

Exploration cognitive, logical, and metacognitive abilities of biology education students across academic semesters

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Article Information	Abstract
Keyword: Cognitive ability; Logical thinking ability; Metacognitive Awareness; Experiment ability; Higher student Kata Kunci: Kemampuan kognitif; kemampuan berpikir logis; kesadaran metakognitif; kemampuan bereksperimen; Pendidikan tinggi History: Received : 31/08/2025 Revised : 09/02/2026 Accepted : 16/02/2026 Published : 20/02/2026	Cognitive, logical, and metacognitive abilities are core competencies for preservice science teachers; however, comprehensive cross-semester mapping of these abilities using an integrated approach remains limited. This study aimed to explore the profiles and interconnections of cognitive, logical thinking, and metacognitive abilities of biology education students across early and mid-academic semesters. A mixed-method design was employed. Quantitative data were collected from 64 second- and fourth-semester students through a Marzano-based cognitive test, the Test of Logical Thinking (ToLT), and the Metacognitive Awareness Inventory (MAI), followed by qualitative exploration using open-ended questionnaires and semi-structured interviews with 10 purposively selected students. Quantitative data were analyzed descriptively, while qualitative data were examined using thematic analysis to explain and elaborate the quantitative results. The findings revealed similar patterns across both semesters, characterized by low achievement in error analysis (35.42%–40.63%), experimentation (45.83%–50.00%), control of variables and correlational reasoning in ToLT ($\leq 38\%$), as well as planning and evaluation aspects of metacognitive regulation (79.05–80.09%). Qualitative findings indicated that students tended to focus on procedural aspects and showed limited ability to conduct conceptual error analysis and experimental evaluation. This study concludes that inquiry-based instructional designs that explicitly integrate error analysis, generalization, variable control, and metacognitive reflection are necessary to enhance learning quality and better prepare future science teachers. <i>Abstrak. Kemampuan kognitif, berpikir logis, dan metakognitif merupakan kompetensi inti yang harus dikembangkan secara terintegrasi pada calon guru sains, namun pemetaan ketiga kemampuan tersebut lintas semester masih jarang dikaji secara komprehensif, khususnya dengan pendekatan campuran. Penelitian ini bertujuan untuk mengeksplorasi profil dan keterkaitan kemampuan kognitif, berpikir logis, dan metakognitif mahasiswa pendidikan biologi pada semester awal dan menengah. Penelitian menggunakan desain mixed-method dengan strategi explanatory sequential. Sebanyak 64 mahasiswa semester 2 dan 4 dipilih secara acak untuk pengumpulan data kuantitatif melalui tes kognitif berbasis taksonomi Marzano, Test of Logical Thinking (ToLT), dan Metacognitive Awareness Inventory (MAI), yang kemudian diperdalam melalui kuesioner terbuka dan wawancara semi-terstruktur terhadap 10 mahasiswa terpilih. Data kuantitatif dianalisis secara deskriptif, sedangkan data kualitatif dianalisis menggunakan analisis tematik untuk menjelaskan dan memperkuat temuan kuantitatif. Hasil penelitian menunjukkan pola yang relatif serupa pada kedua semester, dengan capaian rendah pada indikator analisis kesalahan (35,42%–40,63%), eksperimen (45,83%–50,00%), pengontrolan variabel dan penalaran korelasional pada ToLT ($\leq 38\%$), serta perencanaan dan evaluasi dalam regulasi metakognitif (79,05%–80,09%). Temuan kualitatif mengungkap bahwa mahasiswa cenderung berfokus pada prosedur teknis dan belum mampu melakukan analisis kesalahan serta evaluasi eksperimen secara konseptual. Penelitian ini menyimpulkan bahwa diperlukan desain pembelajaran berbasis inkuiri yang secara eksplisit mengintegrasikan pelatihan analisis kesalahan, generalisasi, pengontrolan variabel, dan refleksi metakognitif untuk meningkatkan kualitas pembelajaran dan kesiapan calon guru di masa depan.</i>

A. Introduction

Cognitive ability is a fundamental component of students' learning processes because it is directly related to how individuals acquire, process, store, and use knowledge. Cognitive capacity influences students' ability to understand concepts, solve problems, and apply knowledge to new contexts, which collectively contributes to academic achievement (Marzano & Kendall, 2007; Saddiqa & Malik, 2024). In science learning, cognitive ability functions not only at the level of factual knowledge but also supports analytical skills, decision making, and the application of knowledge in experimental situations (Arastaman et al., 2024; Shi & Qu, 2022). Therefore, mapping students' cognitive abilities is important as a basis for understanding learning readiness and the quality of learning processes in higher education (Grimm & Richter, 2024).

In addition to cognitive ability, logical thinking ability plays an important role in developing meaningful scientific understanding. Logical thinking enables students to construct coherent reasoning, recognize cause-effect relationships, and connect data with concepts in a rational manner (Rakhmawan, 2024). In the context of science learning, particularly in laboratory and experimental activities, logical thinking supports variable control, correlational reasoning, and evidence-based conclusion drawing (Fehér et al., 2023; Yanto et al., 2019). Students with limited logical thinking ability tend to follow laboratory procedures mechanically but experience difficulties in interpreting data and understanding the implications of experimental results (Ha et al., 2021; Zhou et al., 2016).

Metacognitive ability is related to individuals' awareness of their own thinking processes and their ability to regulate learning activities in a conscious and purposeful manner (Tuononen et al., 2023). Metacognition includes planning learning strategies, monitoring understanding during learning, applying error-control strategies, and evaluating learning processes and outcomes (Gaseem et al., 2020; Flavell, 1979; Ishak et al., 2025). In higher education, metacognitive ability is crucial because students are expected to learn independently and reflectively (Tuononen et al., 2023). Effective metacognitive regulation allows students to recognize limitations in their understanding, identify sources of error, and adjust learning strategies to achieve learning goals more effectively (Hamzah et al., 2023; Tezer, 2024).

Although cognitive, logical thinking, and metacognitive abilities are distinct constructs, they operate in an interconnected manner during learning activities. Logical thinking processes require adequate cognitive support, while the effective use of cognitive and logical abilities is strongly influenced by metacognitive regulation (Tak et al., 2022). These abilities are not only important for general university students but are particularly essential for preservice

teachers, who need to be systematically trained through learning experiences in higher education (Kandemir & Karadeniz, 2021; Yurttaş & Şahin, 2022). Preservice teachers who are accustomed to such learning processes tend to replicate their learning experiences in their future classrooms (Kozulin, 2021; Yildiz & Yildiz, 2021). This issue is critical given that teachers serve as agents of change and are expected to possess essential skills such as critical, analytical, and reflective thinking (Khan et al., 2019; Lillo & Aponte-Safe, 2019; Manulu et al., 2024).

Previous studies have shown that teachers' metacognitive abilities contribute to improvements in learning quality and student learning outcomes (Kyriakides et al., 2020; Putra et al., 2021; Thienngam et al., 2020). However, findings from studies conducted in Indonesia indicate that preservice teachers' metacognitive abilities, particularly in pedagogical reflection, are still not optimally developed (Adiansyah et al., 2022). This condition indicates a gap between the competency demands placed on preservice teachers and the learning experiences they receive during higher education. In addition, several studies have examined the interconnections between two abilities, such as cognitive and metacognitive abilities or logical thinking and problem-solving skills (Albab et al., 2020; Amin et al., 2020; Miharja et al., 2019; Punia et al., 2022). However, studies that map all three abilities simultaneously as an integrated profile remain limited. Furthermore, most previous studies have relied on quantitative approaches, providing limited insight into students' learning experiences that may explain observed ability patterns.

These issues are increasingly relevant in the context of preservice teacher education. Preservice teachers, who will play an important role in future teaching and learning processes, face substantial challenges in guiding students to master various skills. Twenty-first-century skills are essential for future students to develop in order to compete globally and respond wisely to rapid and significant changes (Kay, 2010; Nahum, 2022). These challenges require future teachers to possess strong competencies to prepare learners for such demands. Among the key competencies needed by preservice teachers are metacognitive abilities that support instructional planning, self-evaluation, and the ability to adapt quickly to diverse student needs (Briška & Siliņa, 2022; Vilpu et al., 2024).

Without clear cross-semester mapping of preservice teachers' cognitive, logical thinking, and metacognitive abilities, teacher education programs face limitations in evaluating the effectiveness of implemented learning practices. Comparing students' abilities in second- and fourth-semester is important for understanding developmental patterns in thinking skills and the influence of learning experiences. Such mapping can provide empirical evidence to support

curriculum development and the design of learning activities that are better aligned with students' developmental needs (Molnár & Csapó, 2019).

Based on this background, this study aims to explore the profiles and interconnections of cognitive, logical thinking, and metacognitive abilities of preservice biology teachers across second- and fourth-semester. This study is expected to provide a more comprehensive understanding of students' ability patterns and the learning experiences that influence their development. The findings are expected to serve as an empirical basis for developing instructional designs in preservice teacher education that intentionally and integratively foster cognitive, logical thinking, and metacognitive abilities to support the preparation of reflective and adaptive future teachers.

This study was conducted to address the following research questions: (1) What are the profiles of cognitive, logical thinking, and metacognitive abilities of preservice biology teachers in second- and fourth-semester? (2) How are cognitive, logical thinking, and metacognitive abilities interconnected based on students' performance patterns across semesters? (3) What learning experiences influence the development of students' cognitive, logical thinking, and metacognitive abilities?

B. Material and method

The interconnections among students' cognitive, logical thinking, and metacognitive abilities were first explored using quantitative methods, followed by qualitative exploration through interviews to deepen the analysis. This study focused on second- and fourth-semester students in the Biology Education Study Program at the Faculty of Teacher Training and Education, Universitas Sriwijaya. Conducted between March and May 2025, Random sampling was used for survey participants, while purposive sampling was applied to select interviewees based on ToLT cognitive levels. A total of 64 students were selected through random sampling. Subsequently, ten students were chosen through purposive sampling for the interview process. The selection of interview participants was based on their cognitive levels, as determined by the results of the Test of Logical Thinking (ToLT) for each semester cohort.

This study employed both test and non-test data collection techniques. Test data were collected using cognitive test items and the Test of Logical Thinking (ToLT), while non-test data were obtained through the Metacognitive Awareness Inventory (MAI), an open-ended metacognitive exploration questionnaire, and student interview questions. Each instrument used in this study is described as follows:

1) The cognitive test was developed using the Marzano and Kendall framework (Marzano & Kendall, 2007). The test administered to students focused on 13 cognitive indicators distributed across four levels: Level 1 – Retrieval (2 indicators),

Level 2 – Comprehension (2 indicators), Level 3 – Analysis (5 indicators), and Level 4 – Knowledge Utilization (4 indicators). Each indicator was represented by two questions, resulting in a total of 26 multiple-choice questions, each with five answer choices. Before being used in the study, the test items were validated by five expert validators and analyzed using the CVI/CVR method. The validation results indicated that the developed instrument was valid (CVR = 0.95). The test was administered online using Google Forms.

- 2) The Test of Logical Thinking (ToLT) used in this study was developed by Tobin and Capie (Tobin & Capie, 1981). The test emphasizes several aspects of reasoning, including (1) control of variables, (2) propositional reasoning, (3) combinatorial reasoning, (4) probabilistic reasoning, and (5) correlational reasoning. Each aspect is represented by two items, resulting in a total of ten questions. The test consists of eight two-tier multiple-choice questions and two open-ended questions focusing on combinatorial reasoning. The ToLT was administered online via Google Forms.
- 3) The Metacognitive Awareness Inventory (MAI) used in this study is an instrument developed by Schraw and Dennison (Schraw & Dennison, 1994) to measure students' metacognitive awareness. The MAI consists of 52 positive statements grouped into two main domains: (a) Knowledge of cognition, which includes declarative knowledge (8 statements), procedural knowledge (4 statements), and conditional knowledge (5 statements); and (b) Regulation of cognition, which includes planning (7 statements), comprehension monitoring (7 statements), information management strategies (10 statements), debugging strategies (5 statements), and evaluation (6 statements). This instrument is constructed as an attitude scale. Data obtained from the MAI were analyzed using descriptive quantitative methods to provide an overview of students' metacognitive awareness.
- 4) The interview questions were prepared after the cognitive test and ToLT results had been analyzed descriptively. The questions were developed based on the specific aspects and indicators from both instruments that showed relatively lower tendencies compared to others. The interview questions were application-based and derived from presented experimental data. The key focus areas of the interview questions included: (1) students' understanding of experimental variables; (2) students' ability to control variables in an experiment; (3) students' ability to analyze the causes of errors; (4) students' ability to draw conclusions from graphs or tables; and (5) students' decision-making skills.

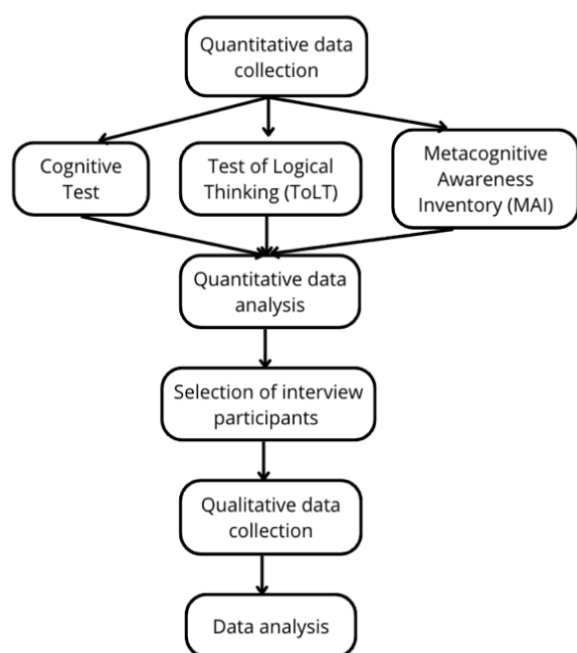


Figure 1 Research flowchart using mixed-methods

The data analysis technique for the cognitive test began with assigning a score of 1 for each correct answer and 0 for each incorrect answer. The percentage was then calculated for each cognitive indicator tested. As previously explained, the ToLT consisted of two types of questions: two-tier multiple-choice items and open-ended questions. The scoring

for the two-tier questions followed this rule: (a) a score of 1 was given if both the answer and the reasoning were correct, and (b) a score of 0 was given if either one or both were incorrect. For the open-ended questions, a score of 1 was awarded if the student's response matched the predefined scoring rubric.

After assigning scores to each item, a total score was calculated for each student. This total score was then interpreted into cognitive levels based on the classification by Valanides (1997) as shown in Table 1. The frequency of each cognitive level was calculated and subsequently converted into percentages. The Metacognitive Awareness Inventory (MAI) attitude scale used a scoring system in which all "Yes" responses were given a score of 1, and all "No" responses were scored 0. The scores from each subcategory, both within the cognitive knowledge domain and the cognitive regulation domain, were summed for each individual. The percentage achievement for each indicator was then calculated to describe the overall level of students' metacognitive awareness as well as their awareness within each subdomain.

The analysis of interview data began with transcribing the interviews for each participating student. The interview transcripts were then examined in greater depth to identify students' responses and group them into key sections related to specific cognitive and reasoning indicators previously identified from the cognitive test and ToLT results. The obtained data were then analyzed descriptively. The research flow is presented in Figure 1.

Table 1 Cognitive level classification based on the test of logical thinking (ToLT)

Skor	Cognitive Level
0-1	Operational concert
2-3	Operational transition
4-10	Operational formal

(Valanides, 1997)

C. Results and discussion

The study was conducted to gain an overview of the interconnections among cognitive, logical, and metacognitive abilities of students across semesters in the Biology Education study program. This was achieved using a variety of instruments, including a cognitive test (Marzano & Kendall, 2007), the Test of Logical Thinking (Tobin & Capie, 1981), the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994), an open-ended questionnaire, and student interviews. The use of diverse instruments aimed to provide a comprehensive and holistic picture of these three abilities. The collected data were then analyzed qualitatively to explore the relationships among them. The results have valuable implications for instructional design planning, enabling educators to enhance students' abilities by focusing on specific indicators that require development through

classroom learning routines. This study utilized a cross-semester approach, involving second- and fourth-semester students, to obtain a more comprehensive understanding of students' ability profiles. Such a cross-semester investigation may reveal distinct characteristics unique to each academic level — or it may not — depending on the findings.

The exploration of students' cognitive abilities was measured using multiple-choice questions with five answer options. A total of 13 cognitive indicators were assessed through 26 questions, with two questions representing each indicator. The indicators included recognition, recall, integrating, symbolizing, matching, classifying, analyzing error, generalizing, specifying, decision making, problem solving, experimenting, and investigating (Marzano & Kendall, 2007). These were categorized into four cognitive levels: retrieval, comprehension, analysis, and

knowledge utilization. The average score for each indicator was calculated by computing the mean achievement of students on each question per semester (Table 2). The cognitive achievement results revealed several patterns, with some indicators showing higher achievement levels among fourth-semester students based on descriptive percentage comparisons. As presented in Table 2, larger increases in percentage scores were observed in the indicators of generalizing, specifying, problem solving, and

investigating. These indicators showed increases of approximately 19% to 30% when comparing second- and fourth-semester students. This pattern indicates that students in higher semesters tend to perform better on cognitive indicators related to applying and integrating knowledge. This improvement may be related to greater learning experience through coursework and practicum activities that require the application of concepts in more complex learning situations.

Table 2 Student cognitive achievement

Cognitive	Semester 2	Semester 4
Recognition	93,75	98,44
Recall	81,25	87,50
Integrating	81,25	82,81
Symbolizing	79,17	82,81
Matching	81,25	68,75
Classifying	85,42	87,50
Analyzing error	35,42	40,63
Generalizing	31,25	60,94
Specifying	75,00	96,88
Decision making	81,25	87,50
Problem solving	72,92	93,75
Experimenting	45,83	50,00
Investigating	66,67	85,94

Indicators that showed significant improvement, with increases ranging from 19% to 30%, included generalizing (31.25% to 60.94%, an increase of 29.69%), specifying (75% to 96.88%, an increase of 21.88%), problem solving (72.92% to 93.75%, an increase of 20.83%), and investigating (66.67% to 85.94%, an increase of 19.27%). The significant improvement in these indicators from second- to fourth-semester students can be attributed to better conceptual understanding, increased analytical practice during coursework, improved ability to concretize conceptual knowledge, and greater academic experience, all of which enhance the ability to solve problems that require knowledge integration and application. Furthermore, frequent engagement in laboratory-based practical or research activities has likely contributed to this development. These findings are consistent with field observations that fourth-semester students have completed more practicum-based courses, including observation-based practicums such as taxonomy or identification of plants and animals, as well as experimental laboratory work. However, despite this, the results also show that students' performance on the "experimenting" indicator only improved slightly and not significantly. Laboratory activities are inherently complex and involve the development of multiple skills, particularly in the context of science education (Akintemi & Oduolowu, 2021; Fadzil & Saat, 2017; Shana & Abulibdeh, 2020). In practice, laboratory activities require students to solve problems presented through experiments, generalize from obtained data, apply

their knowledge, and conduct in-depth investigations to explain the phenomena illustrated in the practicum tasks (Alberida, 2020; Deniz & Dere, 2022; Gültekin & Altun, 2022; Hafizah et al., 2022).

Indicators that showed improvement but were not statistically significant included recognition, recall, integrating, symbolizing, classifying, decision making, analyzing error, and experimenting, with increases ranging from 1% to 6% from the second to the fourth semester. The relatively low improvement in these cognitive skills suggests that they did not develop significantly through the learning processes that had taken place. These findings also indicate that students' abilities in analyzing errors and experimenting remain underdeveloped, as reflected by their relatively lower performance in critical analysis and experimental design compared to other indicators. Among the nine indicators with non-significant improvement between second- and fourth-semester students, two—analyzing error and experimenting—were found to have the lowest levels of achievement among the 13 cognitive indicators assessed in this test. Analyzing error is a fundamental skill that students need to develop in order to enhance their experimental design abilities (Feyzioğlu, 2009; Siegel, 2007). A lack of strong error analysis skills can lead to decision-making that may not be based on accurate reasoning and to experimental processes that cannot be effectively reflected upon. While students may be capable of conducting experiments procedurally, they may fail to recognize important cues or indications that arise during the learning process.

The “matching” indicator in the cognitive domain was the only indicator that experienced a decline of 12.50%, with second-semester students achieving a score of 81.25%, while fourth-semester students only reached 68.75%. This presents an anomaly in the overall cognitive data. Further investigation is needed to confirm the underlying difficulties faced by fourth-semester students in completing tasks related to this indicator—especially since it is classified as a lower-order thinking skill within the cognitive domain. In fact, when viewed from the perspective of other higher-order thinking indicators—such as analyzing error and generalizing—although these fall within the category of low achievement, a consistent pattern emerges: fourth-semester students tend to perform better than second-semester students. This raises the question: why do fourth-semester students exhibit weaknesses in lower-order thinking or when completing simpler tasks? One possible explanation is that fourth-semester students tend to use more complex analytical approaches when solving basic problems, which may lower their response accuracy. Another contributing factor could be that the learning processes experienced by fourth-semester students have predominantly emphasized higher-order skills, such as analytical reasoning, resulting in less practice with solving simpler problems. This assumption is supported by the interview results between second- and fourth-semester students (Table 3). Fourth-semester students demonstrated more advanced analytical abilities compared to second-semester students, likely due to their broader and more complex learning experiences. They also considered more variables when answering questions. These findings further reinforce the notion that habitual learning practices shape students' experiences and perspectives, influencing how they approach and solve problems (Thórisson et al., 2019).

Although experimental activities have been shown to improve certain cognitive indicators as previously mentioned, the findings of this study reveal that students have not yet developed the ability to evaluate the results of experiments as an integral part of the experimental process itself. This suggests that while students are capable of conducting experiments in accordance with provided laboratory manuals, they struggle to follow up with evaluative reflections on their experimental outcomes. This limitation is linked to the prevailing practice of recipe-based laboratory learning in classrooms, which has not yet fully supported inquiry-based practical activities where students are encouraged to design their own experiments. In fact, inquiry-based practicum activities offer numerous benefits compared to recipe-based labs. These include activating student participation in the learning process and discovery of new information, fostering higher-order thinking, improving scientific process skills, enhancing cognitive abilities and problem-solving related to real-life contexts, boosting reasoning skills, and enabling students to design their own scientific investigations (Öztürk et al., 2022). When implementing inquiry-based experimentation is still challenging due to students' lack of familiarity, instructors can adopt a reasoning-based inquiry approach and encourage students to engage in scientific research, combining it with direct instruction techniques (Jong et al., 2023). Gradual training in inquiry-based experimentation has been shown to foster habitual reasoning (Van et al., 2023), particularly related to control of variables and correlational reasoning (Lorch et al., 2010; Schwichow, Christoph, et al., 2016; Schwichow, Croker, et al., 2016). This becomes especially important in light of this study's additional finding: reasoning related to control of variables and correlational reasoning, as measured by the ToLT instrument, also showed the lowest performance among all aspects of logical thinking (see Figure 2).

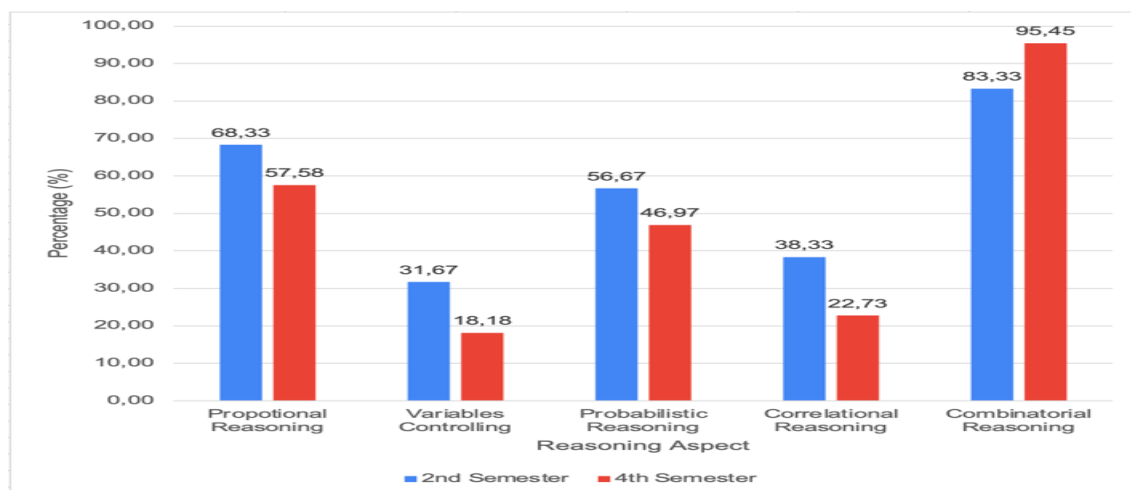


Figure 2 Comparison of ToLT performance between second- and fourth-semester students

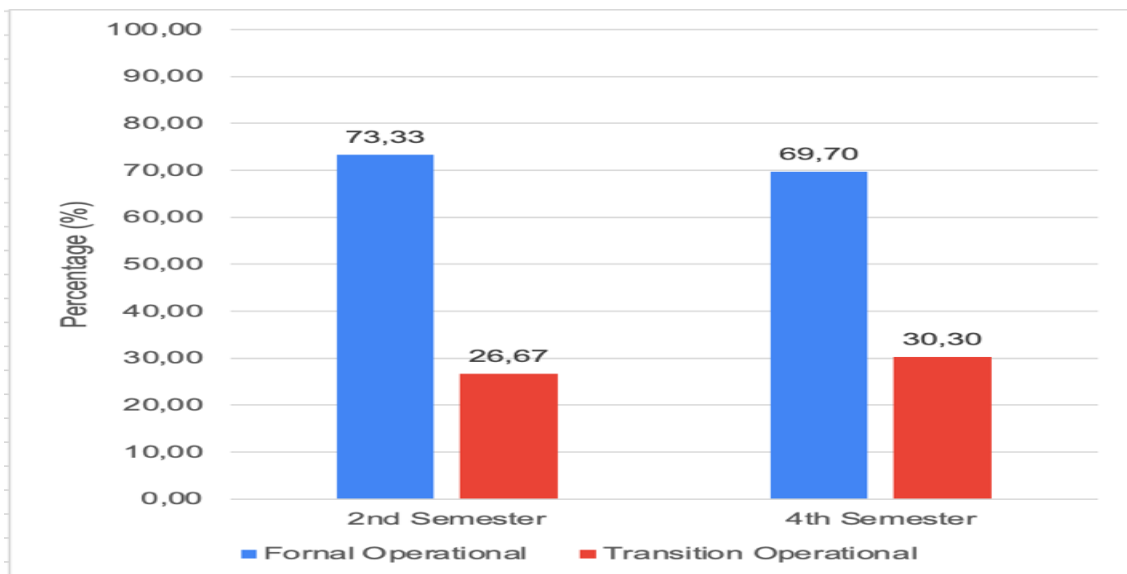


Figure 3 Cognitive profiles of second- and fourth-semester students as measured by ToLT

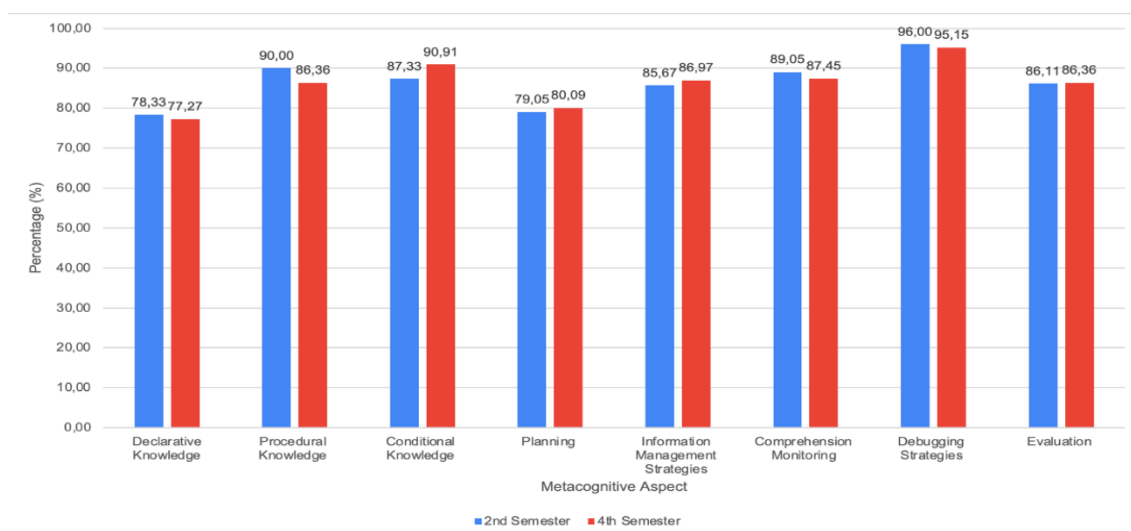


Figure 4 Students respond in metacognitive awareness inventory (MAI)

Figure 2 presents five aspects of logical reasoning assessed using the Test of Logical Thinking (ToLT), namely propositional reasoning, control of variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. These five aspects were evaluated using two-tier multiple-choice questions. Among the assessed aspects, control of variables (31.67%/18.18%) and correlational reasoning (38.33%/22.73%) demonstrated the lowest levels of achievement. The low performance in these two reasoning aspects may be explained by the close relationship between them. Both types of reasoning involve identifying and observing relevant variables (Peteranderl et al., 2023). In control-of-variable reasoning, students are expected to manage variables within a given context, whereas in correlational reasoning, they are expected to recognize relationships among variables that may influence the phenomena

presented (Lorch et al., 2010; Schwichow, Christoph, et al., 2016; Schwichow, Croker, et al., 2016; Van et al., 2023). The data from the ToLT instrument also revealed a pattern that differs from the cognitive test results, although both aim to measure students' cognitive abilities. Unlike the cognitive test, which showed overall improvement in student performance between the second and fourth semesters, the ToLT results revealed a decline in most reasoning aspects—except for combinatorial reasoning, which showed improvement. This finding appears to be influenced by external factors that may have biased the data. However, this requires confirmation and further investigation through in-depth interviews (see Table 3). In addition to providing an overview of the reasoning aspects with relatively lower performance, the ToLT instrument also offers a clear mapping of students' cognitive levels. The instrument allows the

identification of three cognitive levels: concrete operational, transitional, and formal operational (see Figure 3).

The interpretation of cognitive levels based on the ToLT instrument revealed that both second- and fourth-semester students demonstrated cognitive level within the formal operational and transitional stages. Although there were differences in the percentage of students classified within these two cognitive levels between the two groups, the differences were not statistically significant and can be considered relatively equivalent. Given that the data indicate a tendency toward parity between the two groups, interviews were conducted to explore this phenomenon further and to uncover any underlying differences. Although such differences between the groups were initially hypothetical, this in-depth exploration through interviews was considered essential for gaining a deeper understanding

Interviews were conducted with second- and fourth-semester students who were categorized as having either formal operational or transitional cognitive levels. The interviews were held online via Zoom Meetings. During the session, students were asked to read data prepared by the researcher and respond to a series of questions. The context of the interview focused on the effect of seedling weight on the respiration rate of mung bean sprouts, within the broader concept of respiration in living organisms. The interviews were then transcribed and analyzed using thematic content analysis. The data obtained from the interviews not only provided a general overview of students' abilities related to understanding experimental variables, controlling variables, identifying sources of error, drawing conclusions from presented data, and making decisions, but also allowed for a comparison between the two groups — both in general and with a specific focus on cognitive levels.

Interview results (Table 3) revealed several important findings related to the logical thinking abilities of students across semesters. In the aspect of understanding experimental variables, it was found that fourth-semester students used more accurate terminology for variable types (independent and dependent variables) compared to second-semester students who tended to use the terms variable X and Y. This indicates that fourth-semester students have a more mature conceptual understanding. Although some fourth-semester students still used those general terms, none of them failed to correctly identify the variables, unlike several second-semester students. Other studies focusing on the exploration of students' ability to understand variables have shown that this

skill is indeed difficult to master and requires a long period of time to develop in students. Moreover, learning processes involving the use of variables require thorough preparation (Tairab, 2015).

Furthermore, in the aspect of control of variables, all students were able to successfully control the experimental variables, suggesting that basic competencies in manipulating experimental procedures had been achieved in this group. The ability to identify and control variables requires repeated practice, typically gained through laboratory activities during the learning process (Lorch et al., 2010). An analysis of the curriculum in the Biology Education Study Program at the Faculty of Teacher Training and Education, Universitas Sriwijaya, showed that fourth-semester students were more exposed to experimental laboratory courses in addition to observational labs—such as invertebrate physiology and animal ecology practicums. The ability to control variables in an experiment-based learning process is crucial to master. It serves as the foundation for the success of experimental procedures in learning. This includes the process of testing hypotheses, selecting appropriate experimental setups in line with learning objectives, controlling more than two variables, and determining valid explanations based on the experimental data (Tairab, 2015; Van et al., 2023).

In the error analysis aspect, it was found that students still experienced difficulties. Some fourth-semester students even analyzed errors outside the context of the given problem. Even when students were able to identify errors, they mostly associated them with technical or procedural aspects of the experiment, such as errors in weighing, improper insertion of eosin into the respirometer tube, or loosely sealed respirometer lids. Critical reasoning beyond procedural or technical issues was rarely observed. These findings are consistent with results from the cognitive test but contradict the results of the MAI (Metacognitive Awareness Inventory), which showed that students' metacognitive ability related to error-control strategies was already very good (96%/95.15%) (see Figure 4). This suggests that in this case, cognitive level may not correlate directly with students' practical performance during experiments. Meanwhile, the ability to draw conclusions indicates a significant development in students' systematic thinking skills. Fourth-semester students demonstrated a clearer reasoning process, while second-semester students still heavily relied on the presented data and were unable to develop implications beyond it.

Table 3 The ability to understand experimental variables, control variables, identify sources of error, make conclusions from presented data, and make informed decisions

Code	Cognitive level	Understanding of experimental variables	Ability to control variables	Explanation of experimental error	Drawing conclusions	Considerations in selecting experimental tools
2nd Semester						
DR	Formal	Identified variables as variable X and Y	Able to identify variables that need to be controlled	Able to identify causes of error in the experiment	Able to draw conclusions and infer variable relationships clearly	Has specific basis for decision-making
DD	Formal	Unable to identify independent and dependent variables	Unable to identify variables that need to be controlled	Able to identify errors, but focused on procedural aspects	Able to conclude, but reasoning is unclear	Has general basis for decision-making
MK	Formal	Able to identify independent variable	Able to identify variables that need to be controlled	Able to identify causes of error in the experiment	Able to conclude, though reasoning is unclear	Has specific basis for decision-making
FA	Transitional	Able to identify both independent and dependent variables	Able to identify variables that need to be controlled	Able to identify causes of error in the experiment	Able to conclude, though reasoning is unclear	Lacks a clear basis for decision-making
PK	Transitional	Identified variables as variable X and Y	Able to identify variables that need to be controlled	Identified errors but focused on procedural aspects	Able to conclude, though reasoning is unclear	Has specific basis for decision-making
RJ	Transitional	Unable to identify independent and dependent variables	Able to identify variables that need to be controlled	Unable to analyze the experimental error	Able to conclude, though reasoning is unclear	Has general basis for decision-making
4th Semester						
AM	Formal	Identified variables as variable X and Y	Able to identify variables that need to be controlled	Identified errors, but explanation was contextually inaccurate	Able to draw conclusions and infer variable relationships clearly	Has specific basis for decision-making
IK	Formal	Able to identify both independent and dependent variables	Able to identify variables that need to be controlled	Able to identify causes of error in the experiment	Able to draw conclusions and infer variable relationships clearly	Has specific basis for decision-making
DN	Transitional	Able to identify both independent and dependent variables	Able to identify variables that need to be controlled	Identified errors but focused on procedural aspects	Able to draw conclusions and infer variable relationships clearly	Has general basis for decision-making
IN	Transitional	Identified variables as variable X and Y	Able to identify variables that need to be controlled	Identified errors but focused on procedural aspects	Able to conclude, though reasoning is unclear	Lacks a clear basis for decision-making

The analysis of students' metacognitive aspects reveals diverse developmental patterns between second-semester and fourth-semester students. In general, students' abilities in cognitive regulation strategies—such as conditional knowledge (increasing from 87.33 to 90.91), planning (from 79.05 to 80.09), and information management strategies (from 85.67 to 86.97)—show slight improvements. This indicates a strengthening of students' abilities to adapt learning strategies to different contexts, plan learning steps, and manage information more effectively as their academic experience grows. On the other hand, debugging strategies (96.00 in semester 2 and still high at 95.15 in semester 4) and evaluation (rising slightly from 86.11 to 86.36) demonstrate strong stability, reflecting good reflective abilities in recognizing and correcting errors, as well as evaluating learning processes. However, an interesting finding emerges from the decline in declarative knowledge (from 78.33 to 77.27), procedural knowledge (from 90.00 to 86.36), and comprehension monitoring (from 89.05 to 87.45). This decline may suggest a tendency among more advanced students to rely on intuition and experience without consciously evaluating their understanding. These findings highlight the importance of explicit training in planning and comprehension monitoring so that students not only apply strategies mechanically but are also able to internalize and deeply reflect on their thinking processes.

The findings indicate that declarative knowledge and planning are two aspects with relatively lower achievement compared to other metacognitive components. The score for declarative knowledge in the fourth semester even slightly declined compared to the second semester (77.27 vs. 78.33), suggesting that foundational understanding of concepts or factual information has not significantly improved over time. This may indicate that students are increasingly focused on procedural and strategic aspects while overlooking the importance of reinforcing conceptual knowledge as the foundation for scientific thinking. On the other hand, the stagnating planning score (79.05 in the second semester and only slightly increasing to 80.09 in the fourth semester) reflects a weakness in the ability to design systematic steps before engaging in learning or conducting experiments. Yet planning is a crucial component in developing self-regulation and independent learning. Low performance in these two areas may hinder the effectiveness of other learning strategies, as the absence of strong foundational knowledge and well-structured planning can lead to reactive and unfocused learning processes. Therefore, more explicit curricular interventions are needed to foster planning skills and strengthen declarative understanding in contextual ways, enabling students to integrate knowledge, strategy, and reflection into a coherent learning cycle.

One of the most striking findings in this study is the mismatch between metacognitive and cognitive aspects related to the ability to recognize and address errors. The data show that debugging strategies—metacognitive strategies used to identify and correct mistakes during the learning process—achieved very high scores in both semesters (96.00 in semester 2 and 95.15 in semester 4). In contrast, cognitive achievement on the analyzing error indicator was among the lowest of all the indicators assessed. This condition suggests that although students claim or believe they are capable of addressing errors metacognitively, this ability is not yet fully reflected in their actual cognitive performance when faced with error analysis tasks in experimental or data-based contexts. The relatively high debugging scores obtained from the Metacognitive Awareness Inventory (MAI) may reflect students' self-perceived confidence rather than their actual ability to identify conceptual or logical errors. This discrepancy is consistent with research on self-assessment bias, which suggests that learners often overestimate their competencies due to limitations in metacognitive monitoring and calibration (Karpen, 2018). Studies in higher education have shown that students may report high levels of metacognitive awareness while demonstrating weaker performance in applied tasks, a phenomenon often described as metacognitive illusion (Cervin et al., 2021). Similar patterns of miscalibration between self-assessment and actual performance have also been reported in recent empirical studies (Knof et al., 2024; Xu et al., 2024). Therefore, the high MAI debugging scores observed in this study should be interpreted cautiously, as they may represent perceived rather than enacted metacognitive regulation. This finding underscores the importance of strengthening the integration between metacognitive training and higher-order cognitive skills through authentic error-analysis tasks and explicit, structured post-experiment reflections.

Based on the findings of this study, it is recommended that instructional development in higher education—particularly in biology education programs—should focus on strengthening students' higher-order thinking skills and metacognitive regulation. First, it is essential to implement inquiry-based learning designs that explicitly train students in error analysis, generalization, variable control, and reasoning about relationships between variables. This learning should be accompanied by post-laboratory reflection activities to help students evaluate their thinking processes and experimental outcomes more deeply. Second, scaffolding approaches need to be integrated into experimental activities to guide students in organizing systematic procedures, selecting appropriate strategies, and gradually constructing a strong scientific reasoning framework. Third, since students' planning and comprehension monitoring abilities remain relatively low, learning

interventions should include explicit training in developing work plans and utilizing reflective instruments such as learning journals or structured metacognitive prompts. Fourth, assessment strategies should also shift toward evaluating thinking processes. This approach enables instructors to identify and provide more relevant formative feedback regarding students' learning strategies. Fifth, considering the disparity between high metacognitive debugging skills and low cognitive performance in analyzing errors, it is necessary to incorporate real-world tasks that directly address target students' ability to recognize and critically address conceptual and procedural errors. Lastly, it is important to introduce more complex and authentic laboratory contexts, particularly through experiments involving multiple variables and requiring data interpretation within real-world contexts. These steps are believed to enhance students' scientific thinking holistically and improve their preparedness as reflective and adaptive future science educators.

D. Conclusion

Based on the findings of this study, the profiles of preservice biology teachers' cognitive, logical thinking, and metacognitive abilities show varied levels across second- and fourth-semester. Students demonstrated moderate performance in several cognitive domains, including declarative and procedural knowledge. However, lower levels of achievement were consistently observed in higher-order cognitive and logical thinking indicators, particularly in error analysis, generalization, experimentation, control of variables, and correlational reasoning. These patterns were evident in both second- and fourth-semester students, indicating that progression across semesters does not automatically lead to the development of more complex thinking skills. The results also indicate clear interconnections among cognitive, logical thinking, and metacognitive abilities based on students' performance patterns. Students who showed limitations in logical thinking indicators, such as variable control and experimentation, also tended to demonstrate weaknesses in metacognitive regulation, particularly in planning, monitoring, and evaluation. This pattern suggests that cognitive performance, logical reasoning, and metacognitive awareness function in a mutually related manner rather than as separate competencies. In terms of learning experiences, the findings suggest that commonly implemented instructional practices, especially recipe-based laboratory activities, may limit students' opportunities to engage in experimental planning, decision making, and reflective evaluation. Such learning experiences appear insufficient to support the development of higher-order cognitive and metacognitive skills. The qualitative findings further indicate that students' self-reported metacognitive awareness does not always align with their actual performance in applied tasks, highlighting the need for

learning environments that explicitly foster reflective and analytical thinking. Based on these findings, this study highlights the importance of instructional designs that intentionally integrate cognitive, logical thinking, and metacognitive skill development. Learning activities that emphasize inquiry-based approaches, guided experimentation, and structured reflection may better support students' ability to analyze errors, generalize concepts, control variables, and evaluate outcomes. These conclusions provide empirical insights that may inform the improvement of instructional practices in preservice teacher education programs, particularly in supporting the development of integrated higher-order thinking and metacognitive skills.

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