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Students' understanding of ecology: Identifying interaction between ecosystem components

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ABSTRACT

Ecology learning in schools should go beyond explaining isolated concepts, involving visual representations to help students comprehend the complexity of ecological systems. This study aimed to analyze high school students' understanding of the interactions among ecosystem components using student-generated drawings. Sixty-three 10th-grade students participated in the study. This study employed a pre-test and post-test design by collecting student-generated drawings at two time points: before the instructional intervention to establish a baseline and after the intervention to assess its impact on students' understanding. The students' drawings of river ecosystems were analyzed and coded on three system levels: biotic-abiotic (BA), micro-macro (MM), and components-mechanisms-phenomena (CMP). Results from the Wilcoxon Signed-Rank Test indicated significant improvements in students' ability to represent interactions across these system levels. Effect size calculations revealed large effects between BA:MM and BA:CMP, suggesting substantial learning gains. A moderate effect was observed between MM:CMP. While students showed a clear improvement in describing BA:MM interactions, their depictions of CMP remained limited. These findings highlight the importance of teaching strategies on ecosystem that explicitly integrate abiotic mechanisms at multiple biological scales. Such approaches can support students in visualizing ecological processes as interconnected systems, rather than fragmented components.

INTRODUCTION

Understanding ecosystems in biology requires critical thinking to integrate ecosystem components into meaningful knowledge. The difficulty in learning biology on the topic of ecosystems is that students must comprehend the intricate relationships between ecosystem components, which include hierarchical levels of organisms as well as abiotic components related to space and time (Eberbach et al., 2021; Hmelo-Silver et al., 2017). Furthermore, the interaction among ecosystem components is an abstract concept because their interrelationships cannot be observed simultaneously (Martín-Gámez et al., 2020). For example, understanding the flow of energy and food chain in an ecosystem can be viewed as a process of nutrient and energy transfer from one trophic level to the next (Glettler & Torkar, 2021).

A holistic understanding of ecosystems is a challenge for teachers when developing learning strategies to assure students' mastery of learning outcomes. The expected learning outcome for students in ecology is to understand multiple-linked subsystems with processes and relationships that occur at both the macroscopic and microscopic levels (Wanselin et al., 2023; Hmelo-Silver et al., 2007). Students need to understand the relationships between the living things involved, biochemical processes, and the dynamic flow of energy within ecosystems (Mambrey et al., 2022; Akçay, 2017). Students' perception about the interactions that occur in ecosystems includes not only macroscopic levels, buat also microscopic levels that have an impact on the macroenvironment. For instance, understanding decomposition requires considering the function of bacteria and chemical processes that are difficult to monitor, but have an impact on soil nitrogen availability (da Silva et al., 2022).

Several studies have demonstrated that students have misconceptions regarding ecosystems, such as their inability to analyze the abiotic elements that influence biome formation (Triana, 2023). In addition, students are unable to examine the relationship between changes in one population and other populations linked in food webs (Putri & Rusyati, 2021). Another study discovered that students have a substantial number of misconceptions about energy flow and biogeochemical cycles (Azrai et al., 2025; Glettler & Torkar, 2021). Students are often apprehensive about matters they understand and require extensive reinforcement of ecosystem concepts (Azrai et al., 2025). To eliminate students' misconceptions, teachers must establish relevant learning procedures that reinforce ecosystem principles and create learning tools that promote student understanding. Teachers' instructions serve as a bridge that supports students in developing conceptual knowledge (Horne et al., 2025).

Organised instructions that mention the microbiological level are critical in the implementation of ecosystem learning because if these instructions are not mentioned, students will only mention components that are easily observed rather than the processes or mechanisms that occur in the ecosystem. The study found that some students were unable to apply what they learnt in class in real-life situations. As a results, a mental model is required to represent abstract concepts owned by students, one of which is to represent thoughts in a drawing based on the instruction provided (Dentzau, 2021). Visual-based assessments, such as drawing analysis, enable teachers to identify students' mental representations of ecological systems as cause-and-effect interactions (Gansemer-Topf et al., 2021). Moreover, a study using 2D media graphics increased learning motivation in ecology topics. Teachers can use visuals to teach students about how systems work and evaluate their learning outcomes. Furthermore, sketching requires cognitive processes that combine existing knowledge, new information, and comprehension into long-term memory (Ainsworth & Scheiter, 2021).

The use of graphical representations in ecosystem learning can indicate students' comprehension while tracing the carbon atom trail in the ecosystem's carbon cycle (Düsing et al., 2019). Visuals can also help students understand the structure-behaviour-function (SBF) link, which is supported by direct observation and computer modelling (Eberbach et al., 2021; Hmelo-Silver et al., 2017). However, study into the linkages between the components that make up ecosystem processes through drawing is still limited. Based on this, the present study aims to describe the development of students' understanding of the relationships among ecosystem components and how student represent the connections between biotic-abiotic components (BA), micro- and macro-levels (MM), and the mechanisms by which each component operates (components-mechanisms-phenomena; CMP), based on visual analysis using drawings. Drawing activities are used as a learning assessment, and students are required to expand their knowledge of ecosystems by analyzing the interconnected levels of the BA, MM, and CMP structures that underlie system functioning. The following research questions were employed to address the aims of the study.

(1) Based on students' drawings, which ecosystem components are identified?
(2) How do students explain the connections among the ecosystem components?

METHODS

Research Design

This study employed a quantitative approach using a one-group pre-test—post-test design. This study aims to examine students' development of understanding of the relationships among ecosystem components through visual analysis using drawings. Modeling experiences using drawings enable students to make visible of their understanding about complex phenomena (Eberbach et al., 2021).

Participants

The participants in this study were 63 tenth-grade high school students (28 males and 35 females) from a private school located in Bandung Regency. The school is classified as a middle-level institution with a high economic status.

Instrument

The students' river ecosystem drawings were analyzed and coded based on three system domains: biotic-abiotic (BA), micro-macro (MM), and component-mechanisms-phenomenon (CMP). Each domain was scored on a scale of 1 to 3, with higher scores indicating a greater demonstration of the expected skills. The coding process was guided by an adapted rubric (Eberbach et al., 2021, Hmelo-Silver et al., 2017) as shown in Table 1.

Table 1
Three ecosystem domains rubric

Domain	Description	Score
Biotic – Abiotic (BA)	No answer	0
	Only biotic or abiotic components are depicted Example: only fish, plants, or the sun are illustrated	1
	Both biotic or abiotic components are depicted Example: fish, plants, and the sun are illustrated	2
	Both biotic or abiotic components are depicted, along with the relationship between them Example: a fish swimming in water	3
Micro – Macro (MM)	No answer	0
	Only micro- or macro-level structures/processes are depicted Example: illustrating the presence of microorganisms or showing a food chain process	1
	Both micro- or macro-level structures/processes are depicted Example: a food chain and the water cycle are shown, but they are not connected (no arrows indicating relationship between the two components)	2
	Both micro- or macro-level structures/processes are depicted, along with the relationship between them Example: a food chain and the water cycle are shown and connected to each other	3
Component – Mechanism – Phenomenon (CMP)	No answer	0
	Only relationship among structures are depicted Example: fish and water	1
	Relationship between structures and mechanisms or between structures and functions are depicted Example: (C-M) Fish use water to obtain oxygen (C-P) Fish release CO_2 or plants produce O_2	2
	Relationships among structures, mechanisms, and function are depicted Example: Fish use water to obtain oxygen and produce energy	3

Procedure

The learning process was conducted over three meetings. The first meeting began with a pre-test, in which students were instructed to describe a river ecosystem based on their prior understanding. This activity aimed to assess students' initial knowledge of ecosystems. Subsequently, instructional material on ecosystems was provided, followed by an assignment requiring students to analyze biogeochemical cycles, including the carbon (C), nitrogen (N), phosphorus (P), and water cycles. In the second meeting, the intervention consisted of small-group discussions (3-4 students per group) on biogeochemical cycles. Each group focused on one specific cycle, and the results of the discussions were then presented in a whole-class session. In the third meeting, post-test data were collected through students' drawings of river ecosystems using the same instructions as in the pre-test.

Data Analysis Techniques

The drawing data were categorized by the depicted components, and mean scores and percentages were calculated. Data normality was assessed using the Kolmogorov-Smirnov test, which indicated that the data were not normally distributed ($p < 0{,}05$). Therefore, subsequent analyses were conducted using non-parametric methods. To compare pre-test and post-test scores across the three domains (BA, MM, CMP), the Wilcoxon signed-rank test was applied. Additionally, differences among the three domains in the post-test scores were examined using the Friedman test. When significant differences were detected, post hoc pairwise comparisons were performed using the Wilcoxon signed-rank test. Finally, effect sizes were calculated from the Wilcoxon test results to assess the magnitude of the intervention's impact.

RESULTS AND DISCUSSION

Ecosystem components recognized from students' drawings

Based on the analysis of students' drawings in the pre-test, the most frequently identified ecosystem components were food chain and photosynthesis, whereas the water cycle and decomposition were the least frequently represented (Figure 1). In the post-test, the nitrogen cycle emerged as an additional concept, although it appeared infrequently in students' drawings. These findings showed progress in students' understanding of ecosystem components, particularly in incorporating micro-level processes as the nitrogen cycle. During the process of constructing an ecosystem by drawing, students may employ different ways of assimilating information to allow aspects of understanding that are not evident in written responses to emerge (Snowman et al., 2017). Furthermore, students' prior knowledge may sometimes conflict with scientific concepts. Therefore, the learning experiences provided to students play an important role in promoting conceptual change. When learning instructions are clear and well-structured, students are more likely to develop a comprehensive understanding and avoiding misconceptions (Azrai et al., 2025). As shown in students' response in Figure 3C, student's drawing depicts the need for nitrogen in plants. Plants obtain nitrogen through the degradation of organic materials by decomposers and the absorption of N_2 from the atmosphere. However, the intake of free nitrogen from the air is not fully explained in terms of nitrogen fixation by bacteria. This finding suggests that students' understanding of ecosystem components requires more advanced system thinking skills. System thinking skills are the ability to understand system organization interact and influence one another that function together as a whole (Momsen et al., 2022; Mambrey et al., 2022). Students tend to find it easier to understand ecosystem components as separate entities than to recognize the complex and interconnected relationships among them. This may be because students' system thinking skills in the context of ecosystem learning remain at varying levels of development (Sudianto et al., 2024; Lankers et al., 2023).

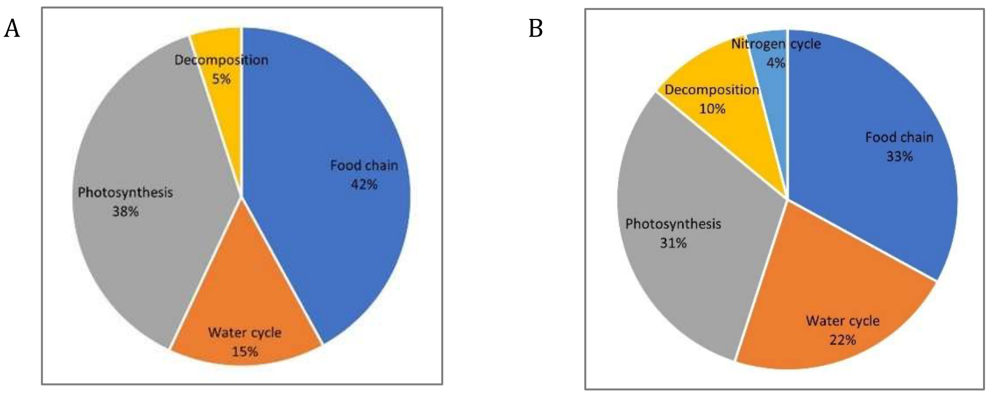


Figure 1. Ecosystem components recognized from students' drawings. A) Pre-test; B) Post-test

Analysis of students' river ecosystem drawings in the pre-test and post-test revealed differences in their understanding of the micro-macro (MM) and component-mechanisms-phenomenon (CMP) domains (Table 2). The mean scores indicate that, overall, students had already demonstrated an understanding of the biotic-abiotic (BA) domain, as reflected in their depictions of biotic and abiotic components and their relationships. Students tend to understand concrete and observable ecosystem concepts, such as biotic and abiotic components, more easily than abstract ecological processes (Ristanto et al., 2023 Martín-Gámez et al., 2020). In contrast, understanding of the MM and CMP domains improved significantly after participation in discussions of biogeochemical cycles. When students construct drawings, they can distribute cognitive processing across visual and textual representations, reducing the cognitive demands of expressing their understanding solely through writing (Wang et al., 2023). Results of the Wilcoxon signed-rank test showed no significant difference in the BA domain, whereas significant differences were found in the MM and CMP domains (Table 3). These findings suggest that the learning intervention did not significantly enhance BA domain but had a positive impact on their understanding of the MM and CMP domains. Lin et al. (2024) found that students with well-established prior knowledge of BA tend to demonstrate stable understanding, resulting in limited gains following learning interventions.

Table 2
Average score of pre-test and post-test results

Domain	**Pre-test**	**Percentage**	**Post-test**	**Percentage**
	Mean ± SD		**Mean** ± SD	
BA (Biotic-Abiotic)	2.98 ± 0.12	99.48%	2.98 ± 0.12	99.49%
MM (Micro-Macro)	0.44 ± 0.55	14.87%	1.89 ± 0.90	63.13%
CMP (Component-Mechanism-Phenomena)	1.36 ± 0.51	45.61%	2.28 ± 0.69	76.26%

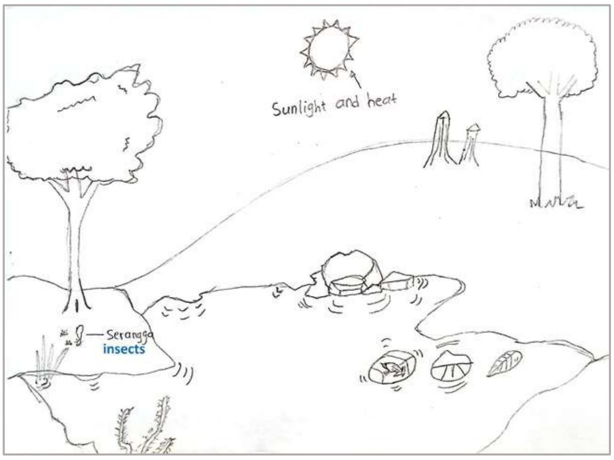
Students' understanding of the BA component showed the highest mean score compared to other components, as this concept forms the foundation of ecosystem understanding and enable the development of stable prior knowledge. These findings are consistent with previous research indicating that students' initial conceptions of ecology are often limited to familiar concept, such as fauna, sunlight, and water, which are often introduced in elementary curriculum (Robles-Piñeros & Tateo, 2023). For abstract and dynamic processes represented I the CMP, such as interactions between micro- and macro-level components, decomposer activity, and biogeochemical chemical cycles, students require deeper and more contextualized learning experiences to understand the underlying mechanisms of these processes and to avoid misconceptions (Dozier et al., 2023; Demssie et al., 2023; Eberbach et al., 2021). The test result for the MM and CMP domains indicate that the learning intervention was effective in improving students' understanding of ecological concepts within these domains. The initially low level of students' understanding in the MM and CMP domains can be attributed to the abstract nature of these concepts, which require the integration of ecological system knowledge across multiple scales (Hmelo-Silver et al., 2017). This poses a cognitive challenge that is difficult for students to articulate without structured instructional support (Mokuku & Tlhakola, 2021). Understanding macro-micro processes, including material cycling and energy flow, provides a fundamental basis for recognizing the interconnected relationships among ecosystem components (Lin et al., 2024).

Table 3
Wilcoxon signed-rank test comparing pre-test and post-test scores of students' drawings

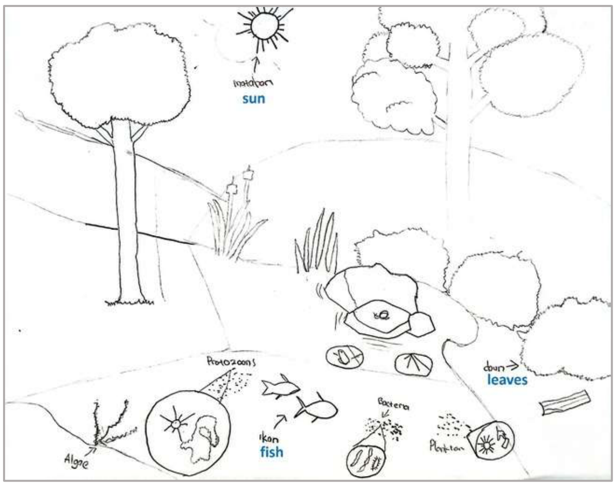
Domain	**Z**	**Sig.**
BA (Biotic-Abiotic)	-1.342[b]	0.180
MM (Micro-Macro)	-6.206[c]	0.000
CMP (Component-Mechanism-Phenomena)	-6.323[c]	0.000

Students' ways of depicting relationships among ecosystem components

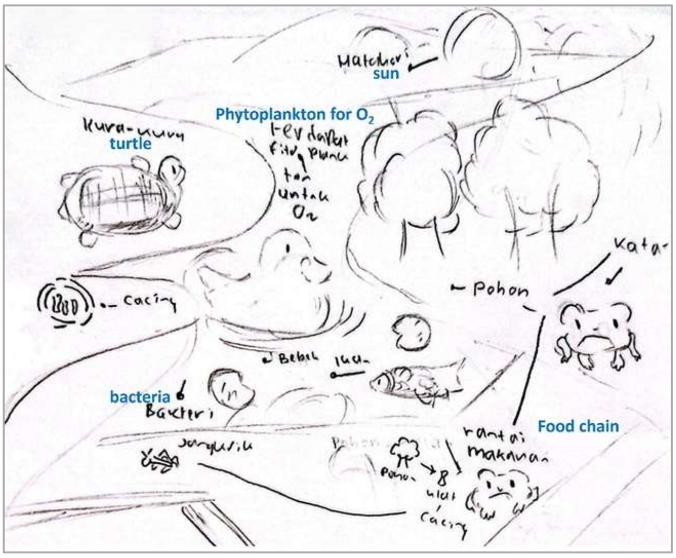
The pre-test drawings revealed that the majority of students still had a limited comprehension of ecosystem structure and function. During the pre-test, students' initial representation mostly depicted biotic components, such as producers (plants) and consumers (as in the food chain), with little comprehension of the dynamic interactions between components or the importance of biotic forces in ecological systems. In Figures 2A-D, students demonstrated the BA domain at a score 3, as the drawings depict both biotic and abiotic components along with the relationships between them. Based on these drawings, the biotic components of the river ecosystem include bacteria, plankton, duck, fish, frog, and lotus plants, while the abiotic components include sunlight and water. In Figure 2A, the MM domain is not represented (score 0), however, the students illustrated a structural relationship, indicating that sunlight produces heat. Figure 2B showed the MM domain at a score of 1, as the students depicts the presence of microorganisms (bacteria, plankton, and protozoans). The CMP domain in this figure is scored 1, as only the relationships among structures are shown, such as fish living in water. A student who obtained a score of 2 in the MM domain (Figure 2C) demonstrated macro-level structures, such as a food chain (e.g., frog preying on a mosquito), as well as micro-level components in the form of microorganisms, without illustrating the relationship between them. The student obtained a CMP score of 2 as mentioned that phytoplankton produce oxygen (C-M). A student who achieved a score of 3 in the CMP domain (Figure 2D) demonstrated relationships between components and mechanisms, such as sunlight being used by plants in photosynthesis to produce oxygen, as well as illustrating water evaporation leading to cloud formation and eventually rainfall (C-M-P).



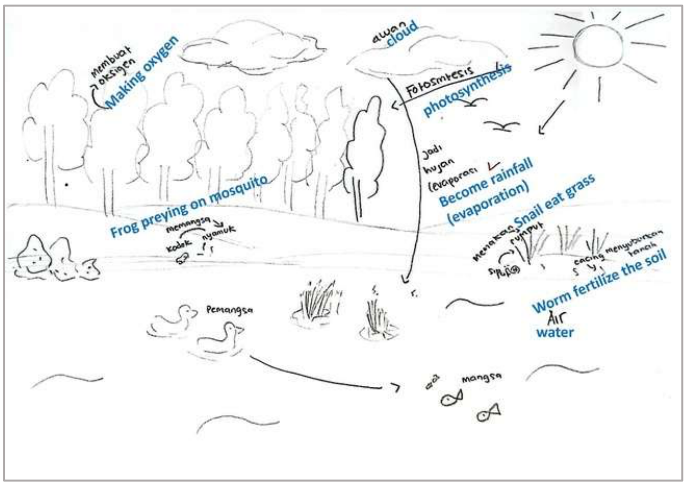
2A



2B



2C

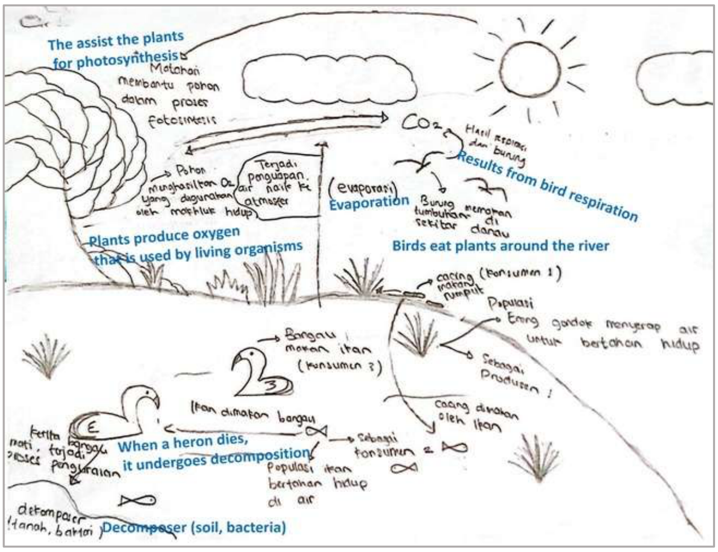


2D

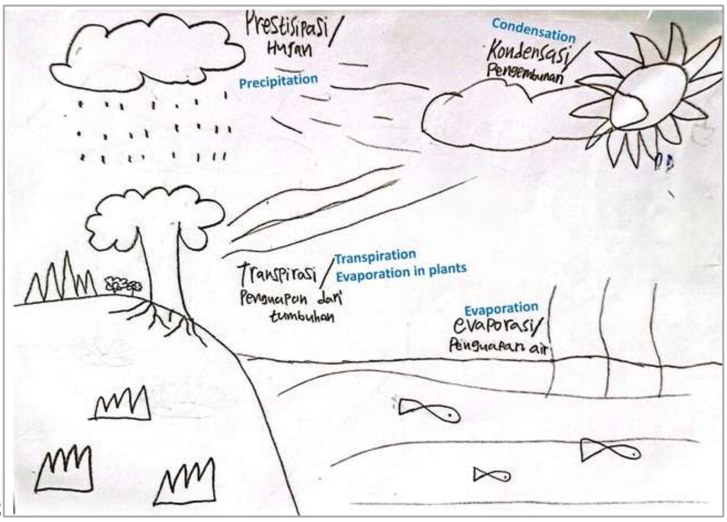
Figure 2. The selected students' drawing from the pre-test. A) Drawing showed BA score 3; B) Drawing showed MM score 1; C) Drawing showed MM score 2 and CMP sore 2; D) Drawing showed CMP score 3

Students' post-test drawing showed a significant improvement in the quality of their conceptual representations compared to the pre-test. This change is reflected in students' ability to identify ecosystem components more comprehensively, including producers, consumers, decomposers, and interconnected abiotic factors. Figure 3A illustrated a student who achieved a score of 2 in the MM domain, as indicated by the depiction of macro-level structures, such as a food chain, and micro-level processes, such as decomposition by decomposers. However, these elements are presented without illustrating the relationship between them. The student identifies decompositions as involving soil and bacteria, but the products of decomposition are not linked to their utilization by other organisms. Figure 3B showed a student who obtained a score of 2 in the CMP domain, as indicated by the depiction of relationship between components and mechanisms. The drawing illustrated that water undergoes evaporation and plants undergo transpiration, which contribute to condensation and eventually results in rainfall (C-M).

Based on the post-test drawing, students are beginning to represent ecosystem as system composed of interconnected components linked through specific mechanisms. Depictions of evaporation, transpiration, condensation, and precipitation indicate that students are beginning to understand the cause-and-effect relationships that connect these components. The ability to identify interrelationships among components and recognize changes occurring within a system is an important indicator of system thinking development in ecology learning (Lankers et al., 2023; Mambrey et al., 2022). However, the representations produced by students showed limited to demonstrate a clear of ecological functions of the processes depicted. Students tend to find it easier to identify mechanistic processes within ecological systems than to explain their functions and implications for the system as a whole (Butwong et al., 2025; Ryan et al., 2023). Although students were able to explain how the water cycle operates, they rarely connected this process to its effects on organism survival or ecosystem stability. This suggests that students' understanding remains focused on the mechanisms operating within the system and has not yet extended to the broader functional interactions among ecosystem components.



3A



3B

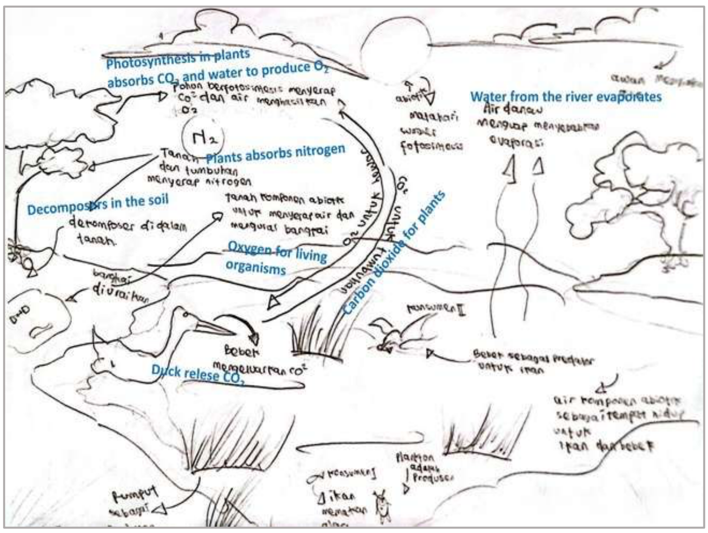


Figure 3. The selected students' drawing from the post-test. A) Drawing showed MM score 2; B) Drawing showed CMP score 2; C) Drawing showed MM score 3 and CMP sore 3

Figure 3C demonstrated the MM domain at a score of 3, as the drawing includes both macro-level structures, such as a food chain, and micro-level processes, such as nitrogen formation through decomposition and nitrogen fixation. The relationship between these components is clearly illustrated, indicating that nitrogen utilized by plants. In addition, Figure 3C showed the CMP domain at a score of 3. The drawing illustrated that plants carry out photosynthesis to produce oxygen, which is then used by ducks and other organisms. This reflects the integration of structures and mechanisms that contribute to the functioning of the ecosystem. The ability to connect micro-level processes, such as decomposition and nitrogen fixation, with macro-level phenomena, such as plant growth and trophic relationships demonstrates an integrated understanding across different levels of ecological organizations (Thyberg et al., 2025; Mambrey et al., 2020). The application of systems thinking and visual representations improves ecological understanding. Students' engagement in ecological systems modelling activities led to significant improvements in system thinking skills and understanding of the dynamics of interactions between ecosystem components (Lankers et al., 2023). Learning strategies that integrate ecological, economic, and social contexts through concept maps can expand system-thinking skills and strengthen students' environmental literacy (Vuorio et al., 2024). Establishing connections among components operating at multiple system levels is an important indicator of system thinking development, as it reflects students' ability to understand the interrelationships that shape functioning of the ecosystem (Shin et al., 2022).

Table 4
Friedman test results for comparing post-test drawing scores

Domain	Mean	χ^2	Sig.
BA	2.64	81.650	0.000
MM	2.59		
CMP	2.17		

The results of the Friedman test indicated significant differences in post-test scores among the three domains (Table 4). The BA had the highest mean score followed by the MM and CMP. To further examine the differences between domains, the Wilcoxon signed-rank test revealed significant differences across all pairwise comparison (MM:BA; CMP:BA; and MM:CMP) in students' post-test drawings (Table 5). These findings suggest that the implemented learning intervention was effective in enhancing students' conceptual understanding of relationship among ecosystem components. A study reported that inquiry-based learning and visual representation can encourage students to think more deeply about the relationships between structure and function in ecological systems (Yoon et al., 2018). In addition to these significant differences, effect size analysis (r) showed that most comparisons between MM:BA and CMP:BA had large effect sizes, whereas the comparison between CMP and MM showed a moderate effect size. These results indicate that students were able to connect BA with MM and CMP domains. However, they were less able to represent the relationship between MM and CMP domains in forming a coherent ecosystem understanding.

Table 5
Wilcoxon signed-rank test comparison of post-test scores across domains

Domain	Z	Sig.	r (effect size)	Interpretation
MM:BA	-5.605	0.000	0.74	Large
CMP:BA	-5.514	0.000	0.72	Large
CMP:MM	-3.394	0.001	0.45	Medium

Based on the findings of the post-test drawings, students' understanding of ecosystem components has improved, as seen by the appearance of MM and CMP domains in their drawings. Drawing activities serve not only as alternative forms of assessment, but also as tools for exploration and knowledge construction(Ainsworth & Scheiter, 2021). Learning activities such as discussions of ecosystem components and biogeochemical cycles help students develop a deeper understanding that ecosystems involve more than biotic and abiotic components or simple food chain concepts. Instead, students are encouraged to understand ecosystems as complex systems that extend beyond visible forms and interactions. The involvement of microorganisms in decomposition is a crucial component of energy flow in ecosystems, although it is not directly observable. Through this process, students can learn about the cycling of carbon, nitrogen, phosphorus, and water, as well as the underlying mechanisms that regulate these processes and sustain ecosystem functioning.

CONCLUSION

The results of this study indicate that students' conceptual understanding improved after participating in discussions of biogeochemical cycles. Analysis of students' drawings showed that they were able to incorporate both macro- and micro-level components, visualized through representations of structures, mechanisms, and functions that reflect interactions among ecosystem components. Further analysis of the learning process is needed to validate the effectiveness of visual analysis-based approaches in understanding and supporting students' learning trajectories. The findings of this study cannot be generalized broadly due to limited number of participants. However, these results contribute to development of instructional practices that require the explanation of abstract phenomena through visually supported discussions, enabling more measurable and meaningful student understanding of complex concepts.

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