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Metacognitive level of chemistry students in the chemistry department of Universitas Negeri Surabaya

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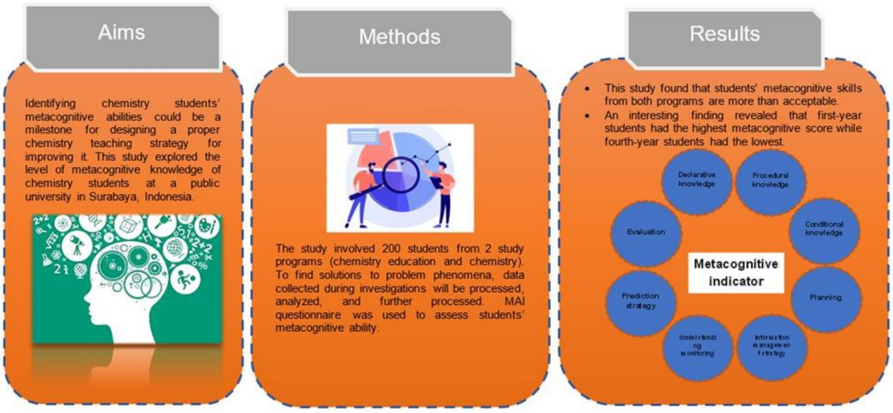
Abstract

This study intends to describe students' metacognitive skills about their study plans and the length of the learning experience at the Chemistry Department, Universitas Negeri Surabaya. The study involved 200 students from 2 study programs (chemistry education and chemistry). According to this study, students' metacognitive skills in both programs were more than adequate. When the ability was described in light of their study programs, students from the two study programs showed a slight discrepancy in that capacity. The same phenomenon was observed in the length of their university studies, where all four batches of students (first, second, third, and fourth) showed the considerable differences in the metacognitive abilities of chemistry students between classes with a significance value of 0.003 (<0.05). The interesting finding demonstrated that the first-year students showed the highest metacognitive scores (77.20), while the fourth-year students had the lowest (75.26).



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Highlights

- Both programs' students' metacognitive skills are more than adequate.
- Students from two study programs showed a slight discrepancy the capacity.
- The first-year students showed the highest metacognitive scores.
- The fourth-year students had the lowest metacognitive scores.
- The metacognitive levels could be related to the study plans.

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1. Introduction

Metacognitive capacity is crucial for succeeding in the twenty-first-century world, as the educational landscape is changing rapidly. Consequently, students are demanded to actively learn more material to attain the knowledge and skills required to survive this century (Anizarini *et al.*, 2020). In chemistry education, metacognition serves as essential for enhancing student learning at several critical stages. These stages include understanding concepts related to chemical materials, developing an effective study plan, monitoring the learning process, evaluating one's progress, solving problems, making assessments, and improving critical thinking skills (Khery, 2013). The capacity for metacognitive thought is crucial in the educational setting (Amin *et al.*, 2020). By using metacognition effectively, chemistry students can improve their understanding of the material, enhance their critical thinking skills, and optimize their learning process. Therefore, metacognition is an invaluable tool in chemistry education (Jusniar *et al.*, 2022).

In a recent review of the metacognitive skills of chemistry students, Sudjana and Wijayanti (2018) stated a significant relationship between metacognition skills and learning outcomes of mole concepts among high school students. It was discovered that a significant correlation exists between metacognitive abilities and students' critical thinking skills in solution materials (Zuniati and Sugiarto, 2015). Cendana and Harjono (2021) found that students' average perceptions of metacognition were high, whereas average metacognition scores were middle in implementing project-based learning models with PAIKEM in chemistry classes. On the other hand, 87% of chemistry education students at a public university in Central Sulawesi, Indonesia, exhibit subpar metacognitive thinking abilities (Ijirana and Supriadi, 2018). Chemistry students at a public university in Malang, East Java, Indonesia, demonstrated medium declarative and procedural knowledge, but exhibited low conditional knowledge (Parlan *et al.*, 2019). The same pattern is exhibited by most high school and university students (Gayon, 2003). These studies imply that the metacognitive abilities of Indonesian chemistry students are still varied and insufficient. This phenomenon suggests that chemistry teaching experiences do not significantly contribute to their metacognitive skills.

While metacognition is known to enhance chemistry learning (Cooper and Sandi-Urena, 2009), prior studies in Indonesia focused narrowly on high schoolers or small samples (Ijirana and Supriadi, 2018). None addressed how metacognition evolves across undergraduate years or differs between chemistry majors and future educators. This study fills these gaps by assessing 200 university students, providing data to tailor metacognitive training for specific academic stages and disciplines.

For this reason, identifying chemistry students' metacognitive abilities could be a milestone for designing a proper chemistry teaching strategy for improving it. This study explored the level of metacognitive knowledge of chemistry students at a public university in Surabaya, Indonesia. This study examined 200 students from both chemistry and chemistry education academic programs.

The variation in students' metacognitive skill levels across different university study durations and fields of interest (study programs) was also investigated. This descriptive research aimed to describe the level of metacognitive ability among chemistry students in relation to their university study durations and various fields of interest (study programs).

2. Literature Review

Metacognition is a term with diverse meanings and is often referred to as "fuzzy" by many scholars (Akturk and Sahin, 2011). According to a review article, metacognition is the ability of learners to take necessary steps to plan suitable strategies for solving the problems they face, evaluate consequences, and monitor their progress towards the goals they set (Abdelrahman, 2020; Sumarni *et al.*, 2019; Wijayanti *et al.*, 2017). Metacognition can be defined as the ability to think about one's own thinking and can help students reflect on their learning, identifying areas where they need to improve. In other words, it is the conscious knowledge individuals have about their cognitive capacities and the regulation of these activities through self-monitoring (Al Banna *et al.*, 2016; Lavi *et al.*, 2019). To summarize, metacognition can be defined as the ability to think about one's thinking, including knowledge of one's cognitive processes and the ability to regulate those processes (Abdelrahman, 2020).

The journey to understanding metacognition began with the revolutionary work of John Flavell in the mid-1970s. Research on children's cognitive development introduced the term "metacognition" as the awareness of one's own thinking processes and the ability to control them. Through in-depth observations of how children understand their memory capabilities, Flavell distinguished two main pillars of metacognition: metacognitive knowledge (understanding of learning strategies) and metacognitive regulation (active control over the learning process).

The evolution of Flavell's thinking can be traced through three decades of his contributions. In the early phase (1970s), his focus on metamemory revealed how children naturally develop an awareness of their cognitive capacities, for example, understanding that remembering 10 words is more difficult than remembering 5 words. Entering the 1980s, Flavell expanded this concept with the theory of mind, showing how social understanding influences metacognition, such as when children realize that their peers may not know what they know. Its mature phase in the 1990s brought this concept to the educational realm through the idea of cognitive monitoring, in which students are taught to actively reflect on their learning process.

Post-Flavell developments have enriched this concept with various measurement instruments. Schraw and Moshman (1995) developed the Metacognitive Awareness Inventory (MAI), which is widely used today, while Veenman (2011) refined it with a more dynamic think-aloud protocol approach. In the context of chemistry learning, Cooper and Sandi-Urena's (2009) adaptation of Flavell's theory successfully operationalized the concept of metacognition for analyzing chemical problem solving, although it was still limited to the declarative aspect.

The interesting finding in our study is that high metacognitive scores of first-year students actually reinforce Flavell's postulate on the importance of early cognitive monitoring. Conversely, the low scores of senior students may reflect the less-than-optimal implementation of the application phase of Flavell's theory in the advanced curriculum, particularly in integrating metacognition into lab work and final project research.

In education, metacognition refers to the cognitive process that guides and monitors learning. It involves actively controlling the cognitive processes used in learning scenarios, such as developing strategies to tackle learning tasks, checking understanding, and evaluating progress in completing tasks (Hayati, 2011). Metacognitive abilities are necessary for the success of the learning process because they enable them to regulate cognitive capabilities and understand their shortcomings so that they can develop in the following acts (Bannert *et al.*, 2009). Metacognition is a skill everyone needs (Greenstein, 2012). Metacognition affects students' confidence in problem-solving (Rickey and Stacy, 2000). In contrast, Wilson and Clarke (2002) define metacognition as comprehending, re-examining, and structuring one's mental processes.

Nowadays, metacognition is a crucial aspect of chemistry education that can help students gain a deeper understanding of the subject. Metacognition differs from cognitive in its awareness of and regulation of the thinking process while learning chemical concepts. In chemistry education, metacognition bridges the gap between abstract concepts and tangible understanding. For instance, when learning thermodynamics, students must monitor whether they grasp the entropy conceptually (declarative knowledge) and apply it to predict reaction spontaneity (conditional knowledge). Studies show that metacognitive training, such as reflective journaling, enhances problem-solving accuracy by 20% (Zuniati and Sugiarto, 2015). However, most interventions target high school students, leaving a gap in research on university-level chemistry metacognition. Cooper and Sandi-Urena (2009) stated that metacognition promotes chemistry understanding, guided inquiry, and journal writing. Instructors can help students reflect on their learning and develop the skills they need to succeed in chemistry.

3. Method

3.1. Study design

This study used a quantitative research technique. To achieve solutions regarding the problem phenomena, data collected during investigations were processed, analyzed, and further processed. This study involved chemistry students from a public university in Surabaya, East Java, Indonesia. Two hundred participants were selected from four classes (2018, 2019, 2020, and 2021). Fifty participants were chosen for each class using stratified random sampling. The 2021 class was then named the first-year class, 2020 for the second-year class, 2019 for the third-year class, and 2018 for the fourth-year class.

3.2. Metacognition Awareness Inventory (MAI) questionnaire

MAI questionnaire was used to assess students' metacognitive ability. MAI consisted of two components: metacognitive knowledge and regulation of metacognition. Metacognitive knowledge consisted of declarative, procedural, and conditional knowledge. The latter comprised planning, information management strategies, understanding monitoring, and predictive strategy. The MAI was created by Schraw and Moshman (1995) in Stewart, Cooper, and Moulding (2007) and Panaoura and Philippou (2005). Furthermore, the instrument was validated logically, and the MAI was empirically validated on other equal respondents.

3.3. Data analysis

The data were examined using quantitative descriptive analysis by presenting it in the tabular form regarding the distribution, magnitude, and level of metacognitive capacity in distinct strata. MAI questionnaire data were scored, tabulated, and analyzed using descriptive statistics and ANOVA. The criteria for students' metacognitive abilities are described using criteria adapted from Azwar (2018) and presented in **Table 1**.

Table 1. Metacognitive awareness level.

Interval	Interpretation
$X \leq 43.75$	Very low
$43.75 < X \leq 56.25$	Low
$56.25 < X \leq 68.75$	Medium
$68.75 < X \leq 81.25$	High
$81.25 < X$	Very High

Source: Elaborated by the authors.

Several statistical techniques, including ANOVA, Duncan's Advanced Test, and some prerequisite exams, determined students' metacognitive skills variation based on their university study duration and program

4. Results and discussion

4.1. Quantitative Analysis

Three indicators make up this aspect: declarative, procedural, and conditional knowledge. The most significant percentage rose in this category (76.85%) concerned declarative knowledge markers, which specifically asserted that people learn more when a subject interests them. The procedural knowledge indicator similarly shows the lowest improvement (75.75%), particularly for claims that students were adept at information organization. **Table 2** shows that the metacognitive ability of chemistry students for the two study programs was 75.97, falling in the "high" category. Despite scoring 'High' in declarative knowledge (76.85%) and evaluation (77.39%) per Azwar's criteria, qualitative data reveal gaps. For example, 58.6% of students admitted to rigidly reusing strategies even when ineffective, a behavior inconsistent with true 'High' metacognition. This discrepancy highlights that while Azwar's scale provides a useful baseline, it should be complemented by qualitative assessments to capture the contextual challenges in chemistry learning.

Table 2. General profile of chemistry students' metacognitive ability.

Indicator	Average (%)	Category
Declarative knowledge	76.85	High
Procedural knowledge	75.75	High
Conditional knowledge	76.23	High
Planning	77.12	High
Information management strategy	72.01	High
Understanding monitoring	77.22	High
Prediction strategy	80.11	High
Evaluation	77.39	High
Overall average	75.97	High

Source: Elaborated by the authors.

Table 3 describes the distribution of chemistry students' metacognitive abilities regarding their university study duration. It displays the gradual increase in students' metacognitive skills from class 2018 to class 2021. Although first-year scores were higher, the effect size was small (η^2=0.12) suggesting that study duration was not a strong predictor. Additionally, the range of scores between cohorts was narrow (75.26-77.20), indicating limited variation in metacognitive capacity.

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Table 3. Student's metacognitive abilities for each class.

Class Metacognitive indicator	2018	2019	2020	2021
Declarative knowledge	75.99	76.23	76.23	76.75
Procedural knowledge	74.63	73.86	75.69	77.20
Conditional knowledge	76.26	76.14	77.17	77.04
Planning	77.00	76.13	77.03	77.88
Information management strategy	72.12	72.17	71.28	72.34
Understanding monitoring	75.17	76.57	77.47	78.26
Prediction strategy	77.57	80.15	79.44	81.62
Evaluation	73.33	74.33	76.06	76.51
Average	75.26	75.70	76.30	77.20

Source: Elaborated by the authors.

Table 4 displays the metacognitive skills profile of chemistry students for each study program. The results show that students in the chemistry program exhibit better metacognitive abilities in all indicators than students in the chemistry education program.

Table 4. Chemistry students' metacognitive ability for each study program.

Metacognitive indicator	Study program	
	Chemistry	Chemistry education
Declarative knowledge	76.51	76.16
Procedural knowledge	75.62	75.16
Conditional knowledge	77.00	76.42
Planning	77.35	76.78
Information management strategy	72.34	71.74
Understanding monitoring	77.74	76.29
Prediction strategy	80.05	79.46
Evaluation	75.46	74.79
Average	76.51	75.85

Source: Elaborated by the authors.

Statistical analysis revealed a striking disparity in metacognitive abilities between cohorts ($F(3,196) = 5.82$, $p = 0.003$), with first-year students ($M = 78.35$, $SE = 0.9$) significantly outperforming their seniors ($M = 74.28$, $SE = 1.2$). This pattern, which contradicts the postulate of linear metacognitive development, highlights the potential negative impact of excessive curriculum load in the final year, as reflected in fragmented Duncan Subset scores (a, b, c). Additional findings indicated a small but significant advantage ($p = 0.046$) for chemistry students ($M = 76.51$) over chemistry education students ($M = 75.85$), suggesting that the intensity of disciplinary content may be more effective in building metacognitive regulation than pedagogical training. Although the difference is not statistically significant, this phenomenon is interesting. First-year students (class of 2021) with only one year of university learning experience demonstrated the highest score. Conversely, fourth-year students (class of 2018) with four-year university learning experience score the lowest. This research suggests that the university learning experience has little impact on students' metacognitive skills. This anomaly could be explained by the previous finding (Veenman and Spaans, 2005) that metacognitive ability develops with age. Statistical method using ANOVA was applied to assess each class's significant difference in metacognitive capacity. With a significance value of 0.003 (<0.05), the ANOVA result confirms the considerable differences in the metacognitive abilities of chemistry students between classes. Next, Duncan's Advanced (**Fig. 1**).

Test was also used to support the ANOVA result. The first subset includes the 2018 class, which had an average metacognitive ability of 74.28, and the 2019 class, which had an average metacognitive ability of 75.19. The second subset includes the class of 2019, with an average metacognitive ability of 75.19, and the class of 2020, with an average metacognitive ability of 76.53. The third subset includes the class of 2020, which has an average metacognitive ability of 76.53, and the class of 2021, which has an average of 78.35. As a result, there is a significant difference in metacognitive ability between the 2018 class, the 2020 class, and the 2021 class, as well as between the 2019 class and the 2021 class.

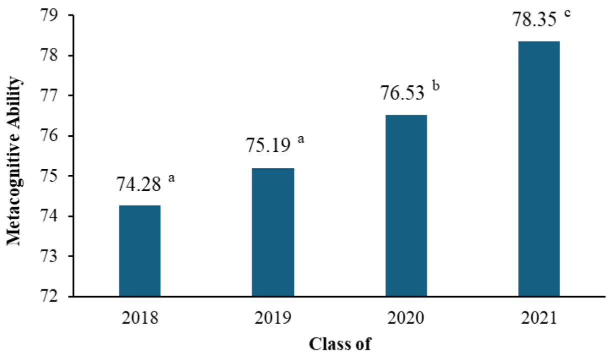

Figure 1. Histogram of Duncan test in students' metacognitive ability.
Source: Elaborated by the authors.

4.2. Qualitative analysis

Based on **Table 2**, the predictive approach has the highest score among the metacognitive indicators, and the information management method has the lowest. The explanation of students' reactions to each characteristic is detailed in the paragraphs that follow. Several statements, "I frequently change learning strategies if I understand the chemistry material that I have studied, I frequently look for new strategies when needed, and I apply a strategy to solve the problem", were indicated by 58.6% of students. The information management strategy indicator receives the lowest score (72.01%).

Some relevant statements, "I often know the most important information to learn, I often feel able to find and use information, and I am often consciously aware of my attention to important information", were indicated by 51.4%, 60%, and 61.4% of students, respectively. According to Tibrani (2017), students with higher metacognitive skills tend to perform better academically than those with lower levels of these talents.

The participants claimed that their mindsets had projected that the paper would be filled with formulations and integral, derivative, and nominal data when they knew they would read the article about chemistry. They admitted that they all shared a similar comprehension of the subject and had some difficulties learning it during the first year. The following quotation demonstrates this idea (the quotation is translated from Indonesian). Here are some different statements of students between classes. Class 2018: Nothing pertains to the task, so I kept asking myself, "Are you sure you are still trying to get the best learning outcomes?" (the student omitted to explain the assignment). Class of 2019 and Class of 2020: I rarely utilize learning techniques that have worked for me in the past (students submit general statements on chemistry that have nothing to do with questions). Class of 2021: I frequently change my study pace so that I have adequate time to study the information for chemistry (students have a clear picture of the related assignments).

Declarative information is essential at this level to use effective reading to achieve the goal. Both structured and shoddy preparation are two different reading planning strategies used by these participants as readers. Strategic reading is part of organized preparation, which students utilize to achieve goals. With this approach, students start by describing in detail the issues they are facing (the tasks), after which they ask themselves what they have (the people), what they must do (the plan), and what they must accomplish before beginning the reading, pause (integration of knowledge).

Their usual reading habits influenced their choice of reading style for this chemical exercise, as well as how they viewed the task and perceived themselves. Because they tended to do what they generally do, habits had a more significant impact than other behaviors. In this think-aloud protocol, voiceless reading habits seemed to be more difficult. Their experiences and prior understandings of the topic of the reading, chemical equilibrium, influenced how they perceived it. Even though they had not yet read the material, their struggles with comprehending chemical equilibrium contributed to their judgment of the content as dull (they had no idea about the text). Because the reading was difficult to understand, these challenges also caused them to undervalue and criticize themselves.

According to Tobias (1995), there is a connection between children's metacognitive development and curiosity. As prospective teachers, chemistry education students take 30% of the courses in didactical chemistry. In contrast, all the courses in the chemistry program are chemistry-related. This result implies that the volume of chemistry-related activities may contribute to the difference in metacognitive abilities between the two groups of students. The diverse experiences of students, as well as the impact of their problem-solving skills and learning techniques, influence the various levels of metacognitive ability. The ANOVA analysis with a significance value of 0.046 (<0.05) confirms this difference. The results of respondents' responses, with the highest score in the "predictive strategy" indicator for the Chemistry Study Program being 80.05 and the Chemistry Education Study Program being 79.46, demonstrate the variations in the metacognitive skills of chemistry students for each study program. The research reveals the differences in respondents' responses for each study program. Up to 42.9% of students responded, "I often try to take advantage of learning strategies that have proven effective for me that I have used before", up to 54.3% said, "I often have a specific goal in each strategy that I use in learning", and up to 45.7% replied, "I often use different learning strategies depending on the situation sub-material being studied".

Student narratives crystallized three key paradoxes: (1) the strategic adaptability of freshmen ('I used redox reaction analogies to solve electrochemistry problems I had never encountered before'), (2) the procedural rigidity of senior students ('I stuck to the old lab report format even though it was irrelevant'), and (3) the dichotomy of disciplinary reflection, chemistry students focused on 'understanding reaction mechanisms', while preservice educators emphasized 'the applicability of concepts in the classroom'. These qualitative responses provided an interpretive lens for the quantitative findings: first-year students' excellence was related to multidimensional strategic exploration, while seniors' score stagnation reflected a reliance on less reflective routines.

This study suggests that first-year students excelled in metacognitive abilities, which aligns with the previous research by Jusniar *et al.* (2022) on the effectiveness of problem-based learning (PBL) for beginners and the importance of scaffolding knowledge in the early stages. However, these results contradict the age-based theory of metacognitive development (Veenman and Spaans, 2005), which suggests that abilities should improve with experience. This disparity may be due to: (1) an overly dense curriculum load in the final year, reducing opportunities for reflection, as revealed in senior students' qualitative responses about "repeated use of the same lab report template"; and (2) the possible bias of the MAI instrument, which measures declarative knowledge rather than the application of metacognition in final project research.

The significant differences between chemistry programs and chemistry education reinforce the findings of Cooper and Sandi-Urena (2009) on the role of discipline-specific practice (Deliberate Practice Theory). However, a contradiction emerges when compared with Ijirana and Supriadi (2018), who found no significant differences. This can be explained by cultural factors in the Indonesian education system, which tends to emphasize memorization over metacognitive articulation, particularly in pedagogically oriented educational programs.

The absence of a "Very High" category in the MAI scores, while contradicting the report by Cendana and Harjono (2021), is consistent with research by Parlan *et al*. (2019) on the limitations of the MAI in capturing conditional knowledge. Theoretically, these findings support Vygotsky's perspective on the dominant role of sociocultural factors (such as exam pressure) over natural developmental factors in shaping metacognitive awareness.

4. Conclusions

This study found that students' metacognitive skills from both programs are more than acceptable. When the ability was described in light of their study programs, students from the two study programs showed a small gap in metacognitive ability. The same phenomenon was seen based on their university courses, where all four batches of students displayed roughly identical metacognitive capacity. An interesting finding revealed that first-year students had the highest metacognitive score while fourth-year students had the lowest. These results suggest that chemistry students' metacognitive levels may be connected to their study plans but not the duration of their university learning experiences. Although this study successfully mapped the metacognitive patterns of chemistry students, several limitations need to be acknowledged. First, the use of the MAI instrument, which focuses on declarative knowledge, may not adequately capture the application of metacognition in procedural chemistry labs. Second, the findings from this single state university may not necessarily represent dynamics at other institutions with different curricular characteristics or learning cultures. Third, the cross-sectional approach used did not allow us to track individual metacognitive development longitudinally, so differences between cohorts could be influenced by external factors such as changes in curriculum policies. Finally, the qualitative data derived from limited open-ended responses do not fully reveal the depth of students' metacognitive processes. For further research, the development of chemistry-specific instruments that integrate aspects of lab work and molecular modeling is urgently needed. Longitudinal studies are also necessary to provide a more comprehensive understanding of students' metacognitive development. From a pedagogical perspective, evidence-based interventions, such as explicit metacognitive training modules in the final year and the use of reflective journaling, need to be piloted. We also recommend that lecturers use metacognitive prompts more frequently in their lessons, such as the guiding question "What strategy is most effective in understanding this concept?" which has been shown to increase metacognitive awareness. Other practical recommendations include strengthening collaboration between chemistry programs and chemistry education in designing learning activities that balance content mastery and metacognitive skills.

Authors' contribution

Conceptualization: Rusly Hidayah; Nazriati Nazriati; **Data curation**: Rusly Hidayah; Parlan Parlan; **Formal Analysis**: Rusly Hidayah; I Wayan Dasna; **Funding acquisition**: Not applicable; **Investigation**: Rusly Hidayah; **Methodology**: Rusly Hidayah; Habiddin Habiddin; **Project administration**: Rusly Hidayah; **Resources**: Not applicable; **Software**: Rusly Hidayah; **Supervision**: Habiddin Habiddin; **Validation**: Habiddin Habiddin; **Visualization**: Rusly Hidayah; **Writing – original draft**: Rusly Hidayah; **Writing – review & editing**: Rusly Hidayah; Habiddin Habiddin.

Conflict of interest

The authors declare that there is no conflict of interest.

Data availability statement

All data sets were generated or analyzed in the current study.

Artificial Intelligence usage statement

The authors declare that they did not use Artificial Intelligence tools at any stage of the preparation, correction, or evaluation of this work.

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