



Cognitive processes in problem-solving across biogeochemical cycles: A comparative study of carbon, water, and nitrogen cycles

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Article Information	Abstract
Keyword: Biogeochemical cycle; Carbon cycle; Cognitive processes; Nitrogen cycle; Water cycle Kata Kunci: Daur biogeokimia; Daur karbon; Proses kognitif; Daur nitrogen; Daur air History: Received : 04/05/2025 Revised : 02/06/2025 Accepted : 14/06/2025 Published : 18/06/2025	Biogeochemical cycle is one of the topics in biology learning that can train students' problem-solving ability. This study aims to analyze and compare the cognitive processes in students' problem-solving ability on carbon cycle, water cycle, and nitrogen cycle topics. 32 high school students were assessed using a descriptive method with problem-solving test based on Marzano & Kendall's indicators, which emphasize how cognitive processes function in solving problems. Data were analyzed using Kruskal-Wallis statistical test, followed by grouping students into problem-solving ability categories. Based on the number of students in each category of problem-solving ability, students have better problem-solving ability in nitrogen cycle compared to carbon cycle and water cycle. The difference in the distribution of problem-solving abilities of three biogeochemical cycles shows that students' cognitive processes vary for each cycle. This study highlights the importance of integrating the three biogeochemical cycles in learning to develop problem-solving ability comprehensively. The findings also suggest that students' cognitive processes in problem-solving may be supported by their mastery of concepts and experience relevant to the problem. <i>Abstrak. Daur biogeokimia merupakan salah satu topik dalam pembelajaran biologi yang dapat melatih kemampuan problem solving siswa. Penelitian ini bertujuan untuk menganalisis dan membandingkan proses kognitif dalam kemampuan problem solving siswa pada materi daur karbon, daur air, dan daur nitrogen. Sebanyak 32 siswa SMA diuji menggunakan metode deskriptif dengan tes problem solving berdasarkan indikator Marzano & Kendall, yang menekankan bagaimana proses kognitif bekerja dalam memecahkan masalah. Data penelitian dianalisis dengan uji statistik Kruskal-Wallis, diikuti dengan pengelompokan siswa ke dalam kategori kemampuan problem solving. Berdasarkan jumlah siswa pada setiap kategori kemampuan problem-solving, siswa memiliki kemampuan problem-solving yang lebih baik pada materi daur nitrogen dibandingkan daur karbon dan daur air. Perbedaan distribusi kemampuan problem-solving ketiga daur biogeokimia menunjukkan bahwa proses kognitif berbeda-beda pada setiap daur. Penelitian ini menyoroti pentingnya integrasi ketiga daur biogeokimia dalam pembelajaran untuk melatih kemampuan problem-solving secara utuh. Temuan penelitian juga menemukan bahwa proses kognitif dalam problem-solving kemungkinan didukung oleh penguasaan konsep dan pengalaman yang relevan dengan masalah.</i>

A. Introduction

Various elements such as carbon, water, nitrogen, sulfur, and phosphorus are available in unlimited quantities in nature since the elements are always recycled through a natural process called the biogeochemical cycle (Fernández-Remolar, 2014; Smith et al., 2015). While maintaining the availability of elements for reuse by living things, the biogeochemical cycle also plays a role in balancing ecosystems, preventing climate change, and maintaining biodiversity (Berhe et al., 2018; Powers & Marín-Spiotta, 2017). Given the importance of biogeochemical cycles, the concept is taught to students from elementary school to high school. Students are introduced to the basic concepts of biogeochemical cycles in primary school, while in high school, students learn more about the complex mechanisms of biogeochemical cycles (Diwaluthfi, 2017; Pradini et al., 2015). In high school, the concept of biogeochemical cycles is studied more deeply in biology subjects, more precisely in ecosystem material.

The concept of biogeochemical cycles has distinctive characteristics when studied, as it relates to biological phenomena in everyday life, yet involves abstract mechanisms (Diwaluthfi, 2017). In addition, this concept is highly complex and therefore requires a deeper level of understanding (Soltis et al., 2021). At school, students often encounter difficulties in understanding the concept of biogeochemical cycles, which can hinder overall comprehension and potentially lead to misconceptions (Asih & Saptono, 2021; Astuti et al., 2024; Faujiyati et al., 2021; Santi et al., 2019). In fact, a solid understanding of biogeochemical cycles plays a crucial role in developing students' cognitive abilities, particularly in practicing problem-solving abilities (Fatmawati et al., 2021; Saefudin et al., 2022).

Problem-solving ability is a high-level thinking skill that requires logical and critical thinking to solve complex problems (Safirda et al., 2024; Zahra et al., 2021). It is also defined as the process of finding the best solution by utilizing existing knowledge (Juliyanto, 2017). This ability is essential to train because it develops students' ability to think analytically, critically, and creatively (Syarif, 2020). With specific strategies and approaches, problem-solving abilities can develop students' social and emotional skills (Lestari, 2020). In addition, problem-solving ability is one of the important skills needed to face the challenges of the 21st century (Csapó & Funke, 2017).

Students' problem-solving ability can be improved through the concept of biogeochemical cycles (Ramadhan et al., 2023). It is due to the concept of biogeochemical cycles that are related to everyday problems, concerning the balance of ecosystems, and closely related to human activities (Husain et al., 2024). In addition to practicing problem-solving

ability, the concept of biogeochemical cycles trains students to have an awareness of nature, thus increasing student involvement in environmental problems (Gough, 2024; Soltis et al., 2021). Students also learn to make decisions, act by considering ecological impacts, and train a sense of responsibility for the environment (Afia, 2018).

Marzano and Kendall (2007) suggested that problem-solving is included in the highest cognitive system, which is the ability to use knowledge (Knowledge Utilization). Problem-solving ability has four indicators of cognitive processes, namely (1) identifying obstacles to the goal, (2) identifying alternative ways to accomplish the goal, (3) evaluating the alternatives, and (4) selecting and executing the alternatives. These four indicators are interrelated steps in the problem-solving process. In the first indicator, students must be able to identify the problems presented or found. In the second indicator, students must identify various solutions to solve the problem. Furthermore, in the third indicator, students must analyze the advantages and disadvantages of various solutions that have been identified. Finally, in the fourth indicator, students must choose the best solution and implement the solution to solve the problem. These four indicators become the steps of students in solving problems, so students are said to have good problem-solving abilities if they are able to pass the four indicators mentioned. Moreover, understanding the cognitive processes involved in problem-solving is essential for developing contextual learning strategies that can be applied to solving environmental problems, such as global warming, climate change, drought, and others (Csapó & Funke, 2017; Putri et al., 2024).

Many researches related to students' problem-solving ability on biogeochemical cycles material have been developed (Hamdani, 2015; Juliyanto, 2017; Nugraha, 2019; Putri et al., 2023; Saefudin et al., 2022; Santi et al., 2019; Zahra et al., 2021; Zhang & Paquette, 2024). However, the research is less specific in revealing the cognitive processes involved in problem-solving. Therefore, this study aims to analyze and compare cognitive processes in problem solving in each biogeochemical cycle. Of the five cycles taught in the concept of biogeochemical cycles (carbon cycle, water cycle, nitrogen cycle, phosphorus cycle, and sulfur cycle), this study focuses on three main cycles, namely the carbon cycle, water cycle, and nitrogen cycle. The three cycles were chosen because they are more closely related to human life than the other two (Raimi et al., 2021).

Based on these points, there are two problem formulations in this study, which is:

- 1) How are students' problem-solving abilities regarding the concepts of the carbon cycle, water cycle, and nitrogen cycle?

- 2) How are students' cognitive processes in problem-solving related to the concepts of the carbon cycle, water cycle, and nitrogen cycle?

With the formulation of the questions above, this study is expected to provide insight into the level of students' ability to solve problems related to the concept of biogeochemical cycles, especially in the carbon cycle, water cycle, and nitrogen cycle.

B. Material and method

This study is a descriptive study that aims to analyze and compare the cognitive processes in students' problem-solving ability in the carbon, water, and nitrogen cycle. This study was conducted from February until March 2025. The participants in this study were 32 high school students in one of the high schools in Cimahi City. The participants had studied the concepts of carbon cycle, water cycle, and nitrogen cycle in the subtopic of biogeochemical cycle in ecosystem material in grade 10 biology subject. The selection of participants was carried out using the convenience sampling method, which is based on the willingness of students to participate in the study. The research procedure can be seen in Figure 1.

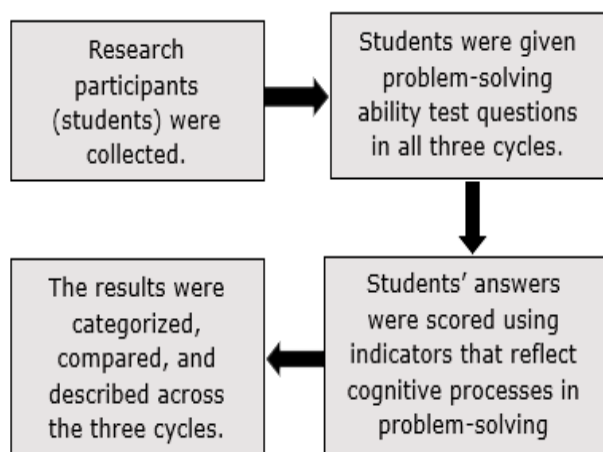


Figure 1 Research procedure

Data collection was carried out using a problem-solving ability test consisting of 15 essay questions—five questions for each cycle concept (carbon cycle, water cycle, and nitrogen cycle). The test was developed based on the problem-solving indicators proposed by Marzano and Kendall (2007), which include: (1) identifying obstacles to the goal, (2) identifying alternative ways to accomplish the goal, (3) evaluating the alternatives, and (4) selecting and executing the alternatives. Each problem-solving question on the carbon cycle, water cycle, and nitrogen cycle has been tested for validity and reliability, with an average reliability value of 0.90 (very high category) and validity ranging from high to very high.

After the data were collected, analysis was conducted by evaluating students' problem-solving scores based on their answers to the essay questions. Although the test focused on problem-solving, the researcher analyzed the cognitive processes involved in solving problems indirectly through the scores obtained by students on the test, as each question was designed using indicators that reflect the cognitive processes. Each indicator has a different maximum score depending on its level of difficulty. First, second, and fourth indicators each have a maximum score of 3, while indicator 3 has a maximum score of 6 because it requires more analysis to explain the advantages and disadvantages of the solution to solve the problem. The overall maximum score is 15. The scores obtained by students are then converted to a value out of 100 using the Formula 1.

$$\text{Score} = \frac{\text{score obtained}}{\text{maximum score}} \times 100 \dots \dots \dots \text{Formula 1}$$

Researchers compared the average scores of the three cycle concepts and the average scores for each problem-solving indicator, then conducted a non-parametric test (Kruskal–Wallis) to determine whether there were statistically significant differences in cognitive processes during problem-solving across the three cycles. If the significance value is less than 0.05 ($p\text{-value} < 0.05$), it indicates a significant difference in the cognitive processes involved in student's problem-solving abilities across the three biogeochemical cycles. However, if the significance value is greater than or equal to 0.05 ($p\text{-value} \geq 0.05$), it indicates that there is no significant difference.

Table 1 Problem-solving ability categorization

Formula	Category
$X \leq (\text{Mean} - 1,5 \text{ SD})$	Very low
$(\text{Mean} - 1,5 \text{ SD}) < X \leq (\text{Mean} - 0,5 \text{ SD})$	Low
$(\text{Mean} - 0,5 \text{ SD}) < X \leq (\text{Mean} + 0,5 \text{ SD})$	Medium
$(\text{Mean} + 0,5 \text{ SD}) < X \leq (\text{Mean} + 1,5 \text{ SD})$	High
$X \geq (\text{Mean} + 1,5 \text{ SD})$	Very high

(Source: Azwar, 2017)

In addition, researchers categorized students' cognitive processes in problem-solving into five categories, namely very low, low, medium, high, and very high problem-solving ability (Azwar, 2017). The problem-solving categorization can be seen in Table 1. After students were categorized based on their problem-solving abilities, the researcher analyzed the distribution of students in the form of percentages. The percentage is calculated using Formula 2.

$$\% = \frac{\text{students in each category}}{\text{total number of students}} \times 100\% \dots \dots \dots \text{Formula 2}$$

C. Results and discussion

Students' problem-solving abilities in carbon, water, and nitrogen cycle

The results of the average analysis showed that the highest problem-solving ability of students was in the concept of the water cycle ($M = 57.47$), followed by the carbon cycle ($M = 57.13$), and the lowest was the nitrogen cycle ($M = 56.28$). However, the results of the statistical test showed no significant difference between students' problem-solving abilities in the three concepts ($p\text{-value} = 0.975$). This finding indicates that based on the average scores, students' problem-solving abilities were relatively even in the concepts of the carbon cycle, water cycle, and nitrogen cycle. However, the categorization of students' problem-solving abilities showed differences. The results of this categorization, based on students' average problem-solving ability scores for each concept, are presented in Figure 2.

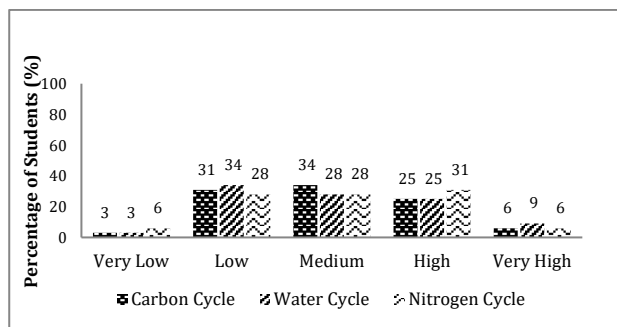


Figure 2
Categorization of students' problem-solving ability in the three cycles

Based on the data in Figure 2, the majority of students' problem-solving abilities fall within the low to medium categories, with the highest percentage in the low category for the water cycle (34%) and in the medium category for the carbon cycle (34%). This percentage shows that students' problem-solving ability in the biogeochemical cycle concept is still not optimal. Meanwhile, in the nitrogen cycle, most students' problem-solving abilities are in the high category (31%). This finding shows that among the three cycles, students have better problem-solving ability in the nitrogen cycle concept.

The findings of this study are not in line with the findings of Zhang and Paquette (2024), who suggested that students are skilled in solving problems in the water cycle. Based on Akben (2020) opinion, problem-solving ability is influenced by students' understanding of related concepts. This is in line with the opinion of Malleus and Kikas (2019) and Nugraha (2019), where the concept of the water cycle is more familiar to students and is taught earlier in the elementary school than the carbon or nitrogen cycle, so students should have a better understanding of the water cycle concept than the other two

concepts. Instead, the results showed that students' problem-solving ability was higher on the nitrogen cycle concept, which has a more complex mechanism than the water cycle. This result may be due to students' perception of the water cycle, where students perceive it as a simple concept, so they do not hone their problem-solving skills in depth. According to Attari et al. (2017), students' perception of the water cycle affects their understanding of the water cycle process itself. Another factor that can affect the difference in research results is misconceptions that may occur in understanding the water cycle process (Asih & Saptono, 2021; Astuti et al., 2024; Faujiyati et al., 2021).

Students' cognitive processes of problem-solving abilities in carbon, water, and nitrogen cycle

In addition to analyzing the overall average problem-solving score, this study analyzed students' cognitive processes in solving problems represented through problem-solving indicators. In the first indicator, identifying obstacles to the goal, the highest average value of problem-solving ability is found in problems related to the water cycle ($M = 68.75$), then the nitrogen cycle ($M = 60.56$) and the lowest in the carbon cycle ($M = 60.31$). Statistical test results showed no significant difference in the first indicator of problem-solving ability ($p\text{-value} = 0.326$), therefore based on the average score, students' cognitive ability in identifying problems is relatively the same in the concept of carbon, water, and nitrogen cycle. However, based on the categorization of scores, there are variations in the distribution of students' cognitive abilities on the first indicator (identifying obstacles to the goal). Based on the data in Figure 3, majority of students have the ability to identify problems in the low category in the carbon cycle (50%), high category in the water cycle (47%), and medium category in the nitrogen cycle (66%). These results indicate that students' cognitive abilities in identifying problems are greatest in the concept of water cycle.

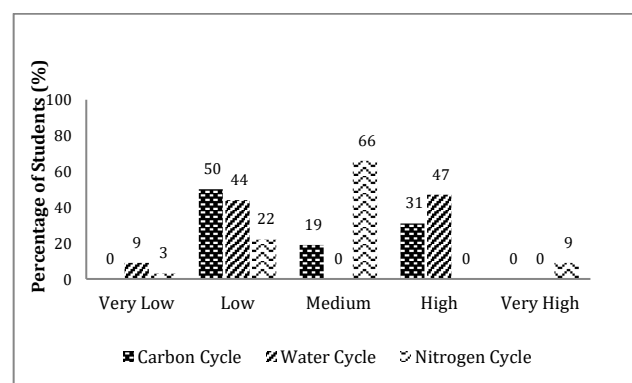


Figure 3
Categorization of students' problem-solving ability in the first indicator (identifying obstacles to the goal)

Students' better cognitive abilities in identifying water cycle problems can be caused by students' direct experience in observing the phenomenon of water cycle, so the students more easily recognize the problem. This is in line with research by Hamdani (2015) which explains that direct experience can improve students' understanding of the water cycle. However, the majority percentage of students in the low category in the carbon cycle and the medium category in the nitrogen cycle indicates that students' cognitive abilities in identifying the problems of the two cycles have not been maximized. This can be caused by the complexity of the material or the abstract nature of the two cycles. According to Dusing et al. (2019) and Houlton et al. (2019), the complexity of the material causes students to have difficulty identifying problems thoroughly. However, students with a very high category in identifying nitrogen cycle problems indicate that some students have high cognitive abilities in nitrogen cycle problems.

After students are able to identify problems, the next cognitive process in problem solving according to Marzano and Kendall (2007) is identifying alternative ways to accomplish the goal. At this stage, students must identify various solutions to solve problems related to carbon, water, and nitrogen cycle. In the second indicator, the average value of problem-solving ability is highest in the carbon cycle ($M = 63.59$), then the water cycle ($M = 63.50$) and the lowest in the nitrogen cycle ($M = 62.59$). The statistical test results showed no significant difference in the indicators of the two problem solving abilities ($p\text{-value} = 0.977$). These results conclude that based on the mean score, students' cognitive ability in identifying various solutions to solve problems is relatively the same in the three cycles.

Furthermore, the results of categorizing the average values on the second indicator (identifying alternative ways to accomplish the goal) can be seen in Figure 4. Based on the data in Figure 4, the cognitive ability of the majority of students in identifying solutions is in the medium category in the nitrogen cycle (56%), supported by a more even distribution of students. As for the carbon cycle and water cycle, the majority of students' cognitive abilities in identifying solutions were in the low category for the water cycle (41%) and medium for the carbon cycle (44%). These results indicate that students' cognitive abilities in identifying various solutions to solve problems are still limited and less explored, especially in the carbon cycle and water cycle. However, some students with a very high category in the nitrogen cycle showed that students had better cognitive abilities in identifying solutions related to the nitrogen cycle.

These findings disagree with the research of Wang et al. (2023), which suggests that students can understand the concept and solve carbon cycle

problems well. In fact, according to Raimi et al. (2021), the problem in biogeochemical cycle is close to human life, so humans should think of many solutions to solve problems in that cycle. Students' ability to find solutions in solving problems is influenced by their understanding of concepts, critical thinking skills, and learning experiences (Diwaluthfi, 2017; Elvianasti et al., 2022). Less than optimal learning experiences cause students to explore less various solutions to solve problems, thus providing limited solutions (Rahmat & Arham, 2022).

The next cognitive process in problem-solving is the third indicator, namely evaluating the alternatives. At this stage, students are expected to be able to evaluate the various solutions that have been given by analyzing the advantages and disadvantages of each solution. In the third indicator, the average value of problem-solving ability is highest in problems related to the carbon cycle ($M = 54.69$), then the nitrogen cycle ($M = 51.56$) and the lowest in the water cycle ($M = 50.47$). The statistical test results showed no significant difference in the indicators of the three problem solving abilities ($p\text{-value} = 0.480$). These results conclude that students' cognitive abilities in evaluating various solutions to solve problems are relatively the same in the three cycles.

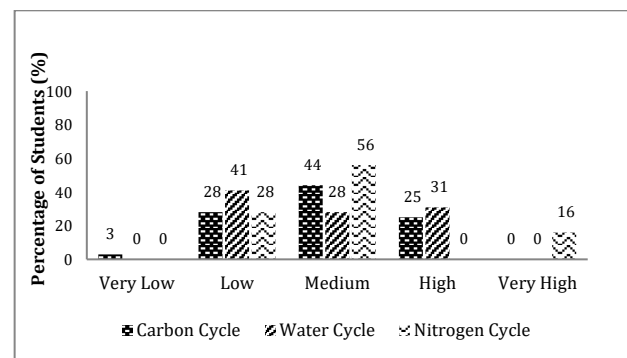


Figure 4

Categorization of students' problem-solving ability in the second indicator (identifying alternative ways to accomplish the goal)

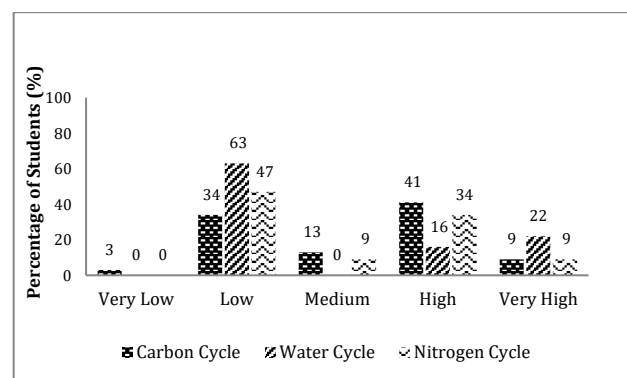


Figure 5

Categorization of students' problem-solving ability in the third indicator (evaluating the alternatives)

The results of the categorization of average scores on the third indicator (evaluating the alternatives) can be seen in Figure 5. Based on the data in Figure 5, there are differences in students' cognitive abilities in evaluating solutions. The majority of students have the ability to evaluate solutions in the high category in the carbon cycle (41%) and the low category in the other two cycles, namely the water cycle (63%) and the nitrogen cycle (47%). The distribution of students on the carbon cycle problem was also more even, where each category had student representatives. These results indicate that students are more adept at evaluating various solutions to the carbon cycle concept. In other words, students' cognitive abilities are best at evaluating solutions on carbon cycle problems.

Students' ability to evaluate solutions can be influenced by their cognitive level and understanding of relevant concepts (Supena et al., 2021). According to Soltis et al. (2021), in the context of biogeochemical cycles, students' involvement in emerging global issues can improve students' understanding and strengthen their ability to evaluate solutions. The problems of global warming and carbon emissions that are often discussed in various media are some of the factors that make students more skilled in analyzing solutions related to the carbon cycle compared to the water cycle and nitrogen cycle (Gough, 2024; Putri et al., 2024).

The last cognitive process in solving problems is represented in the fourth indicator of problem-solving, namely selecting and executing the alternatives. After identifying the problem, identifying various solutions to solve the problem, and analyzing the advantages and disadvantages of each solution, students are expected to have the ability to choose the best solution and execute the solution in order to solve the problem. In the fourth indicator, selecting and executing the alternatives, the highest average problem-solving ability score is on problems related to the water cycle ($M = 57.81$), then the nitrogen cycle ($M = 55.28$) and the lowest on the carbon cycle ($M = 52.13$). However, the statistical test results showed no significant differences in the indicators of the four problem solving abilities ($p\text{-value} = 0.936$). The average results of these scores indicate that students' cognitive abilities in selecting and executing solutions are relatively the same in the concept of carbon cycle, water cycle, and nitrogen cycle.

Furthermore, the results of the categorization of average scores on the fourth indicator (selecting and executing the alternatives) can be seen in Figure 6. The data in Figure 6 shows a difference, which is the majority of students have the ability to select and execute solutions in the low category in the carbon cycle (44%) and the medium category in the other two cycles, namely the water cycle (38%) and the nitrogen cycle (47%). The higher percentage of students in the nitrogen cycle indicates that the

majority of students have better cognitive abilities in selecting and executing solutions to nitrogen cycle problems. In addition, the data showed that the distribution of students on the water and nitrogen cycle problems was more even, where the very low category to the high category had student representation. This indicates that students' understanding of the concept varies, although the majority of students are in the medium category.

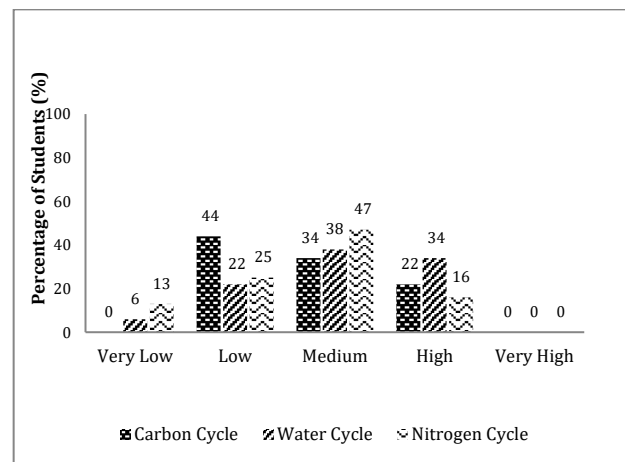


Figure 6
Categorization of students' problem-solving ability in the fourth indicator (selecting and executing the alternatives)

The findings on the fourth indicator of problem-solving show different results from the previous indicator (evaluating the alternatives), where students were better able to evaluate solutions related to the carbon cycle. In selecting and executing solutions, however, students were more skillful in solving problems related to the nitrogen cycle. This finding could be due to the large number of solution options for carbon cycle and water cycle problems, which makes it more difficult for students to determine the best solution (Chernev et al., 2012). In contrast, students tend to propose fewer solutions for nitrogen cycle problems. The narrower choice space allows students to focus more on evaluating and selecting the most appropriate solution (Cattaneo et al., 2021).

Overall, although the statistical test results were not significant, the percentage of students in each category showed differences in problem solving abilities in the three biogeochemical cycles. Table 2 is a summary of data on the category of problem-solving ability in majority of students. The data shows that the cognitive process in problem solving varies in the concept of biogeochemical cycles, especially in the three cycles tested in the study: the carbon cycle, water cycle, and nitrogen cycle.

In the carbon cycle concept, majority of students have the ability to identify problems (identifying obstacles to the goal) in the low category. However, the percentage of students increased in the

ability to identify various solutions (identifying alternative ways to accomplish the goal), which is in the medium category. In fact, in evaluating the alternatives, majority of students showed the ability in the high category, indicating that they were able to analyze the advantages and disadvantages of each solution well. Unfortunately, in selecting and executing the alternatives, majority of students were

again in the low category. The findings show that students have good cognitive ability in identifying and evaluating solutions, but they still have difficulty in determining the best solution and applying it to solve the problem. This may be due to the ability to identify problems that are in the low category. Students had difficulty understanding the problem root, so they could not apply the solution to overcome the problem.

Table 2 Students' problem-solving ability categorization in the majority of students (highest percentage)

Biogeochemical cycles	Categorization of students' problem-solving ability in the majority of students				
	1 st Indicator (Identifying obstacles to the goal)	2 nd Indicator (Identifying alternative ways to accomplish the goal)	3 rd Indicator (Evaluating the alternatives)	4 th Indicator (Selecting and executing the alternatives)	Overall average scores
Carbon cycle	Low (50%)	Medium (44%)	High (41%)	Low (44%)	Medium (44%)
Water cycle	High (47%)	Low (41%)	Low (63%)	Medium (38%)	Low (34%)
Nitrogen cycle	Medium (66%)	Medium (56%)	Low (47%)	Medium (47%)	High (31%)

In the concept of water cycle, majority of students were in the high category in identifying problems (identifying obstacles to the goal). However, in identifying and evaluating solutions (identifying alternative ways to accomplish the goal & evaluating the alternatives), the ability of majority of students was in the low category. This finding shows that students are able to identify problems well, but have difficulty in proposing and analyzing solutions to solve problems. As for the ability to select and execute the alternatives, the percentage of students has increased in the medium category. The findings show that although students have difficulty in identifying and evaluating solutions, some students have good cognitive abilities in determining the best solution and applying it to solve the problem. This indicates that students tend to select and apply solutions to the concept of water cycle without analyzing the solutions.

In the nitrogen cycle concept, the majority of students have the ability to identify problems and identify solutions (identifying obstacles to the goal & identifying alternative ways to accomplish the goal) in the medium category. However, in evaluating the alternatives, the percentage of students decreased to the low category. However, in evaluating the alternatives, the percentage of students decreased to the low category. This shows that although the majority of students have the ability to identify problems and propose various solutions, students have difficulty in evaluating these solutions. However, students' ability in selecting and executing the alternatives was in the medium category. This means that in choosing and implementing solutions, students do not analyze the advantages and disadvantages of each solution in depth. Students are likely to choose and consider the best solution based on logic and familiarity with the solution.

The difference in the distribution of problem-solving abilities across the three biogeochemical

cycles above shows that students' cognitive processes in problem-solving vary for each cycle. Students' ability in identifying problems is better in the concept of water cycle. In evaluating solutions, students' abilities are better in the carbon cycle concept. As for identifying solutions and selecting and executing solutions, students' abilities are better in the nitrogen cycle concept. These results show that each cycle has advantages in the cognitive process of problem-solving. Based on this, to train the cognitive process of problem-solving completely, the three biogeochemical cycles must be taught simultaneously.

Indirectly, this study also highlights the importance of concept mastery in supporting cognitive processes in problem-solving abilities. Several studies support this finding, where problem-solving ability is strongly influenced by students' concept mastery (Akben, 2020; Amanda et al., 2022; Riong et al., 2022; Sapriyadin et al., 2023). Students with an intact understanding of concepts are able to analyze the causes and impacts of problems, so that they can propose the best solution to avoid bigger problems, such as climate change and ecosystem imbalance. In addition to students' concept mastery of biogeochemical cycles material, the complexity of the material is also a factor that causes differences in problem solving abilities (Astuti et al., 2024). Unfortunately, this study did not explore in depth the effect of concept mastery and material complexity on students' problem-solving abilities.

Apart from concept mastery, problem-solving abilities in the three cycles may be influenced by students' experiences. The findings of this study are in line with previous studies, which state that students' experiences and understanding of global problems, such as drought, global warming, or environmental pollution, also influence students' abilities to analyze and solve problems (Putri et al., 2023). In terms of learning, students' suboptimal problem-solving abilities can be caused by inadequate learning

experiences, ineffective learning, or uninformative reading materials, so students' abilities to construct knowledge and think intensely are not trained (Aritia & Suyanto, 2019; Düsing, 2025). Learning experiences that do not follow the concept can cause students to experience misconceptions in understanding biogeochemical processes (Astuti et al., 2024; Febrianti & Hamimi, 2024; Noor, 2023).

The findings of this study also highlight the differences in the instruments used to measure problem-solving ability compared to instruments commonly used in other studies. This study assessed students' problem-solving ability using an instrument arranged based on the fourth level in the cognitive dimension of The New Taxonomy (Marzano & Kendall, 2007), where students are required to utilize the knowledge they already have to solve problems (knowledge utilization). The fourth level in the cognitive dimension of Marzano and Kendall (2007) emphasizes higher-order thinking skills, which require students to make decisions and solve problems after going through the previous three stages: remembering concepts (retrieval - level 1), understanding concepts (comprehension - level 2), and analyzing concepts (analysis - level 3).

Several problem-solving ability instruments that are different from this study are the research of Amanda et al. (2022), Elvianasti et al. (2022), and Rahmat & Arham (2022), who used the Polya problem-solving instrument, Akben (2020) used the Problem-Solving Inventory instrument from Heppner & Petersen, and Saefudin et al. (2022) used a problem-solving instrument adapted from Eibensteiner. In addition, several studies measure problem-solving ability with conceptual understanding questions (Malleus & Kikas, 2019; Nugraha, 2019); some also compile case studies based on Bloom's C5 taxonomy (Safirda et al., 2024). Specifically in measuring water cycle problem solving, Zhang and Paquette (2024) used Mayer's problem-solving instrument, while in measuring carbon cycle problem-solving, Wang et al. (2023) used the problem-solving instrument from Heideman and colleagues. Unlike the problem-solving instruments mentioned above, Marzano and Kendall's problem-solving measures problem-solving ability by considering deeper cognitive processes, thus providing a more in-depth overview of students' ability to solve problems. The difference in instruments used to measure problem-solving ability may cause the results of the study to differ from other studies.

D. Conclusion

This study reveals that students' cognitive processes in problem-solving differ across the carbon, water, and nitrogen cycles. While overall performance was strongest in the nitrogen cycle, students showed the best ability to identify problems in the water cycle

and to evaluate solutions in the carbon cycle. These variations suggest that students' concept mastery and learning experiences may influence cognitive processes in problem-solving. Integrating all three biogeochemical cycles in learning may foster more balanced and comprehensive problem-solving ability. Although this study did not directly examine the link between concept mastery and cognitive processes in problem-solving, the findings can serve as a reference for educators to integrate the three biogeochemical cycles in learning and enhance students' mastery of concepts and learning experiences. Future research should investigate how concept mastery shapes problem-solving ability across biogeochemical cycles.

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