion of students who selected "Yes" across the range of ability measures. The plot for Item 12a indicates the option choice "Yes" becomes increasingly frequent as the students' ability measures increases from 0.0 logits to 4.5 logits. Hence, this provides evidence that Item 12a is functioning as expected (Wind & Gale, 2015). At the same time, low-ability students at –1.0 logits to 0.0 logits tend to choose the wrong option, "No", as illustrated from the curve for the option "No", where the probability of low ability students selecting the wrong option is high. Figure 4(a) illustrates the option probability curve for Item 12a.

For Item 12b, the probability of students selecting the correct answer (D) is increased with the increase of students' ability. This shows that high ability students do not have a misconception regarding when respiration in plants occurs. Apart from that, by studying the curves for other three distractors, only the curve for option (C) shows a high peak, indicating low-ability students have a misconception associated with option (C); green plants only respire at night when there is no light. Therefore, option (A), respiration occurs only in the presence of sunlight, and option (B), plants carry out respiration when there is too little energy, are considered as weak distractors, as the probability of students selecting these two options was low. So, only the misconception represented by option (C) is considered in this item. Figure 4(b) illustrates the option probability curve for Item 12b. Table 4 shows a summary of misconceptions detected from the distractor analysis of Items 7 to 12.



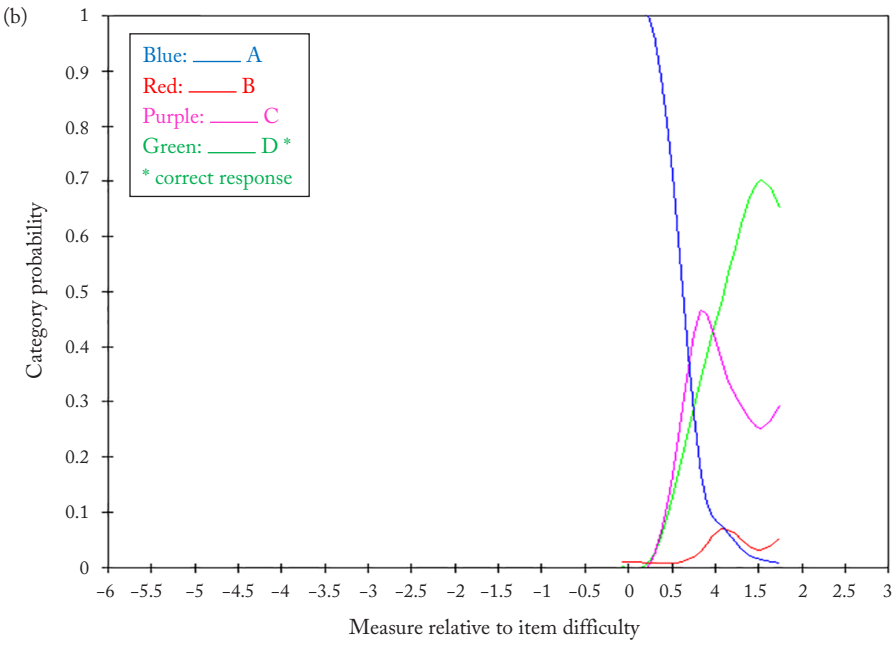


Figure 4. (a) Option probability curve for Item 12a and (b) Option probability curve for Item 12b

Table 4. A summary of misconceptions related to not tracing energy

Item	Dimension		Misconception detected
	Photo.	Resp.	
7b	•		1. Photosynthesis is to release energy. 2. Photosynthesis involves the breaking down of glucose. 3. Catabolism is a process where smaller molecules unite to form larger molecules.
8b		•	4. Respiration is an anabolic process. 5. Respiration is to synthesis glucose.
9b	•		6. Photosynthesis is a process to release energy. 7. Photosynthesis is to produce energy for plant growth.
10b		•	8. Respiration is a process to obtain energy from sunlight. 9. Sunlight is stored as chemical energy during respiration. 10. Energy is released when glucose is formed during respiration.
11b	•		11. Photosynthesis occurs in green plants at all times.
12b		•	12. Green plants only respire at night when there is no light energy.

Analysis of Items Designed to Diagnose Misconceptions Related to Not Tracing Scale and Location

Item 13 was designed to detect students' knowledge and understanding of the type of plants that carry out photosynthesis. For Item 13(a), the probability curve reveals that students with high ability from –0.5 logits to 4.5 logits tend to choose "Yes", which is the wrong answer. The probability of students selecting the correct answer "No" decreases with the increase of the students' ability. Low-ability students at –1.0 logits to –0.5 logits are likely to choose the correct option "No". Hence, this provides evidence that Item 13(a) may not function as expected (Wind & Gale, 2015). Figure 5(a) illustrates the option probability curve for Item 13(a).

For Item 13(b), the majority of high-ability students select the correct answer, (C). This is shown by the curve for option (C), where the probability of high-ability students at 0.5 logits to 1.0 logits selecting the correct answer is high. However, the curves for options (B) and (D) show a peak at 1.0 logits, respectively. These findings reveal that high-ability students have misconceptions associated with both option (B), all plants with leaves can carry out photosynthesis, and option (D), all plants carry out photosynthesis to produce energy for daily usage too. Besides, there are also low-ability students from –1.0 logits to –0.5 logits who select option (B). Low-ability students have the misconception associated with another distractor, which is option (A), photosynthesis is the respiration of plants, as shown in the curve where the probability of low ability students at 0.0 logits to 0.5 logits selecting option (A) is high. Hence, misconceptions associated with options (A), (B) and (D) are found prominent. Figure 5(b) illustrates the option probability curve for Item 13(b).

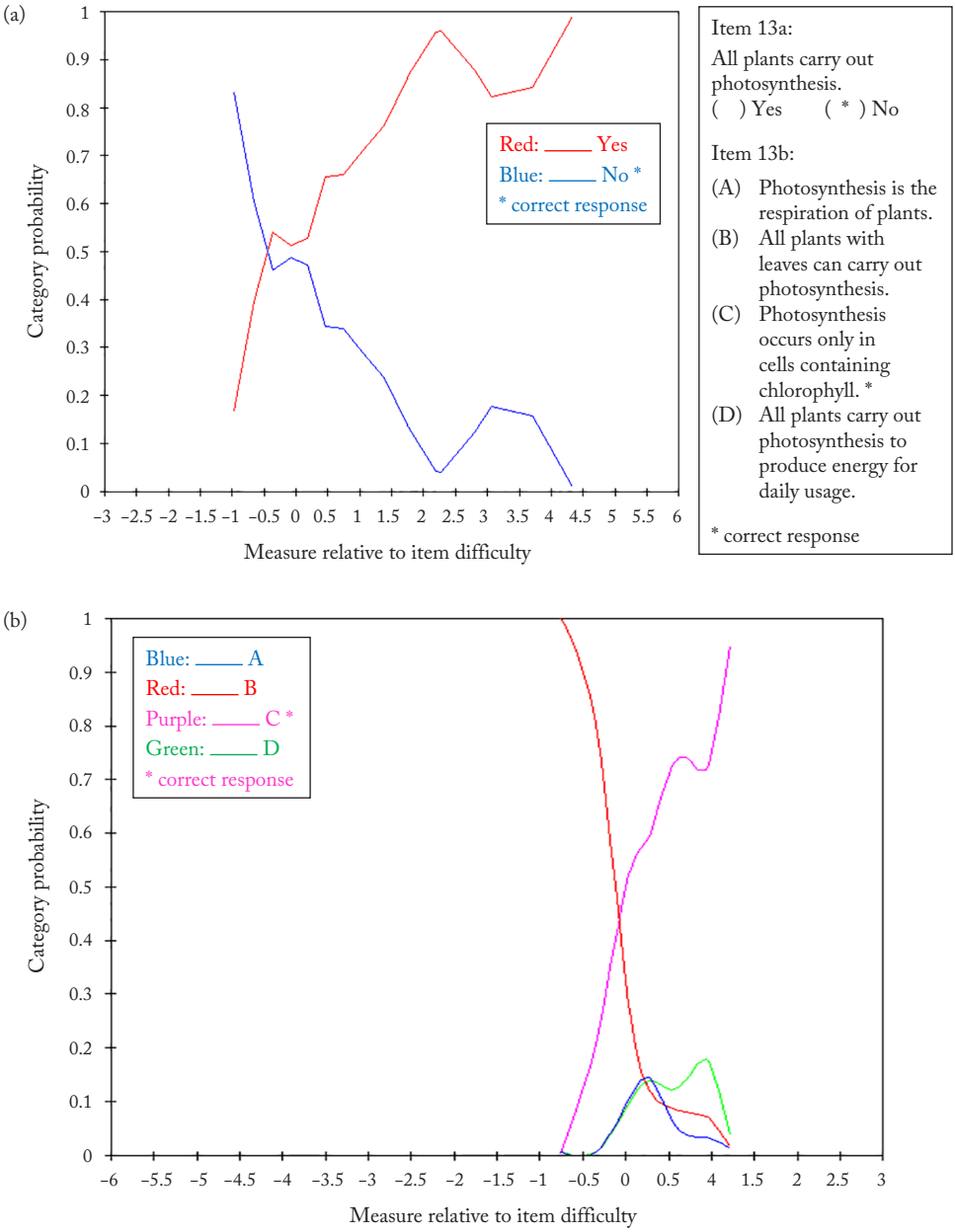


Figure 5. (a) Option probability curve for Item 13a and (b) Option probability curve for Item 13b

Item 17 is designed to detect students' knowledge and understanding about the dependency of chlorophyll in plant respiration. For Item 17(a), the probability curve reveals that the correct answer "Yes" is the most popular choice among high ability students. In contrast, low-ability students are likely to choose the option "No". The plot for Item 17a indicates the option choice "Yes" becomes increasingly frequent as the student's ability measures increase from 0.5 logits to 4.0 logits. Hence, this provides evidence that Item 17a is functioning as expected (Wind & Gale, 2015). The probability of high-ability students selecting the option "No" is low. Figure 6(a) shows the option probability curve for Item 17a.

For Item 17b, option (A) is the correct answer, while options (B), (C) and (D) are distractors that represent misconceptions about the function of chlorophyll in respiration. According to the curve for option (A), the probability of students selecting the correct answer increases with the increase of students' ability. However, high ability students had misconceptions associated with option (B), chlorophyll produces energy for respiration to occur, and option (C), chlorophyll is needed to trap sunlight for respiration. As seen from the curves, there were peaks at -1.5 logits to -0.5 logits. By the way, students with low ability have misconceptions associated with options (B) and (D). For option (B). There is a high peak at -2.5 logits to -1.5 logits showing the probability of low-ability students selecting option (B) is 0.75, which is high. At the same time, low-ability students at -2.0 logits to -1.5 logits tend to select the wrong option, (D), chlorophyll is needed to carry out cellular respiration in plants, as can be seen from the curve for option (D). Figure 6(b) shows the option probability curve for Item 17b. Table 5 shows a summary of misconceptions detected from the distractor analysis of Items 13 to 18.

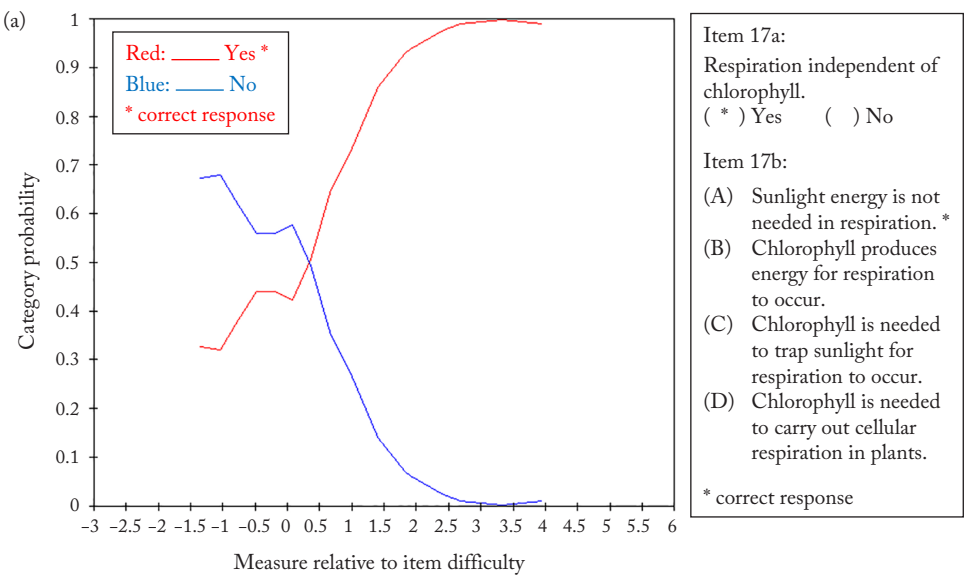


Figure 6 (continues)

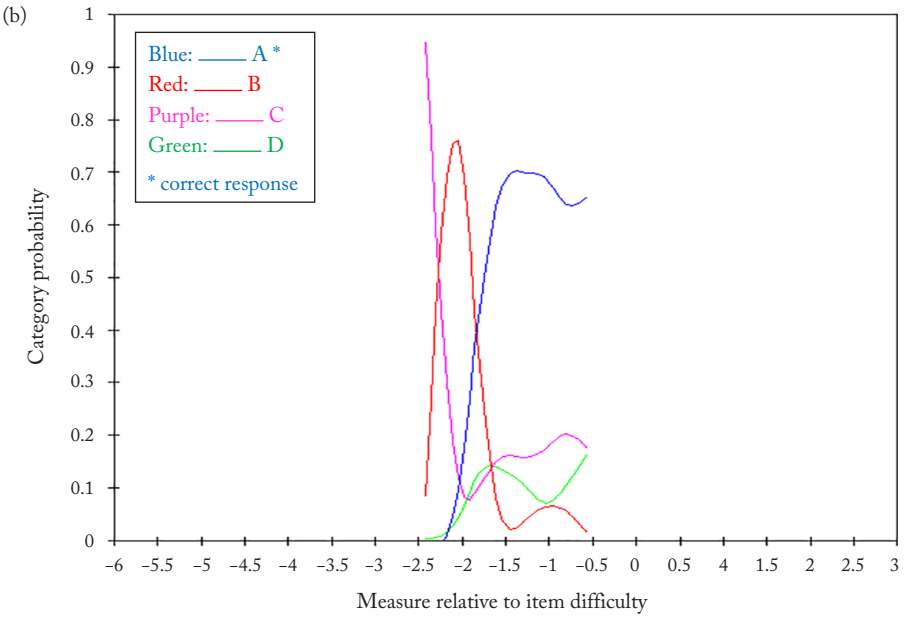


Figure 6. (a) Option probability curve for Item 17a and (b) Option probability curve for Item 17b

Table 5. A summary of misconceptions related to not tracing scale and location

Item	Dimension		Misconception detected
	Photo.	Resp.	
13b	•		1. Photosynthesis is the respiration of plants. 2. All plants with leaves can carry out photosynthesis. 3. All plants carry out photosynthesis to produce energy for daily usage.
14b		•	4. Respiration helps plants to digest their food. 5. Respiration occurs only in cells containing chlorophyll. 6. Only plants with green leaves can carry out respiration.
15b	•		7. The site for photosynthesis is mitochondria. 8. Chloroplast produces energy for photosynthesis to occur.
16b		•	9. Respiration happens in all parts of plant cells. 10. The site for respiration in plants is the chloroplast. 11. Mitochondria help to trap sunlight for respiration.
17b		•	12. Chlorophyll produces energy for respiration to occur. 13. Chlorophyll is needed to trap sunlight for respiration to occur. 14. Chlorophyll is needed to carry out cellular respiration in plants.
18b	•	•	15. Only cells in leaves contain chloroplast and mitochondrion. 16. Photosynthesis only happens in leaves, but respiration occurs in all living cells. 17. Only leaves have special pores to exchange gases for both processes to occur.

DISCUSSION AND CONCLUSION

For the misconceptions related to the inability to trace matter, the results obtained from the analysis of Items 1 to 6, which were specifically designed to detect students' misconceptions in this area in the PDRT instrument, were matched with previous studies. For example, students had misconceptions that:

1. Oxygen and water are required for photosynthesis.
2. Glucose is the raw material for photosynthesis.
3. The only product for respiration is carbon dioxide
4. Water molecules are the product of photosynthesis.
5. Water molecules are broken down to form energy.

All these five misconceptions were stated by Treagust and Haslam (1986), Köse (2008), and Svandova (2013). Students had considerable misconceptions regarding the products and substances of photosynthesis and plant respiration. This was highlighted by Köse (2008) and concurs to the results of this research. The current study also established that "without water, respiration cannot occur", which was a strong misconception that students had, as this misconception was detected from two items.

For the misconceptions that are not related to tracing energy, students showed strong misconceptions associated with the process of anabolic and catabolic, as demonstrated by the analysis of Items 7 and 8. This was not highlighted in previous studies, but the current researchers found that it is crucial to detect misconceptions regarding this area, as the catabolic and anabolic processes are in the Malaysian syllabus. On the other hand, the findings of this research such as: (i) misconceptions that photosynthesis functions to release energy; (ii)photosynthesis involves the breaking down of glucose; (iii) respiration is to produce glucose; (iv) photosynthesis is to produce energy for plant growth; (v) respiration is a process to obtain energy from sunlight and energy is released when glucose is formed during respiration, are also well documented in various studies, such as Treagust and Haslam (1986), Köse (2008), Özay and Öztaz (2003) and Svandova (2013). The misconception that photosynthesis occurs in green plants at all times was also found to be prominent (Svandova, 2013).

For misconceptions related to not being able to trace scale and location, this study found that students misunderstood that photosynthesis is similar to plant respiration, as mentioned in Svandova (2013). Students equated both processes as similar, causing them to further misunderstand all other scientific contents in the study area. This research found some misconceptions tally with the results of Treagust and Haslam (1986), such as: (i) all plants with leaves can carry out photosynthesis, (ii) all plants carry out photosynthesis to produce energy for daily usage, and (iii) respiration occurs only in cells containing chlorophyll. In this research, it is discovered that students cannot recognise the site of both reactions and the function of chlorophyll and mitochondria in photosynthesis and respiration. These results matched with the findings from various literature reviews.

As we know, various research that diagnoses misconceptions of photosynthesis and plant respiration among students are widely available. However, most of the research documenting misconceptions comprised only of simple listing, as seen in Treagust and Haslam (1986), Köse (2008) and Svandova (2013). In this research, the researcher listed all the misconceptions found by categorising them into three groups of misconceptions, namely misconceptions related to the inability to trace matter, misconceptions related to the inability to trace energy and misconceptions related to the inability to trace scale and location. This type of categorisation provided readers with a better understanding of which aspects leads to students' misconceptions (Parker et al., 2012). Hence, students' understanding of both domains can be precisely diagnosed.

Another significant of this research was the use of Rasch data analysis. Rasch analysis is a psychometric technique developed to improve the precision with which researchers construct instruments, monitor instrument quality, and compute respondents' performances (Boone, 2016). Compared to the traditional method of data analysis, Rasch analysis helps researchers analyse the misconceptions in more sophisticated ways with respect to the constructs they wish to measure. Furthermore, the use of option probability curves to analyse how students respond to items is new in the topic of photosynthesis and plant respiration.

This study supported Piaget's Cognitive Learning Theory (McLeod, 2015) and Ausubel's Assimilation Learning Theory (Novak, 1993) in the sense that students get conceptual understanding after experiencing assimilation and accommodation. In other words, students gain knowledge from their teachers about photosynthesis and plant respiration in school. At the same time, the process of assimilation and accommodation transpire, resulting in their conceptual understanding. Subsequently, as students are tested with the PRDT instrument, the misconceptions are established. This shows that something happened in the students' learning process, which affected assimilation and accommodation, resulting in misconceptions. With the application of the Biology Thinking Development Model, the roots of misconceptions that affect the processes of assimilation and accommodation can be explained by the influence of different cognitive construal in the process of learning. For example, the misconception that "all plants carry out photosynthesis" is due to teleological thinking, where students extended the idea that all plants need food, and therefore, all plants need to do photosynthesis. However, this misconception is due to essentialist thinking as well; students make assumptions that all plants can produce photosynthesis by not realising that not all plants contain chlorophyll. At the same time, students' anthropocentric thinking also leads to this misconception, as they make an analogy of a plant to a human that all humans breathe. Therefore, all plants will do photosynthesis as well. Besides, this study also discovers that misconceptions within the domains are interrelated. This was validated by the argument that different cognitive construal might affect how students think simultaneously. Therefore, the building of diagnostic test items must consider how students think.

Besides, this study extended previous studies by contributing to the literature on students' misconceptions about photosynthesis and respiration in plants. This diagnostic test provides teachers with a tool to identify students' misconceptions of photosynthesis and respiration in a plant. By identifying students' misconceptions, teachers can plan learning and teaching accordingly. This will encourage teachers to be more receptive and willing to try or develop alternative teaching methods if they find that their present methods are inadequate in addressing students' difficulties.

In addition, this research also informs curricular and educational experts the need to understand and put in place strategies to correct students' misconceptions. Directly, it also gives feedback to the textbook authors to improve the quality of the Biology textbook. This is very important, as students use a textbook as their main reference in learning scientific concepts. Sometimes, the way the textbook is written, and the language used will lead to misconceptions among students. Therefore, by establishing major misconceptions among students, the textbook can be refined to suit students' needs.

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