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First-year undergraduate biology education students' critical thinking and self-regulation: Implementation of a metacognitive-based e-learning module

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ABSTRACT
This study examines the improvement of first-year students' critical thinking and self-regulation by implementing a metacognitive-based e-module. To address the challenges of learning in accordance with the demands of the higher education curriculum, metacognitive-based e-modules are required. Metacognitive strategies such as analogies, concept maps, mnemonics, and discrepant events integrated into e-modules encourage students to be more critical and independent when understanding concepts and solving problems. The study employed quasi-experimental with two groups, a study group (instructed metacognitive-based e-module) control group (conventional module). Eighty-three students as respondents were involved. The descriptive results indicate that cognitive strategies promote curiosity, facilitate understanding, and aid in long-term memory. Metacognitive-based e-modules could encourage awareness, learning activities, evaluation and interpersonal skills. There is a significant difference in students' ability to think critically and self-regulation. The metacognitive strategy using e-module was found to be stimulating, thought-provoking, and facilitating students to have critical thinking and self-regulation.

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Introduction

In the 21st century, the demand for individuals who possess the intellectual prowess to navigate complex challenges is growing. Driven by technological advancements, society's transformation has highlighted the urgent need for a new breed of skilled and adaptable human resources. This has spurred a call for a paradigm shift in educational institutions, compelling them to undergo significant reforms. It is imperative that we arm our students with the fundamental abilities and capabilities necessary to not just endure but prosper within this time of unprecedented

transformation. The Partnerships for 21st Century Skills (P21CS) in 2008 identified a spectrum of skills that are indispensable to both teacher and learner alike. These skills, range from critical thinking and creativity to communication and collaboration to the ability to apply knowledge in solving problems.

The ability to think critically is paramount. A complementary skill that assumes equal significant is self-regulation where students are trained to manage their learning strategies. This multifaceted skill empowers student to not only navigate their learning journey but to effectively manage and adapt their learning strategies. Enhancing critical thinking skills in higher education requires an increase in self-awareness, self-efficacy and metacognitive regulation through problem-based learning and collaborative learning (Rivas et al., 2022; Sutama et al., 2022). According to Yan (2020), enhanced academic achievement is strongly predicted by self-regulation, which offers positive feedback. Improving critical thinking skills in higher education can be achieved through problem-based learning strategies, experiential learning, and puzzle-solving (Prapulla et al., 2022).

Nurturing critical thinking and self-regulation is not merely a pedagogical concern but a societal imperative for whom the role of education is in sculpting a generation of intellectually agile and resourceful individuals who can confidently navigate the complexities of the 21st century. In the realm of higher education, surveys indicate that first-year students tend to possess low critical thinking skills and self-regulation. The results of a survey of several modules used at the authors' institution revealed that the modules used in the Basic Biology course lacked exercises and assignments based on examples of contextual problems, as well as content that trained analysis and problem-solving skills. According to the needs analysis of 49 respondents, several indicators of critical thinking skills and self-directed learning remain low, particularly in the areas of making conclusions, organizing strategies, and being aware of one's thoughts. This suggests a need for focused interventions to enhance these skills. The availability of self-regulation resources, such as e-modules that incorporate metacognition, is expected to address the challenges of improving learning in higher education, particularly for first-year students. An array of studies conducted by Thomas (2011) highlight a challenge posed by the 1st year students exhibiting deficiencies in both critical thinking skills and self-regulation. Moreover, Thomas, (2011) affirms that the ability to think critically should be developed from the first year students enroll at university. This development is crucial for their academic success and for meeting the demands of prospective employers upon graduation.

However, there are few e-modules available for higher education biology courses in Indonesia. Most universities primarily develop modules focused on metacognition. This study aims to create a module to foster critical thinking and self-regulation in first-year students. In metacognitive theory, students must have a particular aptitude to control and manage what they learn. According to Iskandar (2014) the aptitude encompasses abilities including problem-solving, decision-making, and critical evaluation. In another study, Murtini et al., (2020) state that the a metacognitive approach to teaching and learning optimises students' participation and increases students' critical thinking. That notion is also supported by a study conducted by Ali et al. (2017) which affirms that the metacognitive approach aims to enhance one's awareness in the context of self-regulation encompassing designing, controlling what is known, what is needed to do it, and how to do it, especially in solving problems.

Based on the result of a needs analysis that was previously conducted by the authors, it is necessary to improve the quality of students' learning through the provision of self-regulation resources in the form of an e-module. This e-module was expected to stimulate critical thinking ability and self-regulation by developing metacognitive strategies in students such as mind mapping, mnemonics, discrepant events (unique facts that challenge understanding), analogy, concept maps, and writing summary. An e-module was chosen not only due to the demand for dynamic learning but also because of the numerous advantages it offers, including its interactive nature, the inclusion of images, audio and video, along with formative tests that allow for direct automation with online worksheets, its suitability for university students' problem-oriented learning, its flexibility, as it can be accessed both online and offline, and its allowing students to conduct individual or group investigations, analyses, and evaluations in problem-solving. Therefore, this research focused on methods for improving the critical thinking skills and self-regulation of first-year students through the

implementation of a metacognitive-based e-module. Students' responses to learning using this metacognitive-based e-module were also an important part of the study.

This study applied the metacognitive-based e-learning module to basic science courses of a college located in Riau, Indonesia. Students majoring in biology education used the metacognitive-based e-learning module over 8 weeks.

Research objectives:

1. How does the implementation of a metacognitive-based e-module impact the critical thinking skills of first-year students?
2. How does the implementation of a metacognitive-based e-module impact the self-regulation skills of first-year students?
3. What are the effects of the metacognitive-based e-learning module on promoting first-year students' views on critical thinking and self-regulation?

Literature Review

The literature review in this study begins with the observation that current biology learning conditions are not fully optimized. Various studies indicate that traditional teaching methods in biology often fail to engage students effectively, leading to suboptimal learning outcomes. To address these issues, there is a growing body of research advocating for innovative approaches that integrate metacognitive strategies into teaching materials. Such integration has been shown to significantly enhance critical thinking skills and promote learning independence among students. This literature review explores the necessity and effectiveness of these metacognitive interventions, providing a foundation for the proposed innovations in biology education.

The scope of the conceptual framework for this study focuses on the development and implementation of a metacognitive-based e-module aimed at enhancing critical thinking and self-regulation among students. The metacognitive strategies embedded in the e-module will create an environment conducive to knowledge construction and self-directed learning. These strategies enable students to control and evaluate their learning processes effectively, thereby enhancing their ability to seek and assimilate new information (Dökmecioğlu et al., 2020).

To establish a foundation for this framework, it is essential to review the existing literature on metacognition in education. This review will cover the theoretical underpinnings of metacognitive strategies, their application in educational settings, and their impact on critical thinking and self-regulation. By understanding these aspects, the study aims to justify the integration of metacognitive strategies into the e-module and highlight their potential benefits in improving student outcomes.

Metacognitive-Based E-Module

It is assumed that the integration of the metacognitive approach into learning materials is likely to train thinking control and decision-making, which was supported by the results of this study. The findings disclosed a substantial rise in the post-test average scores of students using the metacognitive-based e-module compared to their counterparts who did not use it, affirming that these strategies enhance critical thinking and self-regulation. According to Kamus Besar Bahasa Indonesia (The official dictionary of the Indonesian Language), a module is a teaching and learning programme that can be studied by students with minimal instructions from the lecturers, and minimum delivery of contents, tools and equipment necessitated to measure students' achievement in learning. The researchers developed a modular digital format consisting of textual and visual content addressing metacognition which users could access either by connecting online or working offline on screens of electronic devices such as computers.

Learning activities using a metacognitive approach involve planning, observation, and results monitoring. Metacognitive activities transpire through four stages: formulating hypotheses, making enquiries, drawing conclusions, and solving problems. Metacognitive skills are beneficial for students

in terms of awareness and responsibility towards their knowledge; thinking skills and problem-solving; cognitive regulation; understanding learning materials and regulating learning strategies, and as preparation for facing learning assessments (Setiawati & Corebima, 2018). The implementation of metacognitive strategies, particularly in the context of discrepant events, can significantly increase higher-order thinking skills. Discrepant events, which are unexpected or surprising occurrences that challenge students' preconceived notions, provide a unique opportunity for deeper cognitive engagement. By prompting students to re-evaluate their understanding and apply metacognitive strategies, these events effectively foster critical thinking and problem-solving skills (Annisa, 2020; Weinert & Kluwe, 1987). The analogy strategy is a conceptualization that is a part of higher-order thinking (Yuningsih & Susilo, 2018). Metacognition constitutes an indispensable aspect of the learning process when it comes to the acquisition of knowledge.

Studies associated with the relationship between metacognitive strategy and academic achievement Abdelrahman, 2020; Neena & Sneh, 2015; Pudiquet et al., 2019; Rum & Ismail, 2016 show a positive correlation between the use of metacognitive strategies and academic achievement in higher education. The correlation can vary depending on the field of study, location and training (Ahdhianto et al., 2020; Rosdiana et al., 2023).

Several strategies can be applied to stimulate metacognitive skills such as a mind map, a discrepant event, a mnemonic, an analogy, making an inference, making a summary, and others. Several strategies can be applied to stimulate metacognitive skills, such as mind mapping, using discrepant events, employing mnemonics, drawing analogies, making inferences, and summarizing. The e-module designed on a metacognitive basis integrates these strategies, including discrepant events, mnemonics, and analogies, into the learning materials for each sub-chapter (learning activity). The integration of discrepant events aims to captivate students' interest and motivation by encouraging them to search for data and solutions to unusual or unexpected occurrences, as well as to explain everyday phenomena that may require deeper understanding. The analogy concept is chosen to create images and metaphors to visualise difficult concepts. The integration of the mnemonic method intends to foster memory through coding principles of long-term memory in an engaging manner.

Critical Thinking

Metacognitive skill correlates with the development of critical thinking and is a key aspect of increasing students' cognitive ability (Warni et al., 2018; Son, 2020). Metacognitive learning activities train one's cognitive processes through experiences of organising, connecting information, critical thinking, and problem-solving (Oflaz, 2021). According to Akpur (2020) critical thinking theory is significantly associated with reasoning and problem-solving. Critical thinking is frequently understood as an intellectual activity that is closely related to reasoning and inference (Maimun, 2022). In addition, Rivas et al. (2022) state that critical thinking encompasses problem-solving and decision-making. Thus, critical thinking, as a multifaceted concept, shares strong ties with diverse cognitive operations.

Further research is expected to expand the implementation to cover at least eight topics or more. Additionally, future studies could be conducted in blended learning environments on a larger scale, involving a more diverse group of participants. This approach could provide a broader understanding of the effectiveness of metacognitive strategies across various subjects and learning contexts.

A study carried out by Elaldı & Semerci (2014) showed a significant correlation between all sub-dimensions of metacognitive beliefs and students' critical thinking scores. Cakici (2018), Gurcay & Ferah (2018), and Lusia & Aloysius (2018). all declare that there is a positive correlation between metacognitive and critical thinking skills. Metacognition is the best predictor for improving critical thinking skills. A person's critical thinking ability will increase in line with the metacognition process (Dökmecioğlu et al., 2020). Metacognition leads to higher-order thinking skills, involving active

control of certain cognitive processes in learning (Chang et al., 2020; Kozikoğlu, 2019). These skills include the ability to reason, problem-solve, infer, and make decisions. The metacognitive strategies integrated into the e-module, such as discrepant events, analogy, and mnemonic techniques, have been shown to specifically enhance university students' critical thinking skills. These skills are essential for effective reasoning, problem-solving, inferring, and decision-making (Chang et al., 2020; Kozikoğlu, 2019).

Self-Regulation

Self-regulation can be described as one's ability to read a situation or the environment, and controlling and managing behavioural factors in a way that is appropriate to the situation at hand. Another way to describe self-regulation is as a person's social-cognitive process of self-control, which includes self-adjustment for behavioural change, environmental adaptation, and conceptual knowledge (Frazier et al., 2021). Self-regulation is also defined as a process that allows an individual to conduct their own pursuits over a period to achieve the desired goals and to change the situation the other way around, including regulating the mind and behaviour. Individuals control themselves by observing, considering, and then awarding, or punishing their behaviour (Porath & Bateman, 2006). This self-regulation system of observing, evaluating, and reacting to oneself is a widely observed aspect of human behaviour (Baumeister, 2018) defines self-regulation as self-control to sustain a desired standard. This understanding of self-regulation underpins its importance in achieving personal and professional goals.

University students who are capable of regulating themselves are likely to have greater academic success. They can study effectively by combining academic learning skills and self-control which can facilitate the learning process and motivation. Mccombs & Marzano (1990) explicate some indicators of self-regulation, namely recognising one's own thoughts, identifying and using information, being receptive to feedback, evaluating the effectiveness of actions, and making effective plans. The integration of metacognitive strategies in the e-module in this study includes features like the "Let's think" section, which guides students in using self-regulation strategies to answer questions and seek information. This approach enhances students' ability to regulate their learning process and improve their academic performance**.**

Methods

This research is quasi-experimental research that commenced with the development of a learning resource in the form of a metacognitive-based e-module. This was developed using the ADDIE model.

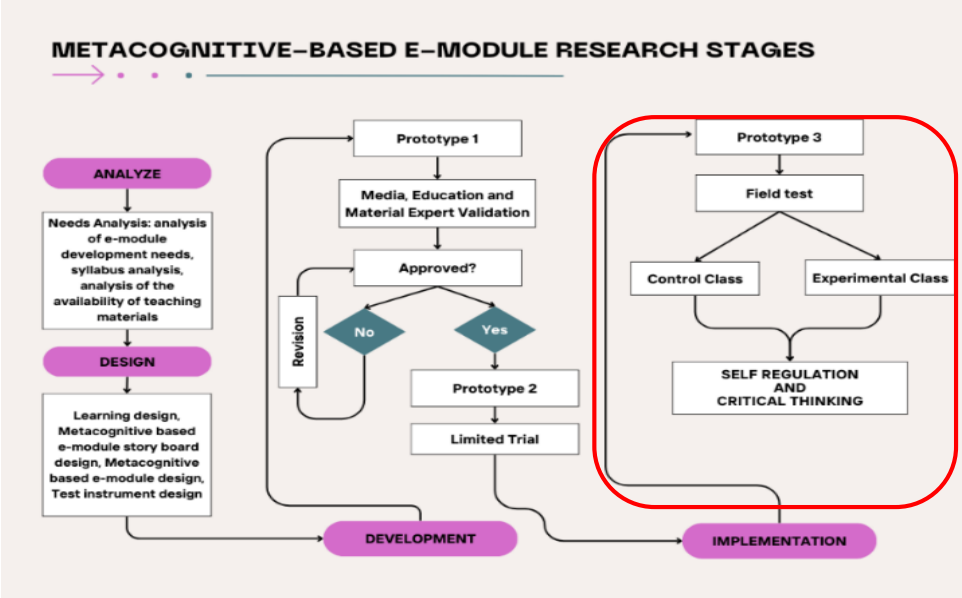
The development of metacognitive based e-module has four stages, analysis, design, development and implementation. The process begins with the analyse stage, the need of analysis conducted evaluating the need for the e-module, analysing syllabus and curriculum requirements, and assessing the availability of existing teaching materials. This basic step ensures that the subsequent design and development are rooted in a clear understanding of the educational context and needs. In the design stage, the focus shifts t creating a detailed blueprint for the e-module. This involves drafting the learning design, constructing a storyboard for the metacognitive based e-module and designing the test instruments. These elements are essential for ensuring that the module not only align with educational standards but also effectively facilitates metacognitive learning strategies.

The development stage begins with the creation of e-module, which undergoes rigorous validation by expert in media, education and material content. In this step, if the e-module is approved, the process moves forward. If not revisions are made until the e-module meets the required standards. Once approved, a limited trial of e-module is conducted to gather initial feedback and make necessary adjustments. This iterative process ensures that the module is refined and effective before broader implementation. The last stage is implementation. In the implementation, e-module is

subjected to a field test. This involves dividing participants into a control class and an experimental class. The goal of this phase is to evaluate the module's impact on self-regulation and critical thinking skills among student. The development stages can be seen in Figure 1.

Figure 1

Research stage



The developed module has undergone experts' validation stages which involved professionals in the fields of educational technology, biology education, physiology and molecular genetics. The module validation includes aspects such as content, presentation, layout, graphics, and language. The e-module was validated by four validators: two professors specializing in biology and biotechnology, and two educational technology experts holding a doctoral degree. The module was used for the experimental groups of participants in the Basic Biology lecture. The implementation was carried out with a quasi-experiment Pre-test/ Post-test Control Group Design. To determine the classes for the study, it had initially been approved by both the lecturers teaching the subject and by the students taking part in the course. Respondents were 83 students participating in the Basic Biology course on cell and tissue topics: 41 students in the experimental class and 42 students in the control class. The research design for the experimental class can be seen in Table 1. While the experimental group was engaged in innovative metacognitive e-module activities, the control group was engaged in traditional/non-metacognitive module activities. This approach was taken to ensure a valid comparison between the two groups.

Table 1

Research design

Class	Pre-Test	Treatment	Post-test
Bio Education A (Experiment)	Critical thinking and Self-Regulation Test	Innovative Metacognitive E-module	Critical thinking and Self-Regulation Test
Bio Education B (Control)	Critical thinking and Self-Regulation Test	Traditional/ Non-Metacognitive Module	Critical thinking and Self-Regulation Test

Data Collection

The instruments utilised to collect data were tests to understand students' critical thinking skills and self-regulation, experts' validation sheets and questionnaires from the e-module users and tests to measure any improvement in critical thinking skills and self-regulation of the experimental and control groups.

The test instrument used in the implementation phase consisted of 30 multiple-choice questions, arranged based on indicators of critical thinking (15 questions, with each indicator having 3 items) and self-regulation (15 questions, with each indicator having 3 items). The questions had undergone validation of construct and content (Sumintono & Widhiarso, 2015; Andrich & Marais, 2019). Validation was conducted by three experts in the fields of biology, biotechnology and pedagogy. The validity of the questions based on the infit MNSQ ranged from 0.83 to 1.17 (Valid). Based on the Outfit ZSTD, the validity ranged from -1.59 to 1.85 (Valid). The validity and reliability of question items analysis had been conducted beforehand, as shown in Table 2 below.

Table 2

Critical thinking question items reliability

Construct	Question items	Infit MNSQ	Outfit ZSTD	Measure	Reliability
Critical thinking	S4	1.00	0.45	-0.93	.803
	S20	0.91	0.44	-0.26	
	S24	0.85	-0.72	-2.91	
	S3	1.02	0.20	0.21	
	S16	1.12	1.42	0.92	
	S21	0.83	-0.69	-1.43	
	S5	1.13	1.69	0.68	
	S15	0.97	0.25	1.94	
	S22	0.83	-1.02	-0.93	
	S2	1.09	0.44	0.8	
	S11	1.01	0.22	-0.38	
	S25	0.99	0.14	0.56	
	S8	1.04	1.55	1.6	
	S14	0.95	-0.39	0.21	
	S26	1.08	1.85	1.94	

Table 3 shows the reliability of self-regulation question items. The table includes various statistical measures such as Infit MNSQ, Outfit ZSTD, and Measure, which are used to assess the consistency and accuracy of the self-regulation construct. Each question item is listed alongside its respective reliability scores, providing a detailed view of how well each item performs in measuring self-regulation. The reliability coefficient for the entire set of items is also included to give an overall indication of the test's reliability. This comprehensive analysis ensures that the self-regulation questionnaire is both valid and reliable for research purposes.

Table 3

Self-regulation question items reliability

Construct	Question items	Infit MNSQ	Outfit ZSTD	Measure	Reliability
Self-regulation	S1	1.12	0.82	1.31	.796
	S18	0.97	-0.45	-0.26	
	S27	1.01	0.16	-0.51	
	S10	0.83	-1.59	0.33	
	S13	1.02	0.70	-0.14	
	S30	0.97	-0.05	1.17	
	S6	1.17	1.58	0.44	
	S12	0.85	-0.84	-1.63	
	S28	0.99	-0.38	1.31	
	S7	0.96	0.13	0.10	
	S19	0.89	-0.77	-0.64	
	S23	1.11	0.70	-0.64	
	S9	1.08	0.98	-0.64	
	S17	0.84	-1.27	-0.78	
	S29	0.89	0.13	-1.43	

The questions' difficulty levels or distractors were analysed using the Winsteps 4.5.2 software. Question distribution on the cell, plant tissues, and animal tissue materials consisted of 13% easy questions, 37% in the moderately hard category, 30% in a difficult category, and 20% of the total question very difficult. Hence, it can be deduced that the questions' suitability in this study positively correlated to the difficulty level of questions the researchers had designed on the test item blueprint. There were 6% of questions in the easy category, 40% of questions in the moderate category, 37% in the difficult category, and 17% in the very difficult category.

The result of the distractor quality analysis on the 30 question items indicated that 27 questions out of 30 exhibited satisfactory distractor power, while 3 questions needed revision. Once the questions had been revised, they were implemented in the pre-test and post-tests.

Implementation of Metacognitive-Based E-Module

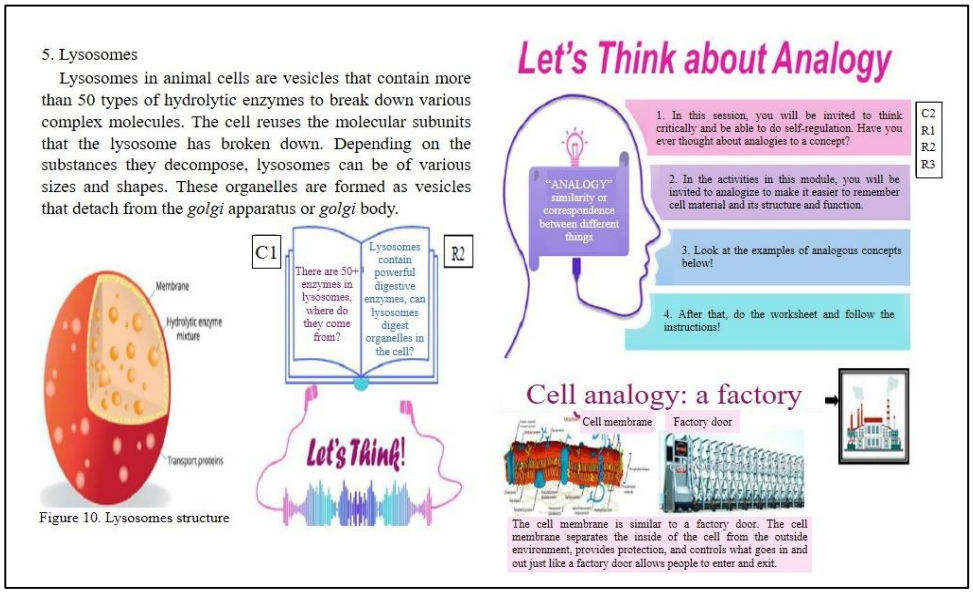
The metacognitive-based e-module was introduced into the Basic Biology course at the Faculty of Teacher Training and Education, University of Riau. In the control class, the implementation spanned four sessions, each of which lasted 100 minutes. During the first session, a pre-test consisting of 30 items based on indicators of critical thinking and self-regulation was administered for 45 minutes. Subsequently, students were instructed to study independently without access to the metacognitive-based e-module. At the second, third and fourth meetings, learning activities included discussions on cell, plant and animal tissues topics before a post-test was carried out in the last 45 minutes of the 4th meeting given through a Google form.

Likewise, the implementation in the experimental class was also conducted four times, with each meeting lasting 100 minutes. The learning activities, however, were facilitated by online learning platforms Google Classroom, Google Form, and a metacognitive-based e-module on cell and tissue topics. At the first meeting of the experimental class, the lesson started with a 45-minute pre-test through a Google Form encompassing 30 question items based on indicators of critical thinking and self-regulation. In the second, third, and fourth meetings, the lesson was continued using the metacognitive-based e-module (link), measures were taken to ensure that students did not access this module outside of the designated sessions. Learning activities centred on doing tasks independently in the "Let's think" section of the e-module with topics on cells, plant tissue, and animal tissue. There

was also a task on an analogy project. The task on the "Let's think" section of the e-module was completed by students using a Google Form.

Figure 2

The "Let's Think" activity based on the e-modul



An additional feature, such as the "Let's Think" activity in the metacognitive-based e-module, has been found valuable for students in the experimental class in stimulating critical thinking and self-regulation. During a scientific debate, students were allowed to present their answers to questions in the "Let's Think" section, each providing different answers and reasons based on scientific references they had read. Researchers then facilitated the discussion, encouraging other students to participate and give their opinions.

Data Analysis

The question items on critical thinking and self-regulation underwent initial testing for validity and reliability, including analysis of difficulty levels and the role of distractors. The validity testing occurred in two stages: (1) construction of the test items by three subject matter experts, and (2) statistical validation of the question items using the Rasch Model. For validity, question items were considered valid if the infit Mean Square (MNSQ) fell within the range of 0.5 to 1.5, and the Z-standard (ZSTD) outfit was between -2.0 and +2.0. The analysis of difficulty levels was conducted using the Rasch model with Winsteps 4.5.2.

The effectiveness of the module was tested by identifying the difference in average scores of pre- and post-test between the experimental and control groups with *t*- test sample using SPSS software version 26 for data analysis.

Findings

Critical Thinking Skills

Table 4 shows presents detailed results on the students' scores.

Table 4

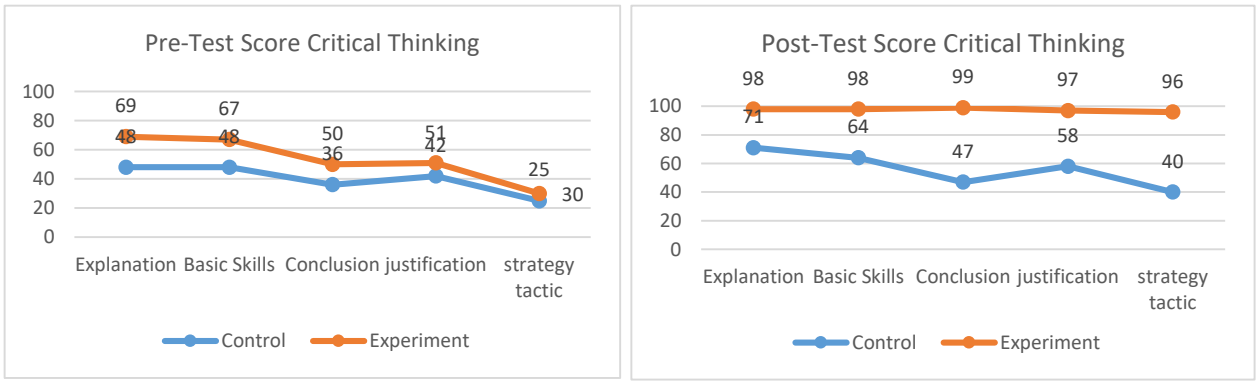
Critical thinking skills descriptive and t-test analysis of pre-test and post test

Factors	Experimental class				Control class			
	Pre-Test		Post-Test		Pre-Test		Post-Test	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Giving a simple explanation	69	25.89	98	7.17	48	29.25	71	26.77
2. Building basic skills	67	24.39	98	7.17	48	28.28	64	30.30
3. Making a conclusion	50	29.53	99	5.14	36	26.01	47	26.34
4. Giving further justification	51	27.61	97	8.67	42	27.24	57	33.34
5. Setting strategies and tactics	30	26.32	96	10.90	25	29.12	40	30.17
Total Mean	53.41		97.83		39.88		56.24	
T	-15.632				-4.714			
P	.001				.001			

The average score on each factors of the pre-test and post-test increased substantially. The highest score difference between the pre-test and post-test was on the students' ability to set strategies and tactics. This implies that students' skills in arranging strategies and tactics grew significantly after using the metacognitive-based e-module. It can be seen from the table that experimental class (t=-15.632) and control class (t= -4.714) each significant value (p-value < 0,05). This suggests a noteworthy difference in students' critical thinking skills before and after the implementation of the metacognitive-based e-module.

Figure 3

The average score of critical thinking skills pre- and post-tests



Self-Regulation

Students' self-regulation was inferred from how the students were aware of their thinking, how they obtained information from different sources, how they respond and give feedback, and how they evaluated and planned effectively. The following are the descriptive data on students' self-regulation in the pre-test and post-test.

Table 5

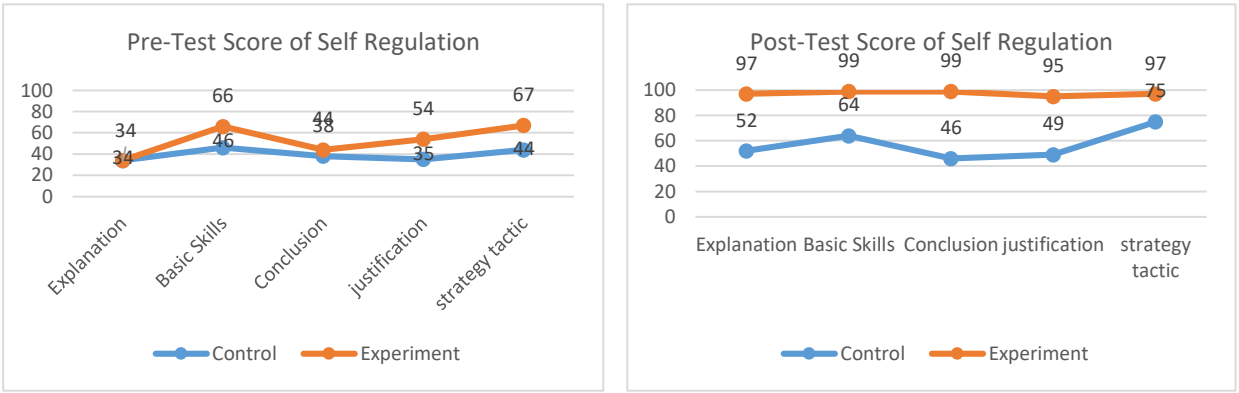
Self-regulation descriptive and t test analysis of the pre-test and post-test

Factors	Experimental class				Control class			
	Pre-Test		Post-Test		Pre-Test		Post-Test	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Aware of one's thought	34	27.01	97	8,67	43	27.66	63	21.57
2. Aware and use the necessary sources of information	66	30.76	99	5,14	61	21.70	67	28.14
3. Sensitive to feedback	44	21.37	99	5,14	36	21.57	45	21.58
4. Evaluate the effectiveness of one's action	54	29.31	95	13,88	55	22.59	63	28.89
5. Plan effectively	67	31.20	97	8.67	28	30.76	65	28.01
Total Mean	52.85		97.66		38.38		55.48	
T	-16.595				-5.053			
P	.001				.001			

The average score on each indicator of the pre-test and post-test increased considerably. The highest increase in self-regulation was found in the students' sensitivity to feedback. From the table, it is evident that there were differences in self-regulation between the experimental class (t = -16.595) and the control class (t = -5.053) (p-value < 0.05). This difference indicates a change in the average score of students' self-regulation before and after the implementation of the metacognitive-based e-module. In conclusion, the metacognitive-based e-module is indeed suitable for improving students' ability to think critically and regulate themselves effectively.

Figure 4

The average score of self-regulation ability pre- and post-tests



Discussion

The goal of this study was to scrutinise the increase in first-year university students' critical thinking and self-regulation by implementing a metacognitive-based e-module. The results disclosed a substantial rise in the post-test average score of those students using the metacognitive-based e-module compared to their counterparts who did not use it. The differences observed between the experimental and control groups suggest that the metacognitive-based e-module effectively promotes students' ability to think critically and regulate themselves. By emphasizing metacognitive skills such as planning, monitoring, and evaluating, the e-module encourages students to take control of their learning processes.

Students' Critical Thinking

Three models namely discrepant events, analogy, and mnemonic were selected to integrate the metacognitive strategies into the e-module. The discrepant events was presented in the form of "content material boxes" containing facts that likely prompt assumptions from students, thus provoking critical thinking. The activity was designed in a way that can elicit students' curiosity. This kind of activity can help students develop a more scientific mindset. When students observe something that provokes their curiosity, it will lead to investigations or research. This is specifically what is meant by the enquiry which develops reasoning skills, problem-solving, and self-regulation. This type of activity aligns with the concept of inquiry-based learning, which is known to promote deeper understanding and critical thinking. By engaging in such activities, students are not only learning content but also developing important cognitive skills necessary for their academic and professional growth.

In the experimental class, the students responded to the discrepant events activity enthusiastically. They were driven to recheck the truth of the facts presented and some were passionate to share unique facts they had just found from reading different scientific sources. Others were motivated to explore the materials in the e-module. Thus, it is evident that integrating discrepant events into the metacognitive-based e-module can stimulate students to think critically. An illustration of this is when the students rechecked the truth of presented facts. Verifying the truth of issues or facts can cultivate students' reflective skills and awareness of their knowledge (metacognitive) (Setiawati & Corebima, 2018).

This finding is in line with the research result conducted by Hastuti & Sutarto (2017) who discover that the metacognitive approach to discrepant events can improve university students' higher-order thinking. Another study found that there were significant differences in metacognitive skills, particularly in the aspects of declarative, procedural, and conditional knowledge. Setiawati & Corebima (2018) found that metacognitive skills can enhance knowledge acquisition and positively influence student learning outcomes. In our study, integrating metacognitive strategies like analogy and mnemonic in the e-module has similarly shown promising results in improving students' critical thinking and self-regulation. Furthermore, there is a positive correlation between metacognitive skills and students' critical thinking skills (Rivas et al.,). Students with high metacognitive strategy statistically have a significant difference in critical thinking contrasted to their peers with low metacognitive strategy (Mohseni et al., 2020). Longfield (2009); Scheiner (2020) affirms that discrepant event concretises abstract concepts. The ability to think critically, develop metacognitive skills and express opinions are the skills students must have in studying. Metacognitive awareness is essential in enhancing critical thinking skills such as organizing tasks, designing strategies and the ability to analyse weaknesses and strengths in task completion (Maksum et al., 2022).

As for the analogy model, it has been shown to increase students' understanding of concepts in physics, with the average score 55.4 on the pre-test and 77.0 on the post-test (Djudin & Grapragasem, 2019). The use of the analogy model can also reduce misconceptions in physics (Djudin & Grapragasem, 2019). The metacognitive-based e-module assists students in comprehending learning materials that are difficult to visualize through the analogy model and interactive videos. The selection of media and learning models can significantly influence students' critical thinking abilities. According to Annisa (2020), media play a crucial role in education and the social realm, as virtual learning environments integrate information, communication, collaboration, learning, and management. These findings underscore the importance of integrating effective media and learning models to enhance students' critical thinking skills and comprehension of complex concepts.

The analogy enables students to create metaphors and visualise learning materials such as associating cells with a factory or comparing the transport tissue system in plants to the circulatory system or likening the multi-layered flat epithelial tissue to the epidermal tissue in plants. In this study, students in the experimental class passionately presented their analogy project. They were actively discussing the analogies they had made supported with reasons or scientific information in terms of structures, functions, or how an object works. This activity integrated into the metacognitive-based e-module can then arouse critical thinking in students and allow them to regulate themselves to create metaphors or visualization so that learning material is easy to be understood. Yuningsih & Susilo (2018) assert that the metacognitive analogical concept is often associated with conceptualisation, which is a part of higher-order thinking skills. The research result of a study conducted by Yuningsih & Susilo (2018) found that the application of the analogy model acts as a bridge to understand materials that are complex to visualize by students through phenomena or objects around them. The use of this analogy model or concept is not limited to the materials of concepts but can also be used to explain a process or a structure of an object. Overall, comparing two similar things using this analogy approach very likely helps students to better remember the materials they learn.

Lastly, integrating a mnemonic model in a metacognitive-based e-module is believed to help memory performance to remember a concept through long-term memory encoding in an exciting way. Some examples of the topic that can be studied using mnemonics are plant cell structure, root structure, meristem tissue classification based on its origin of formation and position, the function of epithelial tissue and its classification in animal tissues, grouping cell organelles based on the membrane, and mnemonic about organelles that are only possessed by animals or plants. Similar to the *discrepant event* and analogy model, students in the experimental class responded positively to this mnemonic technique. Some of them were eager to share the concise and humorous mnemonics they had created so that the learning situation became lively as it triggered other students to share their mnemonics. This pleasurable but meaningful activity can stimulate critical thinking and self-regulation in students. For instance, a mnemonic model such as CAMSEA, which stands for Cnidarians, Annelids, Molluscs, Sponges, Echinoderms, and Arthropods, was found to be particularly effective in helping students remember these animal groups (Lubin & Polloway, 2016). The positive impact of these metacognitive strategies on critical thinking skills is supported by previous research. (Nori et al., 2019) found that such strategies can improve students' study outcomes across cognitive, psychomotor, and affective domains.

Students' Self-regulation

The students' self-regulation in the experimental class was significantly influenced by the implementation of the metacognitive-based e-module. The module was designed to train students' self-regulation, particularly in responding to feedback. For instance, in studying the concept of cells, students were prompted with the "Let's think" section, which stated that there are more than 50 enzymes in lysosomes. This type of question stimulates students' self-regulation by making them sensitive to feedback, as they are initially given insight into the number of enzymes in lysosomes and then asked to analyze the origin of these enzymes.

Another example occurred in a lesson about plant tissues. Students were asked to analyze the type of tissue based on given characteristics. This type of question requires students to work independently, allowing teachers to assess their sensitivity to feedback and their ability to regulate themselves in finding answers. These activities foster self-regulation by encouraging students to observe, evaluate, and respond to their learning process.

The impact of these activities is consistent with previous findings that highlight the

importance of self-regulation in academic success. Self-regulation enables students to adapt flexibly to changing demands, leading to improved learning outcomes. The results of this study align with the research of Baumeister (2018), which emphasize the role of self-regulation in achieving desired goals and adapting to various life situations.

The additional feature of "Let's think" also facilitates students in the experimental class to regulate them. When presenting their answers to the questions in the "Let's think" section, for example, there was a scientific debate among the students due to different assumptions of the correct answers. In response to the debate, the research team encouraged other students to participate in sharing opinions and the team clarified the correct answers afterwards. This typical activity is very conducive and effective to stimulate students' critical thinking and self-regulation. Another justification for the increase in critical thinking and self-regulation is the use of the metacognitive-based e-module with its various advantages. The module's interactive design with images, audio, video and formative tests allows immediate and automatic feedback. This interactive and engaging approach helps maintain students' interest and encourages them to reflect on their learning processes, thereby enhancing their self-regulation skills.

The integration of metacognitive strategies in the e-module also facilitated scientific debates among students, which further stimulated their critical thinking and self-regulation. This interactive approach encouraged students to reflect on their learning processes and share their insights, leading to a more engaging and effective learning environment. The findings of this study align with the literature that highlights the strong link between metacognition and critical thinking (Abdelrahman, 2020; Block & Russell, 2012; Mohseni et al., 2020; Oflaz, 2021; Pradhan & Das, 2021; Rivas et al., 2022; Rosdiana et al., 2023; Sinar, 2018; Sutama et al., 2022). These metacognitive strategies not only accelerated the development of students' critical thinking skills but also improved their self-regulation, making the metacognitive-based e-module a valuable tool in enhancing both cognitive and metacognitive abilities.

Inferential analysis through a t-test was conducted to observe the improvement of critical thinking and self-regulation in this study, based solely on the N-gain of pre-test and post-test scores. The t-test results indicated significant differences in the scores, confirming the effectiveness of the metacognitive-based e-module in enhancing both critical thinking and self-regulation among students. This statistical evidence supports the qualitative observations of increased engagement and reflective thinking, further validating the positive impact of metacognitive strategies on student learning outcomes.

Conclusion and Implications

The integration of a metacognitive strategy in developing a learning source in the form of an e-module can increase first-year students' critical thinking and self-regulation. Implementing the metacognitive-based e-module supports the students in understanding materials that are difficult to visualize with the help of the analogy model and interactive videos. Meanwhile, the mnemonic technique assists students in learning by strengthening long-term memory performance in an enthusiastic way. Additional feature such as "Let's think" is also beneficial for those in the experimental class to ponder analytically and control themselves.

However, this study was limited to two topics only (cells and tissues) in the Basic biology course. Gathering respondents and monitoring students' activity in answering the questions and tasks given online requires certain techniques and more intensive observation compared to face-to-face learning. The availability of self-learning resources that can be used anytime and anywhere will provide convenience for students to access information. This will also have implications for

empowering students' potential in learning and completing tasks in higher education.

Further research is expected to expand the implementation to cover at least eight topics or more. Additionally, future studies could be conducted in blended learning environments on a larger scale, involving a more diverse group of participants. This approach could provide a broader understanding of the effectiveness of metacognitive strategies across various subjects and learning contexts.

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References

Abdelrahman, R. M. (2020). Metacognitive awareness and academic motivation and their impact on academic achievement of Ajman University students. *Heliyon*, *6*(9), 1–8. https://doi.org/10.1016/j.heliyon.2020.e04192

Ahdhianto, E., Marsigit, Haryanto, & Santi, N. N. (2020). The effect of metacognitive-based contextual learning model on fifth-grade students' problem-solving and mathematical communication skills. *European Journal of Educational Research*, *9*(2), 753–764. https://doi.org/10.12973/eu-jer.9.2.753

Akpur, U. (2020). Critical, reflective, creative thinking and their reflections on academic achievement. *Thinking Skills and Creativity*, *37*(9), 100683. https://doi.org/10.1016/j.tsc.2020.100683

Ali, S. M., Harun, H., Massari, N., Puteh-Behak, F., Darmi, R., Mahir, N. A., Selamat, S., & Hamid, Y. E. A. (2017). The 21st century skills in online multiliteracies project approach (eMULPA): learners' reflections on their knowledge processes. *Mediterranean Journal of Social Sciences*, *8*(1), 252–258. https://doi.org/10.5901/mjss.2017.v8n1p252

Andrich, D., & Marais, I. (2019). *A course in rasch measurement theory (measuring in the educational, social and health sciences)*. Springer Singapore.

Annisa, C. (2020). Penerapan strategi metakognitif pada mata kuliah kajian matematika sd untuk meningkatkan kemampuan berpikir kritis mahasiswa pgsd penerapan strategi metakognitif pada mata kuliah kajian matematika sd untuk meningkatkan kemampuan berpikir kritis mahasiswa. *JP2M (Jurnal Pendidikan Dan Pembelajaran Matematika)*, *1*(2), 89–99. https://doi.org/10.29100/jp2m.v1i2.197

Baumeister, R. F. (2018). *Self-regulation and self-control* (1st ed., Vol. 1). Routledge. https://doi.org/10.4324/9781315175775

Block, B. A., & Russell, W. (2012). Teaching students to think critically about fitness and wellness choices. *Journal of Physical Education, Recreation & Dance*, *83*(7), 46–52. https://doi.org/10.1080/07303084.2012.10598812

Cakici, D. (2018). Metacognitive awareness and critical thinking abilities of pre-service efl teachers. *Journal of Education and Learning*, *7*(5), 116–129. https://doi.org/10.5539/jel.v7n5p116

Chang, P. S., Lee, S. H., & Wen, M. L. (2020). Metacognitive inquiry activities for instructing the central dogma concept: 'button code' and 'beaded bracelet making.' *Journal of Biological Education*, *54*(1), 47–62. https://doi.org/10.1080/00219266.2018.1546756

Djudin, T., & Grapragasem, S. (2019). The use of pictorial analogy to increase students' achievement and its retention of physics lessons of direct current. *Jurnal Penelitian Fisika Dan Aplikasinya (JPFA)*, *9*(2), 140–151. https://doi.org/10.26740/jpfa.v9n2.p140-151

Dökmecioğlu, B., Tas, Y., & Yerdelen, S. (2020). Predicting students' critical thinking dispositions in science through their perceptions of constructivist learning environments and metacognitive self-regulation strategies: a mediation analysis. *Educational Studies*, *48*(6), 809–826. https://doi.org/10.1080/03055698.2020.1833838

Elaldı, S., & Semerci, C. (2014). The roles of metacognitive beliefs in developing critical thinking skills. *Bartın Üniversitesi Eğitim Fakültesi Dergisi*, *3*(2), 317–317. https://doi.org/10.14686/buefad.201428187

Frazier, L. D., Schwartz, B. L., & Metcalfe, J. (2021). The maps model of self-regulation: integrating metacognition, agency, and possible selves. *Metacognition and Learning*, *16*(2), 297–318. https://doi.org/10.1007/s11409-020-09255-3

Gurcay, D., & Ferah, H. O. (2018). High school students' critical thinking related to their metacognitive self-regulation and physics self-efficacy beliefs. *Journal of Education and Training Studies*, *6*(4), 125–130. https://doi.org/10.11114/jets.v6i4.2980

Hastuti, I. D., & Sutarto, S. (2017). Karakteristik pergeseran aktivitas metakognitif siswa dalam pemecahan masalah matematika. *Jurnal Ilmiah Mandala Education*, *3*(1), 450–459. https://doi.org/10.58258/jime.v3i1.170

Iskandar, S. M. (2014). Pendekatan keterampilan metakognitif dalam pembelajaran sains di kelas. *Erudio Journal of Educational Innovation*, *2*(2), 13–20. https://doi.org/10.18551/erudio.2-2.3

Kozikoğlu, İ. (2019). Investigating critical thinking in prospective teachers: Metacognitive skills, problem solving skills and academic self-efficacy. *Journal of Social Studies Education Research*, *10*(2), 362–371.

Longfield, J. (2009). Discrepant teaching events: using an inquiry stance to address students' misconceptions. *International Journal of Teaching and Learning in Higher Education*, *21*(2), 266–271.

Lubin, J., & Polloway, E. (2016). Mnemonic instruction in science and social studies for students with learning problems: a review. *Learning Disabilities - A Contemporary Journal*, *14*(2), 207–224.

Lusia, N., & Aloysius, D. C. (2018). The correlation between metacognitive skills and critical thinking skills toward students' process skills in biology learning. *Journal of Pedagogical Research*, *2*(2), 122–134.

Maimun, B. (2022). Student's critical thinking ability from gender and learning style using edmodo e-learning. *World Journal on Educational Technology: Current Issues*, *14*(6), 1943–1961.

Mccombs, B. L., & Marzano, R. J. (1990). Putting the self in self-regulated learning: the self as agent in integrating will and skill. *Educational Psychologist*, *25*(1), 51–69. https://doi.org/10.1207/s15326985ep2501_5

Mohseni, F., Seifoori, Z., & Ahangari, S. (2020). The impact of metacognitive strategy training and critical thinking awareness-raising on reading comprehension. *Cogent Education*, *7*(1), 1–22. https://doi.org/10.1080/2331186X.2020.1720946

Murtini, I., Zubaidah, S., & Listyorini, D. (2020). Improving students' cognitive and critical thinking skills through research-based cell division control module. *AIP Conference Proceedings*. https://doi.org/10.1063/5.0000789

Neena, S., & Sneh, B. (2015). Metacognitive awareness of undergraduate students in relation to their academic achievement. *International Journal of Indian Psychology*, *3*(1), 113–119. https://doi.org/10.25215/0301.136

Nori, A., Zulirfan, Z., & Ma'aruf, Z. (2019). An analysis of student's critical thinking skills in physics lesson in sma 8 pekanbaru. *Jurnal Geliga Sains: Jurnal Pendidikan Fisika*, *7*(1), 11–17. https://doi.org/10.31258/jgs.7.1.11-17

Oflaz, O. (2021). Combination of discovery learning and metacognitive knowledge strategy to enhance students' critical thinking skills. *European Journal of Educational Research*, *10*(4), 1781–1791. https://doi.org/https://doi.org/10.12973/eu-jer.10.4.1781 Introduction

P21CS. (2008). *21st century skills, education & competitiveness.* In *a Resource and Policy Guide* (Vol. 305). https://doi.org/6th August 2016

Porath, C. L., & Bateman, T. S. (2006). Self-regulation: from goal orientation to job performance. *Journal of Applied Psychology*, *91*(1), 185–192. https://doi.org/10.1037/0021-9010.91.1.185

Pradhan, S., & Das, P. (2021). Influence of metacognition on academic achievement and learning style of undergraduate students in Tezpur University. *European Journal of Educational Research*, *10*(1), 381–391. https://doi.org/10.12973/EU-JER.10.1.381

Prapulla, S. B., Patra, S. M., Subramanya, K. N., & Uma, B. V. (2022). Techniques for Strengthening 21st Century Learners' Critical Thinking Skills. *Journal of Engineering Education Transformations*, *36*(special issue 2), 512–518. https://doi.org/10.16920/jeet/2023/v36is2/23078

Pudiquet, F. G., Balualua, M. C., Tumacder, C. G., Matulay, L. T., & Derilo, R. C. (2019). Autonomous learning, metacognitive awareness and science academic achievement of pre-service teachers. *International Journal of Research & Review*, *6*(5), 25–31.

Rivas, S. F., Saiz, C., & Ossa, C. (2022). Metacognitive strategies and development of critical thinking in higher education. *Frontiers in Psychology*, *13*(6), 1–13. https://doi.org/10.3389/fpsyg.2022.913219

Rosdiana, L. A., Damaianti, V. S., Mulyati, Y., & Sastromiharjo, A. (2023). The role of metacognitive strategies in academic writing skills in higher education. *International Journal of Learning, Teaching and Educational Research*, *22*(6), 328–344. https://doi.org/10.26803/ijlter.22.6.18

Rum, S. N., & Ismail, M. (2016). Metacognitive awareness assessment and introductory computer programming course achievement at university. *International Arab Journal of Information Technology*, *13*(6), 667–676.

Scheiner, T. (2020). Dealing with opposing theoretical perspectives: knowledge in structures or knowledge in pieces? *Educational Studies in Mathematics*, *104*(1), 127–145. https://doi.org/10.1007/s10649-020-09950-7

Setiawati, H., & Corebima, A. D. (2018). Improving students' metacognitive skills through science learning by integrating PQ4R and TPS strategies at A Senior High School in Parepare, Indonesia. *Journal of Turkish Science Education*, *15*(2), 95–106. https://doi.org/10.12973/tused.10233a

Sinar, B. (2018). Promoting metalinguistic awareness in a classroom to improve reading comprehension: Examples from Roald Dahl's novel The BFG. *Acta Didactica Norge*, *12*(2), 11. https://doi.org/10.5617/adno.5605

Son, H. K. (2020). Effects of s-pbl in maternity nursing clinical practicum on learning attitude, metacognition, and critical thinking in nursing students: a quasi-experimental design. *International Journal of Environmental Research and Public Health*, *17*(21), 1–12. https://doi.org/10.3390/ijerph17217866

Sumintono, B., & Widhiarso, W. (2015). *Aplikasi pemodelan rasch pada assessment pendidikan*. Trim Komunikata.

Sutama, S., Fuadi, D., Narimo, S., Hafida, S. H. N., Novitasari, M., Anif, S., Prayitno, H. J., Sunanih, S., & Adnan, M. (2022). Collaborative mathematics learning management: Critical thinking skills in problem solving. *International Journal of Evaluation and Research in Education*, *11*(3), 1015–1027. https://doi.org/10.11591/ijere.v11i3.22193

Thomas, T. (2011). Developing first year students' critical thinking skills. *Asian Social Science*, *7*(4), 26–33. https://doi.org/10.5539/ass.v7n4p26

Warni, Sunyono, & Rosidin. (2018). Measuring metacognitive ability based on science literacy in dynamic electricity topic. *Journal of Physics: Conference Series*, *948*, 012041. https://doi.org/10.1088/1742-6596/948/1/012041

Weinert, F. E., & Kluwe, R. (1987). *Metacognition, motivation, and understanding (psychology of education and instruction series)* (1st editio). Psychology Press.

Yuningsih, Y., & Susilo, M. J. (2018). Kajian pendekatan analogi dalam pembelajaran biologi yang bermakna. *Briliant: Jurnal Riset Dan Konseptual*, *3*(3), 268–279. https://doi.org/10.28926/briliant.v3i3.188