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Understanding the Solution-Making Ability of Senior High School Students in Solving Photosynthesis Problems

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Abstract: This study further explains the errors made by senior high school students when trying to solve photosynthesis problems. The method used in this research is descriptive qualitative, involving a sample of four senior high school students. The study results will be discussed with Polya's problem-solving procedure, which includes understanding, planning, execution, and checking. Errors at the comprehension stage are in understanding the relationship between photons and photosynthetic light reactions and in drawing genealogies. Errors in the planning stage, in making wrong assumptions or inaccuracies in interpreting those derived from the understanding stage. In addition, this study found errors in identifying chemical reactions in photosynthesis and errors in mathematical reasoning competence. The conclusion of this study shows the failure in making photosynthesis problem-solving solutions due to the interaction between the problem-solving phase and the student's general competence.

Keywords: Ability to create solutions; Photosynthesis problem; Problem solving errors

Introduction

The ability to make solutions to solve a problem is one of the science learning objectives that need to be developed by students. Therefore, in achieving an optimal science learning process, the ability to make solutions should be mastered by students (Rohmawati & Fadly, 2023). Cognitive psychologists have also researched information processing theory that describes problem-solving as solving a problem (Becker et al., 2015). Cognitive psychologists define the phrase "problem-solving," which is often used to refer to all forms of awareness/understanding/cognition (Sulasamono Bambang, 2012). Creating a problem-solving solution in education includes rules and steps that lead students to the expected answer (Marzano, 1988). There is no previous research that discusses the ability to make solutions in solving photosynthesis problems, but there are many studies that discuss the misconceptions of photosynthesis material, including research conducted (Puspitasari, 2017; Siswana et al., 2017; Yunia et al., 2013). This further encouraged researchers to conduct research related to the ability to make solutions in solving photosynthesis material problems.

Photosynthesis material is a subject matter in science subjects because photosynthesis is essential for life processes and the basis of all plant functions (Andersson, 1986). Photosynthesis is preparing or making complex chemicals from simple chemicals using light energy (photons). Water molecules (H_2O) and carbon dioxide (CO_2) are referred to as simple compounds. At the same time, oxygen and glucose are complex compounds. Meanwhile, Hilyati (2014) stated that photosynthesis is one of the concepts that sometimes need clarification because it is abstract and cannot be observed directly, so it is difficult for students to understand. Students may need help understanding abstract content because they cannot see it with their own eyes. In addition, the complexity of photosynthesis material is a combination of several conceptual components (ecology, physiology, biochemistry, energy, and autotrophic) whose relationship is complicated for students to understand. This is the leading cause of the

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difficulty of photosynthesis material (Waheed & Lucas, 1992).

There are several problem-solving paradigms in learning, such as previous research conducted by Borich (2017) introducing a problem-solving paradigm called IDEAL, which stands for five problem-solving processes consisting of Identify, Define, Explore, Act, and Look-pen. However, the research will use Polya's (1978) problem-solving phases. In this study, researchers used four phases in making solutions as problem-solving, including understanding the problem, planning solutions, implementing solutions, and checking solutions that have been found. With these four phases, researchers were able to explore the difficulties faced by students in each process of finding solutions to photosynthesis problems.

Previous research dominated on applying the problem-based learning model (Nurfiyanti et al., 2019) generally concentrated on describing the activities of teachers and students and improving student learning outcomes with the Problem-Based Learning (PBL) model. This research looked at two case studies to analyze the process of solving complex photosynthesis problems, looking at the types of errors that occurred during the process and examining what caused these errors in detail. The purpose of this research is not just to determine whether the problem-solving was successful or unsuccessful or to create a list of solvable problems. Instead, it is hoped can help educators and students who have difficulty understanding and correcting their errors when dealing with problems related to photosynthesis material.

Theoretical Background

Factors Affecting the Ability to Create Solutions in Science Education

Several previous studies have mentioned that the ability to make students' solutions in solving a problem still needs to be improved. This ability is one of the goals of science education because the ability to produce problem-solving solutions obtained in science learning is usually used to solve other problems (Rohmawati & Fadly, 2023). Two factors influence the ability to create problem-solving solutions consisting of internal factors and external factors (Hillman, 2003). Internal factors consist of curiosity, intelligence, and cognitive capacity of students. At the same time, external factors consist of using learning models and methodologies, learning environments, and encouragement from teachers.

The first factor that encourages students' ability to solve problems is the type of learning model the teacher uses. In learning, there needs to be a strategy to improve students' problem-solving skills in order to produce students who have superior competence (Wena in Hanifa et al., 2018). The second factor is using media when teaching to attract students' interest and focus during lessons by stimulating them correctly. Media can be used as a means of channeling messages to attract interest and stimulate students' thoughts, feelings, and learning processes (Sadiman in Hanifa et al., 2018). The third factor is the learning environment. Posamentier et al. (2020) outlines the factors that can affect students' ability to create problem-solving solutions from the point of view of the learning environment created by the teacher, including an environment that encourages students' freedom of expression in expressing opinions, appreciates every student's questions and ideas, provides opportunities for students to find solutions in their way, and group learning activities that can hone students' problem-solving creativity.

In addition to several factors driving the ability to make problem-solving solutions above, there are also inhibiting factors. According to research conducted by Hanifa et al. (2018), inhibiting factors include the low provision of motivational support by teachers to students in solving problems. Posamentier said that to increase students' enthusiasm for learning to solve problems, and teachers must provide motivational encouragement. The second inhibiting factor is that students' low cognitive capacity makes the results of their ability to solve problems less ideal and precise. For students to apply their knowledge to the task and solve it, they must have essential cognitive capacity skills. Overcoming the difficulties of problem-solving requires a complex way of thinking, namely cognitive ability and awareness to use the correct method. Thus, it can be concluded that if students' cognitive aptitude is weak, so will their ability to solve problems (Insani & Utami, 2016).

From the explanation above, it can be understood that internal factors and external factors can affect students' ability to create solutions to problems that act as supporting factors or inhibiting factors. Students will get a variety of higher-level rules when they create solutions to solve problems in learning. The exercise of creating a problem-solving solution itself requires students to recall some of the basic rules they have learned (Sulasamono Bambang, 2012).

Problem Solving in Photosynthesis

Photosynthesis will more or less affect human life in the future because of its ability to produce food by synthesizing carbohydrates from inorganic materials such as CO_2 and water using the help of light in pigmented plants. However, there are still many students who have difficulty understanding photosynthesis material due to the complexity of the material, which is a combination of several conceptual components (ecology, physiology, biochemistry, energy, and autotrophic) whose relationship is complicated for students to understand (Waheed & Lucas, 1992). In addition, the terms used in photosynthesis material, such as CO_2, O_2, H_2O, and $C_6H_{12}O_6$, are still vunfamineed to be made familiar, and students' humanistic thinking that sees everything from a human perspective, making assumptions about how things behave. Such as the understanding that bright reactions occur during the day and dark reactions occur at night (Haka et al., 2022). Previous research on the ability to make solutions in solving photosynthesis problems is still limited. Honeeds to be completed are many previous studies on the misconceptions of photosynthesis material, e.g., research (Haka et al., 2022; Siswana et al., 2017), which will contribute positively to this study by facilitating information about which parts students still have difficulty in solving problems in this material.

The perception that plants obtain food from the soil is the most common misconception (Wood-Robinson, 1991). There are misconceptions about how respiration works and how it relates to photosynthesis, but this confusion has been resolved (Amir & Tamir, 1994). Instead, some students see respiration as synonymous with breathing (Seymour & Longden, 1991), while others see plant respiration as a reverse gas exchange compared to animals (Cañal, 1999). Regarding the energy component, many students mentioned energy as one of the substances digested by plants (Stavy et al., 1987a). In addition, because few of them can understand how plants use solar energy during photosynthesis, the students struggle to grasp the idea of explaining the energy transfer that occurs during the photosynthesis process (Eisen & Stavy, 1988), and relatively few people understand about energy transformation (Waheed & Lucas, 1992).

Basic understandings of photosynthesis, such as gases, energy conversion, and chemical transformation, need to be understood (Barker & Carr, 1989). According to Bell (1985), the main reason students have difficulty helping photosynthesis is because they have different ideas about these basic principles. For some people, the idea of energy and its changes is quite challenging and complex to understand (Carlsson, 2002a). They think that energy will run out if it is continuously consumed and used (Carlsson, 2002b). Regarding chemical concepts, students have difficulty understanding the concepts of reactants and products (Barker & Carr, 1989). Research conducted by Andersson (1986), focused on the difficulties students face in identifying and understanding chemical changes. For example, many students believe that during respiration, oxygen is converted into carbon dioxide, another type of gas (Seymour & Longden, 1991). This is likely due to their understanding that gases are the origin of other gases in specific processes. Due to their inability to conceptualize gases as matter that has mass and can be weighed, they generally need help understanding gas interactions (Stavy et al., 1987a). In addition, they cannot understand why the properties of compounds are different from the properties of their constituents.

Compared to previous studies, the novelty in this study is that previous studies were dominated by misconceptions faced by students in photosynthesis material. Misconceptions in photosynthesis material also affect students in finding problem-solving solutions; this becomes the basis of students' knowledge to identify the problem at hand. A correct and clear understanding will make it easier for students to get the right solution in the next problem-solving steps. Therefore, this research is here to discuss more deeply the process and errors faced by students in solving photosynthesis problems, and the results of this study are useful for science teachers, especially photosynthesis material. Students' reasoning skills are fundamental as students' capital in making solutions, so researchers strongly recommend that teachers choose the suitable models, methods, and teaching materials by further examining the results and discussions in this study based on the difficulties faced by high school students in solving photosynthesis problems so that students can make problem-solving solutions according to the problem-solving phase and identify the difficulties faced during problem-solving.

Method

The method used in this research is descriptive qualitative with a case study approach. The case study is a method that intensively and thoroughly examines a case (Surachmad in (Rusandi & Muhammad Rusli, 2021). According to the teacher's recommendation, this study used a purposive sampling technique by selecting four high school students, two with a high probability of solving photosynthesis problems and two with a low probability. Data were taken from one of the senior high schools involving four students as the unit of analysis. Data collection in this study used three types of data collection, namely, interviews, test sheets and observations. In this study, data analysis was carried out in four stages: analysis of the process of solving problems, analysis of errors in problem-solving and their causes, and analysis of communication skills in conveying solutions obtained by students to others.

The test items of this study used two questions about the concept of photosynthesis prepared by researchers concerning national exam questions and UTBK.

Table 1. Photosynthesis Problems to be Solved by Students

Questions	
1.	Photosynthesis is a chemical change process that produces glucose and oxygen from carbon dioxide and water through the involvement of light and chlorophyll. Plants have two types of reactions in photosynthesis consisting of light reactions and dark reactions. The light reaction is the initial stage of photosynthesis that converts sunlight energy into chemical energy. This reaction occurs in the thylakoid membrane where there are electron carriers plastoquinone (pq), cytochrome complex (cyt), plastocyanin (pc), and ferredoxin (fd). The bright reaction is divided into two types, namely, non-cyclic phosphorylation and cyclic phosphorylation. Based on the explanation above, tell us the difference between cyclic phosphorylation and non-cyclic phosphorylation. Moreover, what are the products that result from the process?
2.	The dark reaction (Calvin cycle) is the process of carbon ion entry in the form of CO_2, which produces an output in sugar. The sugar produced is not glucose but the compound glyceraldehyde 3-phosphate (G3P). The Calvin cycle consists of three stages, namely the CO_2 fixation stage by RUBP, the APG / PGA reduction stage to PGAL, and the RUBP regeneration stage. Based on these stages, how does the Calvin cycle produce glucose? Moreover, if the Calvin cycle produces glucose, how many rounds of the Calvin cycle are needed to produce 3 compounds?

The two problems were compiled by referring to Polya's (1978) problem-solving indicators to make it easier for researchers to observe each indicator in finding solutions to photosynthesis problems. Both problems do not directly lead students to find solutions. However, students must identify, represent, and connect the information presented in the problem with their other understanding of photosynthesis. For problem number 1, students must understand the difference between cyclic and non-cyclic phosphorylation, and they must also understand the chemical reactions that occur in the bright reaction. In problem number 2, students must be able to solve the first problem because the products produced in the first problem will be used in the second problem. In this second problem, students must also use mathematical reasoning to find how many rounds are needed.

Meanwhile, the problems that students needed help finding solutions for were analyzed using the Prevost et al. (2016) framework. The framework is suitable for this study because it explains student errors in solving biology subject matter, so the study can be a suitable reference for developing the framework in this study, which focuses on examining problem-solving errors in problems.

After knowing the process, errors, and causes of errors in finding solutions to solve problems, the results of the discussion of errors in finding solutions to solve these problems will be discussed based on the phases or stages of problem-solving so that it can be explained where these errors occur. Researchers can find out the characteristics of participants in finding problem-solving solutions. The factors that often cause in finding problem-solving solutions such as poor reading comprehension, weak representative competence, and metacognitive competence.

Table 2. Components of Analyzing Participant Interview Results

Stages of Problem Solving	Performance
Understand the problem	Knowing what is known and what is asked, knowing what to identify, explaining the problem in their own words, relating it to other similar problems, focusing on the critical components of the problem, modeling, and drawing diagrams are some of the tips that can help students understand complex problems.
Make a plan	Students can achieve this by using techniques such as guessing, modeling, drawing diagrams, breaking down problems, finding patterns, creating tables, conducting experiments and simulations, working backward, exploring all options, identifying sub-goals, using analogies, and sequencing data and information.
Implementing the plan	Transforming given information into mathematical form, putting strategies into action while the process is ongoing, and continuing calculations. Students may choose an alternative strategy or plan, for example, if the initial plan cannot be implemented.
Checking back	Verify all essential data identified, verify all calculations, determine if the solution is logical, consider other possible solutions, re-read the question, and determine if the question is fully answered.

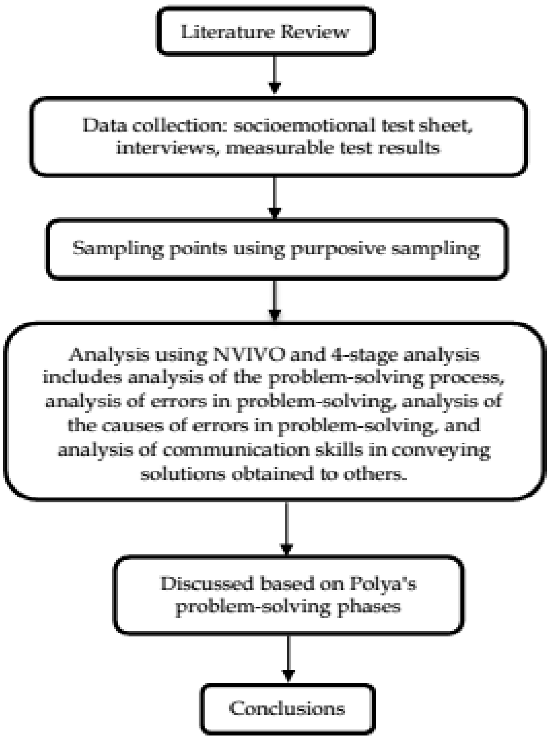
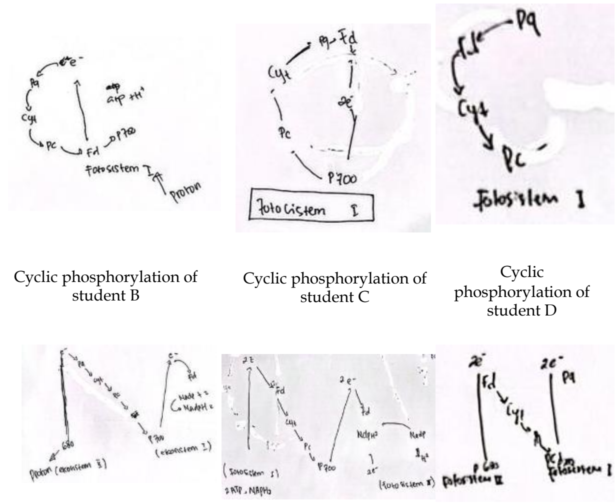


Figure 1. Research flowchart


Cyclic phosphorylation of student B | Cyclic phosphorylation of student C | Cyclic phosphorylation of student D

Nocyclic phosphorylation of student B | Nocyclic phosphorylation of student C | Non-cyclic phosphorylation of student D

Figure 2. Figure of photosynthesis cycle by students

Result and Discussion

Based on the data collection that has been done, several errors are found in each problem-solving phase according to the problem-solving theory (Polya, 1978), which is used as an indicator in this study, including the stages of understanding, planning, implementation, and rechecking. The results obtained were only one of the four participants who were able to make a solution to solve two photosynthesis problems correctly. The weaknesses and features noted in each problem-solving stage will be explained below, along with examples.

Comprehension Phase

Errors in the comprehension phase stem from efforts to connect the information in the problem with the problem to be solved. Each problem-solving process has its error characteristics depending on the information represented in the problem narrative.

Errors in Understanding the Relationship between Photons and the Light Reaction of Photosynthesis

Student C and student D showed errors in understanding related to the role of light in the photosynthesis reaction. This is because they need clarification related to plant photosynthesis, where they assume that the photosynthesis process involving light, water, and carbon dioxide is the process of plant respiration, not the process of plants cooking their own food to survive and grow.

From the figure above, it can be observed that the cycle does not begin with the stimulation of photons; Student C and Student D immediately draw the cycle based on the information in the problem, namely the order of the electron transfer chain. Students' problem-solving regarding the problem is focused on the electron transfer chain in thylakoids listed as information in the problem which consists of plastoquinone (pq), cytochrome complex (cyt), plastocyanin (pc), and ferredoxin (fd). As a result, students ignore the information that bright reactions can occur due to stimulation by photons or light energy. The initial drawing of each cycle shows that students only think about how the cycle of each phosphorylation can be depicted well according to the information they understand in the problem.

Students C and D use a mechanical understanding that plants receive food from water and mineral substances absorbed through the roots. Meanwhile, photosynthesis is seen as a form of respiration, which is the process of inhaling and exhaling air, similar to gas exchange in animals. The theory of photosynthesis plants supports such an understanding require carbon dioxide and produce oxygen. So, the students call it reverse respiration with the understanding of inhaling carbon dioxide and exhaling oxygen. Students' misconceptions about plant food like this have been highlighted in research (Barker & Carr, 1989; Cañal, 1999). These studies revealed that this idea is common among students from elementary to higher levels, including university students (Özay & Öztas, 2003).

The aspects of misconception described above show the cause of students having difficulty finding solutions to photosynthesis problems. Suppose students have yet to be able to understand the actual biological meaning of photosynthesis. In that case, the information stated in the question is that "*photosynthesis is a chemical change process that produces glucose and oxygen from carbon dioxide and water through the involvement of light and chlorophyll.*" is not very meaningful for them to solve this first problem. Students are expected to have completeness in their understanding of photosynthesis and use the competency of understanding any reading information about the principles of photosynthesis. Student C expressed these comprehension difficulties and misconceptions in the interview:

Table 3. Interview Results Regarding Comprehension Difficulties and Photosynthesis Misconceptions

Researcher	:	Can you verbally explain the cycle that you have drawn?
Student	:	The photosystem releases 2 electrons, carried across the electron transfer chain of pd, pq, cyt, and pc.
Researcher	:	Where do the 2 electrons released by the photosystem come from?
Student	:	I do not know. From the photosystem, maybe

Errors Due to Problems Related to Drawing a Pedigree

In question 1, students B, C, and D made similar errors in drawing the cycle to understand the principles of light reactions in photosynthesis. They drew the cycle without paying attention to the chemical reactions in each phase, so they did not get an explicitly stated result from the drawn cycle.

The arrangement of reactants and products in each phase of the cycle must show detailed results that represent a bright reaction process of both cyclic phosphorylation and non-cyclic phosphorylation, both dark and bright reactions. Therefore, students must understand the principle of bright reactions in photosynthesis drawn in each phase. Student C and Student D generated incorrect hypotheses related to their initial misconception, assuming that photosynthesis is a plant respiration process.

Figure 2 illustrates student B's problem-solving mechanism, similar to students C and D for question 1. Student B has correctly understood that photosynthesis is the process of plants cooking their food and requires sunlight to provide energy to be converted into chemical energy. However, the three students, B, C, and D, experienced the same difficulty in the planning process described in the dotted line, namely in drawing the process of each cycle because they needed to learn the reactions in each phase. This was observed because the cycles they drew did not show that during photosynthesis, some substances are converted into other substances. According to scientifically acceptable propositions about the interconversion of matter, water and carbon dioxide are converted into other forms of matter due to chemical reactions (Lumpe & Staver, 1995). Students B, C, and D did not understand that photosynthesis is a chemical reaction because they used the same pair of substances as reactants and products of photosynthesis simultaneously. The students, therefore, had a problem helping the concept of chemical reactions or changes, which is a prerequisite for understanding the chemical aspects of photosynthesis. Understanding the chemical nature of photosynthesis also requires students to understand that, although chlorophyll is essential for photosynthesis, it is neither a reactant nor a product of the reaction.

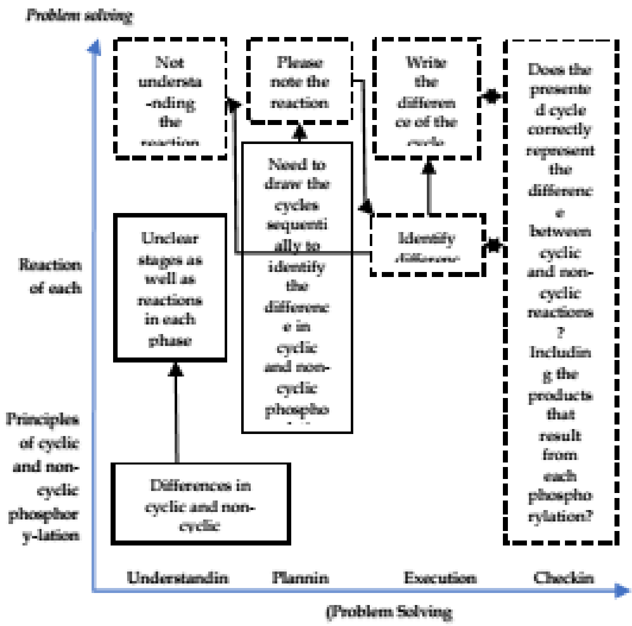


Figure 3. Problem-solving mechanism of student number 1

In particular, the problem of light and dark reactions in photosynthesis is unique because the two phases of photosynthesis involve chemical reactions. According to Stavy et al. (1987), students need help transferring knowledge acquired in a chemistry context to understand the chemical aspects of the topics or materials they study in biology. The bright reaction in the thylakoid membrane captures light energy from sunlight to be converted into chemical energy, namely ATP and NADPH. While hydrogen atoms from H2O molecules are used to reduce NADP + to NADPH, and O2 is released as a by-product of photosynthesis, ATP is formed through ADP + P. The dark reaction, called CO2 reduction, can occur without direct sunlight. However, this dark reaction requires ATP and NADPH2, which are the main results of bright reactions. It can be concluded that dark reactions indirectly also require light energy.

Planning Phase

Errors in the understanding stage cause students to make mistakes in concluding the planning stage when developing problem-solving strategies. Thus, there is a causal relationship between errors in the understanding stage and the planning stage. However, this error can be corrected if the problem-solving process is reviewed in the third stage, namely, checking. Planning stage errors were made by students B, C, and D in numbers 1 and 2.

Figure 3 shows the problem-solving process of students B, C, and D for problem number 2. Problem number 2 has a close relationship with problem number 1; namely, the product produced in number 1 (light reaction) is used in number 2 (dark reaction). So, it is essential to review the checking phase because if students make a slight mistake in the previous number or the previous phase, then their conclusion will also be wrong. In number 1, students B, C, and D had difficulty in the planning stage, namely in drawing the bright reaction cycle, because they needed to understand the chemical reactions that occurred in each phase. Likewise, in number 2, students B, C, and D failed to solve the problem due to difficulties in the planning stage; the mistakes made were dominated by the previous problem number, namely not understanding the reactions that occurred in each phase and incorrectly concluding the total rounds needed to produce 3 glyceraldehyde tri-phosphate compounds.

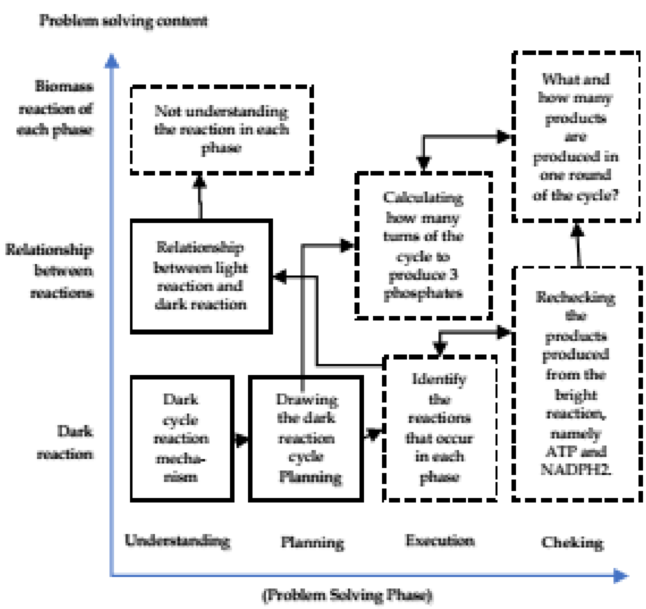


Figure 4. Problem-solving mechanism of student number 2

In contrast to student A, who successfully solved the problem, students B, C, and D experienced errors in determining the conclusion of the results in the bright reaction number 1; they wrote in the bright reaction number 1 to produce ATP, NADPH2, and O2 (Student B) and 2 ATP, NADPH, O2 (Students C and D) even though the correct answer is 2 ATP, NADPH and ½ O2 (Student A). The error in determining the number of rounds needed to produce 3 glyceraldehyde tri-phosphate compounds was due to students B, C, and D not understanding precisely the number of glyceraldehyde tri-phosphate compounds produced in one round of the cycle.

Execution Phase

The students showed various errors in the execution phase when transforming the data presented and applying chemical principles due to the nature of the photosynthesis problem, namely the interpretation of abstract plant food processing properties and the identification of chemical reaction patterns that occur.

Errors in Identifying Chemical Reactions in Photosynthesis Reactions

From the previous stages, it can be observed that the difficulties experienced by students in problems number one and two are the same in determining the reactions that occur in each phase. In the first problem, it was found that there was a student misconception in understanding the conversion of light into chemical energy during photosynthesis, as evidenced by the results of the interview and also supported by the theory (Carlsson, 2002a) where there is indeed a problem in understanding that flowing sunlight is the basis for the energy supply of all organisms. These misconceptions affect students' subsequent ability to solve problems where, in photosynthesis, sunlight is indeed a source of energy that is converted into chemical energy. Based on this, photosynthesis is a chemical reaction that uses the sun as the primary raw material. However, many people need to realize the role of solar energy as a driver of life (Eisen & Stavy, 1988).

The confusion has been observed from the cycle that students B, C, and D drew. In question number 1, they did not explain what reactions occur in the cytochrome complex during the cyclic phosphorylation process, so when drawing the non-cyclic phosphorylation cycle, students did not understand the reactions in the cytochrome complex, how photosystem one and photosystem two were involved, so there was still confusion in concluding determining the difference between the two. The non-cyclic phosphorylation cycle is more complicated than the cyclic phosphorylation cycle. Here is the picture of the cycle of students B, C, and D in number 1.

To strengthen the researcher's observations in the cycle drawn by the students, we asked questions using the term "substance (required or produced)" to match the photosynthesis material textbook. The results were that most students needed to recognize the reactants of photosynthesis.

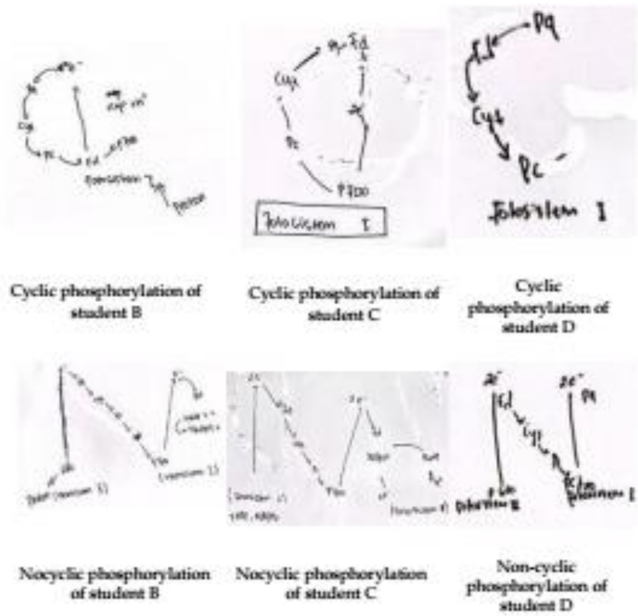


Figure 5. Photosynthesis cycle by students

In addition, the fact that students answered that plants need carbon dioxide and produce oxygen in photosynthesis indicates that students confuse photosynthesis with reverse respiration, as discussed earlier. On the other hand, students recognize the products produced from each phase rather than the constituents. These two facts of misconception are evidence that students do not understand photosynthesis as a chemical reaction. Students have a general understanding of plants, photosynthesis, respiration, and chemical processes in plants, but they need help to connect these understandings into complex knowledge (Svandova, 2014). As a next step, we analyzed students' responses to test questions related to reactants and products of photosynthesis.

In problem number 1, the cycle drawn by student B in the cyclic reaction illustrates that students sufficiently understand that solar energy is used by plants to cook their food, meaning that here, students do not experience misconceptions related to understanding photons in the bright reaction of photosynthesis. Students also understand the connection of the electron transfer chain used in cyclic phosphorylation. However, student B needs help understanding the chemical reactions in cyclic phosphorylation; as a result, in the cycle drawn, students do not write any chemical reactions in the cyclic phosphorylation cycle. While finding solutions to solve problems in non-cyclic phosphorylation, student B was correct in identifying the sequence of photosystems used in non-cyclic phosphorylation. Understanding of the electron transfer chain was also complete. However, again, student B needed help determining chemical reactions and only wrote down one chemical reaction that occurred in non-cyclic phosphorylation, namely NADPH2. In identifying the difference between cyclic and non-cyclic phosphorylation, Student B only wrote one difference according to the process that students understand, namely cyclic phosphorylation using photosystem I and non-cyclic phosphorylation using photosystems II and I.

In contrast to student B, the process of finding solutions for students C and D needs clarification in identifying the difference between cyclic phosphorylation and non-cyclic phosphorylation. Starting with the misconception that sunlight energy is used in photosynthesis for respiration, not for cooking food by plants, in the cycle, they do not describe at all the chemical reactions that should occur in bright reactions, namely the formation of ATP and NADPH. The determination of the photosystems involved in cyclic phosphorylation is all correct. However, in non-cyclic phosphorylation, student D is reversed in determining the photosystem, where the capture of photons in non-cyclic phosphorylation is carried out by photosystem I. In identifying differences, students C and D only wrote one difference that was the same as what student B wrote.

For solving the second problem, student A and student B were correct in drawing the energy flow, but students C and D had difficuneeded helpem between two is very different; where; student D was still correct in determining the flow of the cycle but was unable to determine the chemical reactions that occur in the fixation and reduction phases. At the same time, student D had difficulty in drawing the cycle seen in the cycle sequence that had been drawn and was unable to determine the chemical reactions in each phase. Meanwhile, in determining the number of rounds to obtain 3 tri-phosphate glyceride compounds, only student A, students B, C, and D needed to be corrected in determining the number of rounds.

Errors in Mathematical Reasoning Competency

Students B, C, and D made errors in mathematical reasoning to determine the number of rounds needed to produce 3 glyceraldehyde tri-phosphate compounds. Individual mathematical reasoning competence affects the success of problem-solving in photosynthesis. Problem-solving in photosynthesis requires reasoning skills and mathematical competencies, such as applying probability (Hoskinson et al., 2013).

The inability of mathematical reasoning is evident when students B, C, and D estimate the possible answers to problem 2. Students B, C, and D need to correct their assumptions in understanding the meaning of the number of rounds contained in the problem. They do not know how many glyceraldehyde tri-phosphate compounds are produced in one round of the Calvin cycle. However, this answer can actually be answered correctly if students B, C, and D still use reasoning skills in mathematics. As student A did, he answered correctly that it takes three rounds of the Calvin cycle to produce 3 glyceraldehyde tri-phosphate compounds. He got the correct answer from the results of mathematical reasoning of photosynthesis by representing that one round of the Calvin cycle produces one glyceraldehyde tri-phosphate compound. Student B answered that it takes 5 rounds of the Calvin cycle, while students C and D answered that it takes 2 rounds of the Calvin cycle. Of course, these answers are original answers without the support of conceptual understanding related to the compounds produced in each phase of the Calvin cycle and without using mathematical reasoning.

Checking Phase

The cause of some students' errors in finding solutions is that they need to reach the problem-solving process and ignore the possibility that they can find solutions in the checking phase because they fail to and need help understanding reactions that occur in the photosynthesis process. This may be due to the inability to utilize chemical knowledge in solving problems. The students needed help with chemistry and biology concepts. Finally, another problem with misconceptions about photosynthesis is that students encode new biological information as something utterly different from chemistry (Stavy et al., 1987b).

This was shown by students B, C, and D, where the students used the data in the problem to draw the cycle. However, they did not use the data to check whether the cycle they had drawn was correct and the answers they had written were able to answer the questions in the problem by concluding accurate results or not.

In problem number 1 in the checking phase, students made mistakes related to the previous phase, where most did not recheck, causing the answers to be incorrect and incomplete. The inaccuracy about thneeds to be more accuratedifference between cyclic and non-cyclic phosphorylation where students B, C, and D only mention one difference. Whereas if students B, C, and D understand the concept of photosynthesis material well, at least they can mention two differences that arise from finding answers. Such as the answer by, student A, who mentioned that the difference between cyclic and non-cyclic phosphorylation apart from the photosystem also lies in the photolysis of water, where the process only occurs in non-cyclic phosphorylation.

In problem number 2, students made mistakes at the checking stage related to mathematical reasoning, more precisely in the multiplication used in calculating the number of cycles to determine the number of rounds to produce three glyceraldehyde tri-phosphate compounds. Even though students C and D have correctly drawn in one round of the cycle to produce one glyceraldehyde tri-phosphate compound, they chose to write the original answer without seeing the amount of sugar in the cycle that has been drawn because they are pessimistic about the correctness of the photosynthetic reaction they drew. At the same time, student A could answer correctly because he checked again and used his mathematical reasoning to get the correct answer for three rounds. In addition, if students C and D use their mathematical competence, the answers should be multiples of three, such as three rounds, six rounds, or nine rounds. However, Students B, C, and D did not use the last phase, namely checking correctly. The following is an excerpt from an interview with student D.

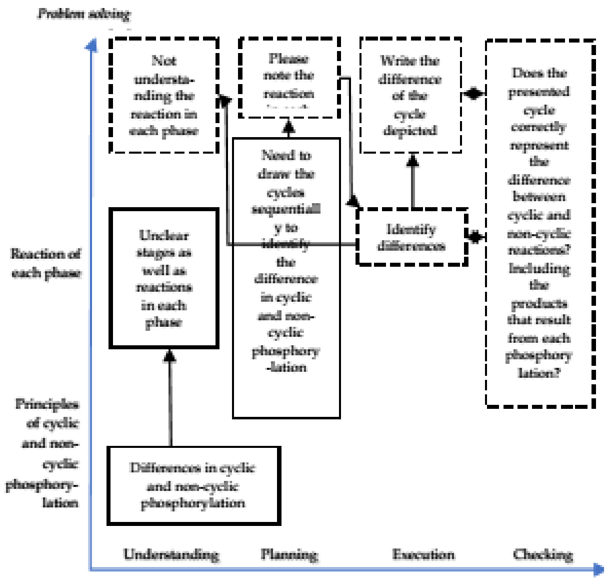


Figure 6. Problem-solving mechanism of student number 1

Table 4. Interview Results Regarding Mathematical Competence in the Checking Phase

Researcher	:	Why, in question number two, to produce three glycerol aldehyde triphosphate compounds requires 2 putaran?
Student	:	I am confused because I do not know.
Researcher	:	If you do not know, why don't you use multiples of three, like 3, 6, or 9? It may be right.
Student	:	I did not think of using a multiple of 3.

Discussion

Difficulty in Finding Problem-Solving Solutions Due to Interaction between Problem-Solving Phases, General Competencies, and Students

Examination of the difficulties and errors made by unsuccessful students at each stage of the problem-solving process showed that the students' reasoning process was hampered by errors related to general competencies such as reading comprehension, chemical reactions, mathematical competencies, and most importantly, the ability to understand the concept of photosynthesis. The results of the relationship between the phases of finding problem-solving solutions, general competencies, and students are as follows:

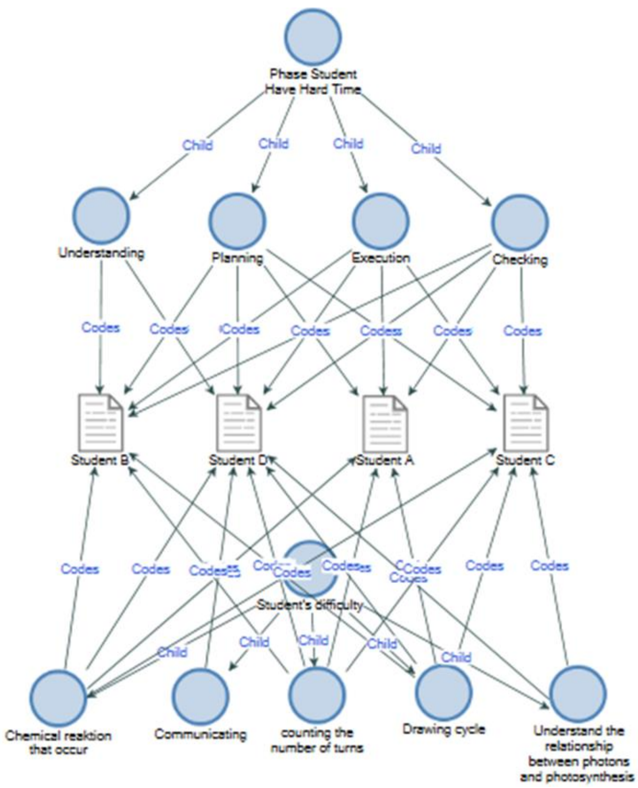


Figure 7. Output NVIVO

From the figure above, it can be understood that all students have difficulty in finding solutions to photosynthesis material on chemical reactions that occur in photosynthesis, mathematical reasoning competence in calculating rounds, and representation skills in drawing cycles that occur. The error connects biology to various other disciplines. First, in chemistry school, students have been taught about the elements that make up living things, but most students need help remembering this information. There are two possible reasons: first, the difficulty of treating living things as a chemical system (as mentioned above). Secondly, students' knowledge is based on memorization without a good understanding of the meaning of the terms. For example, students know the formula of sugar C6H12O6. However, they do not know the meaning of the constituent elements of sugar, or students use the words carbon and carbon dioxide arbitrarily as if they have the same meaning (synonyms) (Stavy et al., 1987b).

The second is mathematical reasoning competence, which in this problem is represented in calculating the number of rounds needed to produce three glyceraldehyde tri-phosphate compounds. It is essential to realize that some problems in biology are quantitative, where ultimately, the goal of many problems is to connect mathematics to make predictions both simple and complex. Problems like number two require students to use predictive models in the process of finding solutions that have the possibility of being correct based on information that has been obtained in the process of finding problem-solving solutions (Hoskinson et al., 2013).

The third is representation ability in drawing cycles. Many problems in biology rely on representation skills to find solutions. These include diagrammatic representations, biological cycles, or relationships between cycles (e.g., light reactions with dark reactions). Some experts in their research have seen and interpreted how these representations can lead to misconceptions (Catley & Novick, 2008) or how these representations affect finding solutions to problems.

Use of Inappropriate Learning Methods in Understanding Photosynthesis Material

Errors related to photosynthesis problem-solving are caused mainly by students' misconceptions and ignorance about the chemical reactions in each phase. This is because the method used by students to understand this material is still using the memorization method. Learning obtained by memorizing without understanding is temporary. It can affect the mastery of ideas that need to be deeper confusing when using the basic concepts they have mastered to produce solutions to various problems (Marsita et al., 2011).

Memorization tends to be a characteristic of Biology subjects (Suryanti et al., 2019). At the same time, this causes students to have difficulty understanding biological concepts because biology subjects are not about memorizing the material but understanding its concepts (Yusup, 2018). The material studied in biology is very diverse, not only discussing the concept of scientific concrete facts but also many concepts about abstract objects (Aisyiyah & Amrizal, 2020). Photosynthesis is classified as one of the abstract materials because it explains the chemical exchange process to synthesize food substances by plants themselves. This is produced by a chemical reaction between carbon dioxide that plants take from the air and water they get from the earth; with the help of energy from sunlight and chlorophyll, this process produces glucose and releases oxygen. Students know this definition of photosynthesis by memorizing, so when learning the process and mechanism of photosynthesis, which involves chemical compounds and chemical processes such as fixation, reduction, and regeneration, students need help. As a result, students know that the photosynthesis process produces oxygen and glucose but need to know how and where these compounds are formed in the photosynthesis reaction. The fact that there are so many misconceptions in photosynthesis material shows how difficult this material is for students to understand.

Based on the results of interviews with students, they mentioned that in learning photosynthesis, the material is still dominated by memorization techniques. Besides that, the learning model used by the teacher has yet to be able to increase student involvement in the learning process and foster a learning environment where students are actively encouraged to find scientific problem-solving solutions. Several learning models can be used to improve the ability to make photosynthesis problem-solving solutions, one of which is problem-based learning (Nurfiyanti et al., 2019). With this learning model, students gain relevant knowledge to solve real-world problems and acquire the necessary skills. According to Putra in Nurfiyanti et al. (2019), the benefits of problem-based learning models include students learning material concepts more effectively because they actively participate in problem-solving and are challenged to use higher-order thinking skills. Students' knowledge is also embedded based on their schema, so learning becomes more meaningful. With the advantages of this learning model, it is expected to improve the ability to make students' problem-solving solutions in photosynthesis material.

Conclusion

This study found that all students needed help finding solutions to photosynthesis material on chemical reactions that occur in photosynthesis, mathematical reasoning competence in calculating rounds, and representation skills in drawing the cycles that occur. The error connects biology with various other disciplines. Firstly, in chemistry lessons, students have been taught about the elements that make up living things, but most students need help remembering this information. The second is mathematical reasoning competence; it is essential to realize that some problems in biology are quantitative, where, ultimately, many problems aim to connect mathematics to make simple and complex predictions. The third is representation skills in cycle drawing. Many problems in biology rely on representation skills to find the solution. Errors related to photosynthesis problem solving are mainly due to the method used by students in understanding this material still using the rote method. Learning obtained by memorization without understanding is temporary. This can affect the mastery of ideas that need further deepening, confusing when using the basic concepts they have mastered to produce solutions to various problems. As a result, students know photosynthesis produces oxygen and glucose but need to know how and where these compounds are formed in the photosynthesis reaction. Several learning models can be used to improve the ability to create solutions to photosynthesis problems, one of which is problem-based learning. Finally, because this study focused on deepening the examination of errors in finding solutions to photosynthesis problems in four students, the results of this study cannot be generalized to other students. However, this study can be helpful for teachers who want to teach photosynthesis material and for the four students involved to discover their weaknesses and errors in learning photosynthesis material.

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Conceptualization, VAA; methodology, VAA .; validation, VAA, WF and MT.; formal analysis, VAA, WF; investigation, VAA.; resources, VAA, WF; data curation, VAA.; writing—original draft preparation, VAA.; writing—review and editing, VAA, WFadly and MT.

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The authors declare no conflict of interest.

References

Aisyiyah, A. T. P., & Amrizal, A. (2020). Penerapan Pendekatan Saintifik (Scientific Approach) Dalam Pembelajaran Biologi Sma. *Jurnal Pelita Pendidikan*, *8*(4), 215–223. https://doi.org/10.24114/jpp.v8i4.20856

Amir, R., & Tamir, P. (1994). In-depth Analysis of Misconceptions as a Basis for Developing Research-Based Remedial Instruction: The Case of Photosynthesis. *American Biology Teacher*, *56*(2), 94–100. https://doi.org/10.2307/4449760

Andersson, B. (1986). Pupils' Explanations of Some Aspects of Chemical Reactions. *Science Education*, *70*, 549–563. Retrieved from https://api.semanticscholar.org/CorpusID:143680451

Barker, M., & Carr, M. (1989). Teaching and learning about photosynthesis. Part 1: An assessment in terms of students' prior knowledge. *International Journal of Science Education*, *11*(1), 49–56. https://doi.org/10.1080/0950069890110105

Becker, F. G., Cleary, M., RM Team, & Holtermann, H. (2015). *Disclaimer the, National Agenda, and others, Nteaching Islamic Studies in the Age of Isis, Islamophobia, And the internet, ed.* Syria Studies.

Bell, B. (1985). Students' ideas about plant nutrition: What are they? *Journal of Biological Education*, *19*(3), 213–218. https://doi.org/10.1080/00219266.1985.9654731

Borich, G. D. (2017). Effective Teaching Methods: Research-Based Practice. In *Pearson Education, Inc.* Retrieved from http://students.aiu.edu/submissions/profiles/resources/onlineBook/a4H2S7_Effective Teaching Methods2017.pdf

Cañal, P. (1999). Photosynthesis and 'inverse respiration' in plants: An inevitable misconception? *International Journal of Science Education*, *21*(4), 363–371. https://doi.org/10.1080/095006999290598

Carlsson, B. (2002a). Ecological understanding 1: Ways of experiencing photosynthesis. *International Journal of Science Education*, *24*(7), 681–699. https://doi.org/10.1080/09500690110098868

Carlsson, B. (2002b). Ecological understanding 2: Transformation- A key to ecological understanding. *International Journal of Science Education*, *24*, 701–715. https://doi.org/10.1080/09500690110098877

Catley, K. M., & Novick, L. R. (2008). Seeing the wood for the trees: An analysis of evolutionary diagrams in biology textbooks. *BioScience*, *58*(10), 976–987. https://doi.org/10.1641/B581011

Eisen, Y., & Stavy, R. (1988). Students' Understanding of Photosynthesis. *American Biology Teacher*, *50*, 208–212. Retrieved from https://api.semanticscholar.org/CorpusID:84001123

Haka, N. B., Muriana, A., & Supriyadi, S. (2022). Analisis Miskonsepsi Materi Fotosintesis Menggunakan Soal Esai Pada Peserta Didik Kelas VIII SMP. *Diklabio: Jurnal Pendidikan Dan Pembelajaran Biologi*, *6*(1 SE-Articles), 17–23. https://doi.org/10.33369/diklabio.6.1.17-23

Hanifa, N. I., Akbar, B., Abdullah, S., & Susilo, S. (2018). Analisis kemampuan memecahkan masalah siswa kelas X IPA pada materi perubahan lingkungan dan faktor yang mempengaruhinya. *Didaktika Biologi: Jurnal Penelitian Pendidikan Biologi*, *2*(2), 121–128. Retrieved from http://jurnal.um-palembang.ac.id/index.php/dikbio

Hillman, W. (2003). Learning How to Learn : Problem-Based Learning. *Australian Journal of Teacher Education*, *28*(2). https://doi.org/10.14221/ajte.2003v28n2.1

Hilyati, I. (2014). Pengembangan Bahan Ajar IPA Materi Fotosintesis Menggunakan CAI (Computer Assisted Instruction) untuk Meningkatkan Hasil Belajar Siswa Kelas 5 MIN Air Kuning Jembrana Bali. In *European Journal of Endocrinology* (Vol. 171, Issue 6). Retrieved from http://etheses.uin-malang.ac.id/7454/1/10140038.pdf

Hoskinson, A. M., Caballero, M. D., & Knight, J. K. (2013). How can we improve problem-solving in undergraduate biology? Applying lessons from 30 years of physics education research. *CBE Life Sciences Education*, *12*(2), 153–161. https://doi.org/10.1187/cbe.12-09-0149

Insani, S. U., & Utami, R. W. (2016). Penerapan Metakognitif dalam Meningkatkan Kemampuan Pemecahan Masalah Matematika Siswa. *Prosiding Dalam Seminar Nasional Matematika Dan Pendidikan Matematika UNY*, MP503–MP508. Retrieved from http://seminar.uny.ac.id/semnasmatematika/sites/seminar.uny.ac.id.semnasmatematika/files/PM-74.pdf

Lumpe, A. T., & Staver, J. R. (1995). Peer collaboration and concept development: Learning about photosynthesis. *Journal of Research in Science Teaching*, *32*(1), 71–98. https://doi.org/10.1002/tea.3660320108

Marsita, R. A., Priatmoko, S., & Kusuma, E. (2011). Analisis Kesulitan Belajar Kimia Siswa SMA Dalam Memahami Materi Larutan Penyangga Dengan Menggunakan Two-Tier Multiple Choice Diagnostic Instrument. *Jurnal Inovasi Pendidikan Kimia*, *4*(1), 512–520. Retrieved from https://journal.unnes.ac.id/nju/index.php/JIPK/article/view/1308

Marzano, R. J. (1988). *Dimensions of thinking: A framework for curriculum and instruction*. The Association for Supervision and Curriculum Development, 125 N. West St., Alexandria, VA 22314-2798. Retrieved from https://eric.ed.gov/?id=ED294222

Nurfiyanti, P. E., Yennita, Y., & Jumiarni, D. (2018). Penerapan Model Problem Based Learning Pada Materi Fotosintesis Dalam Upaya Meningkatkan Hasil Belajar Siswa Kelas Viiia Smpn 2 Lebong Utara. *Diklabio: Jurnal Pendidikan dan Pembelajaran Biologi,* *2*(2), 1-7. Retrieved from https://ejournal.unib.ac.id/jppb/article/view/7950/4076

Özay, E., & Öztas, H. (2003). Secondary students' interpretations of photosynthesis and plant nutrition. *Journal of Biological Education*, *37*(2), 68–70. https://doi.org/10.1080/00219266.2003.9655853

Polya, G. (1978). How to solve it: a new aspect of mathematical method second edition. In *The Mathematical Gazette* (Vol. 30, p. 181). Retrieved from http://www.jstor.org/stable/3609122?origin=crossref

Posamentier, A., & Smith, B. (2020). *Teaching Secondary School Mathematics: Techniques and Enrichment*. https://doi.org/10.1142/11583

Prevost, L. B., & Lemons, P. P. (2016). Step by Step: Biology Undergraduates' Problem-Solving Procedures during Multiple-Choice Assessment. *CBE Life Sciences Education*, *15*(4). https://doi.org/10.1187/cbe.15-12-0255

Puspitayani, D., Jalmo, T., & Marpaung, R. R. T. (2017). Identifikasi Miskonsepsi Siswa Pada Konsep Fotosintesis dan Respirasi Tumbuhan. *Jurnal Bioterdidik: Wahana Ekspresi Ilmiah, 5*(2). Retrieved from http://jurnal.fkip.unila.ac.id/index.php/JBT/article/view/11885

Rohmawati, A. A., & Fadly, W. (2023). Analisis Kemampuan Membuat Solusi Melalui Kegiatan Eksperimen. *Jurnal Tadris IPA Indonesia*, *3*(1), 9–19. https://doi.org/10.21154/jtii.v3i1.1273

Rusandi, & Rusli, M. (2021). Merancang Penelitian Kualitatif Dasar/Deskriptif dan Studi Kasus. *Al-Ubudiyah: Jurnal Pendidikan Dan Studi Islam*, *2*(1), 48–60. https://doi.org/10.55623/au.v2i1.18

Seymour, J., & Longden, B. (1991). Respiration—that is breathing, isn't it? *Journal of Biological Education*, pp. *25*, 177–183. Retrieved from https://api.semanticscholar.org/CorpusID:85943127

Siswana, R., Armen, & Helendra. (2017). Identifikasi Miskonsepsi Materi Fotosintesis pada Siswa Kelas IX SMPN 7 Padang Menggunakan Tes Diagnostik Two Tier Multiple Choice. *Jurnal Biosains*, *1*(2), 277–284. Retrieved from https://ejournal.unp.ac.id/students/index.php/bio/issue/download/355/59

Stavy, R., Eisen, Y., & Yaakobi, D. (1987a). How students aged 13-15 understand photosynthesis. *International Journal of Science Education*, *9*(1), 105–115. https://doi.org/10.1080/0950069870090111

Stavy, R., Eisen, Y., & Yaakobi, D. (1987b). How students aged 13-15 understand photosynthesis. *International Journal of Science Education*, *9*, 105–115. Retrieved from https://api.semanticscholar.org/CorpusID:144893576

Sulasamono Bambang, S. (2012). Problem Solving: Signifikansi, Pengertian, Dan Ragamnya. *Satya Widya*, *28*(2), 155–161. Retrieved from https://ejournal.uksw.edu/satyawidya/article/view/132

Suryanti, E., Fitriani, A., Redjeki, S., & Riandi. (2019). Identifikasi Kesulitan Mahasiswa dalam Pembelajaran Biologi Molekuler Berstrategi Modified Free Inquiry (Identification of Student Difficulties in Molecular Biology with Modified Free Inquiry Learning Strategy). *Perspektif Pendidikan Dan Keguruan*, *X*(2). Retrieved from https://journal.uir.ac.id/index.php/Perspektif/article/view/3990

Svandova, K. (2014). Secondary school students' misconceptions about photosynthesis and plant respiration: Preliminary results. *Eurasia Journal of Mathematics, Science and Technology Education*, *10*(1), 59–67. https://doi.org/10.12973/eurasia.2014.1018a

Waheed, T., & Lucas, A. M. (1992). Understanding interrelated topics: photosynthesis at age photosynthesis at age 14+. *Journal of Biological Education*, pp. *26*, 193–199. Retrieved from https://api.semanticscholar.org/CorpusID:86406265

Wood-Robinson, C. (1991). Young people's ideas about plants. *Studies in Science Education*, *19*(1), 119–135. https://doi.org/10.1080/03057269108559995

Yunia, I., Komariyatin, P., & Aryungga, S. D. E. (2013). Miskonsepsi ipa smp pada topik fotosintesis dan respirasi. *Seminar Nasional Pendidikan Sains*, *2012*, 40–43. Retrieved from https://jurnal.fkip.uns.ac.id/index.php/snps/article/view/12812

Yusup, I. R. (2018). Kesulitan Guru pada Pembelaran Biologi Tingkat Madrasah/Sekolah di Provinsi Jawa Barat (Studi Kasus wilayah Priangan Timur). *Jurnal BIOEDUIN : Program Studi Pendidikan Biologi*, *8*(2), 34–42. https://doi.org/10.15575/bioeduin.v8i2.3187