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Mathematical Critical Thinking Ability Reviewed from Self-Regulated Learning: Systematic Literature Review

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The ability to think mathematically critically is essential in learning as it helps students to think rationally in making decisions and formulating conclusions, as well as choosing the best option for themselves. In fact, PISA results in 2022 and TIMSS results in 2015 show that students' critical thinking skills are not optimum. Therefore, the role of educators is required in order to develop the critical thinking ability of students. Self-regulated learning can affect students' cognitive ability to think critically. The purpose of this research is to identify, study, and make overall related conclusions of research results related to the mathematical critical thinking ability reviewed from self-regulated learning. The method used in this study is the Systematic Literature Review (SLR). The data collection process involved merging similar research articles focused on topics of mathematical critical thinking and self-regulated learning published between 2019 and 2023. The article used in this study is 13 articles obtained from Publish or Perish. The findings results reveal a distinction in mathematical critical thinking proficiency based on students' level of self-regulated learning.

Keywords: mathematics, critical thinking, mathematical critical thinking ability, self-regulated learning, systematic literature review

INTRODUCTION

Mathematics, as a field of knowledge that emphasizes the process of thinking, is considered very relevant to being taught to students. In it, there are various elements that fundamentally direct students to think logically according to the patterns and rules that have been established. Therefore, the primary objective of mathematics teaching is to develop students' ability to mathematical thinking especially critical thinking (Pebianto et al., 2019). Saputra (2020) revealed that critical thinking involves intellectual activity in overcoming challenges, making assumptions, giving reasonable arguments, evaluating, conducting research, and making decisions. In the decision-making process, the ability to search, analyze, and evaluate information becomes crucial. Students with critical thinking abilities will be active in the search, analysis, and assessment of information, as well as concluding on the basis of facts before finally making decisions.

According to Umam (2019), improving critical thinking in the process of learning mathematics will help students use their intellectual potential to conduct logical, orderly, and accurate thinking in solving mathematical problems. The ability to think mathematically critically is very important to students because with this ability students can think rationally in making decisions and formulating

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conclusions, as well as choosing the best option for themselves. Somakim (2011) indicated students will also be able to observe carefully the various problems that arise in everyday life.

The truth is that Indonesian pupils still have a low level of critical mathematical thinking. Evidence of this can be seen from the results of the Program for International Student Assessment (PISA) in 2022. Based on the results of the PISA assessment in 2022, it shows a decrease in math scores which only reached 366 from the highest score of 575. From this it can be seen that Indonesia's average score has decreased by 13 points from the score in 2018 which amounted to 379. According to Sani, as quoted by Shufah & Agoestanto (2023), PISA questions at level 4-6 involve high-level skills, including critical thinking skills, so it can be said that students' ability to think critically is not maximum. In addition, the results of the International Trends in International Mathematics and Science Study (TIMSS) Indonesia conducted to measure mathematical and science skills show that Indonesia has not been able to compete with other countries. Therefore, Indonesia's low performance in the TIMSS study shows that students' critical thinking skills have not yet reached an optimal level (Martyanti & Suhartini, 2018).

One of the factors that determine mathematical critical thinking ability is self-regulated learning. Miatun & Khusna (2020) assert that students who exhibit higher levels of self-regulated learning also possess high levels of mathematical critical thinking ability. So, when self-regulated learning students are low, then it will result in their ability to think critically is also low. Therefore, self-regulated learning should be one aspect of student development. According to Zimmerman, as quoted by Gusmawan et al., (2021) it is called self-regulated learning (SRL), which is the ability of an individual to continuously manage and regulate thoughts, emotions, behaviors, and environments to the desired learning objectives. Self-regulated learning directs learning goals, controls learning processes, cultivates self-motivation and self-efficiency, and chooses and regulates environmental aspects to support learning (Azmi, 2016).

Furthermore, previous research found that students with high self-regulated learning have better organizing and organizing skills when compared to students with low self-regulated learning. A number of previous studies have also discussed the influence of self-regulated learning on students' ability to think mathematically critically. Taking into account the previous research on the impact of self-regulated learning, the study will be literally examined using Systematic Literature Review (SLR) related mathematical critical thinking skills reviewed from students' self-regulated learning. The goal of this study is to identify, examine, and draw general conclusions about the findings of research pertaining to the mathematical critical thinking ability reviewed from self-regulated learning, based on the background information that has been provided.

METHOD

This study uses the SLR method with the aim of concluding findings from research that studies the mathematical critical thinking ability reviewed of self-regulated learning students. SLR is a method used to, evaluate, determine, and interpret all findings of research problems in answering already defined questions (Arief, 2021). The stages of SLR implementation in this study include: research question (RQ), search process, inclusion and exclusion criteria, quality assessment (QA), and deviation from protocol (Triandini et al., 2019). Below is presented the systematic literature review steps in this study.

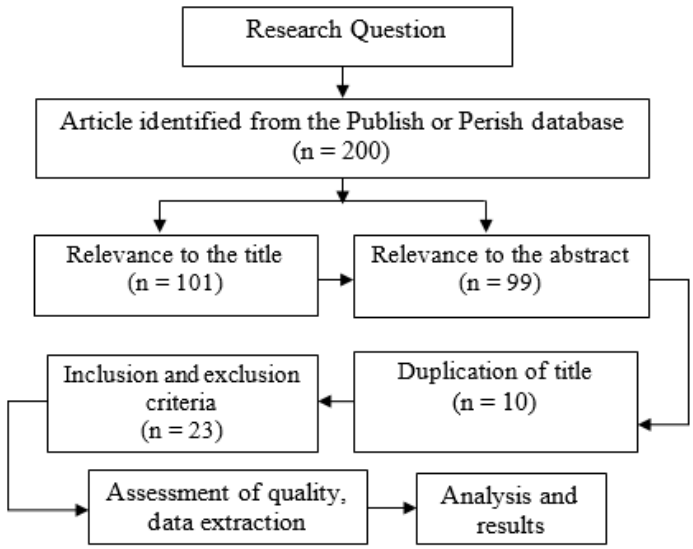

Figure 1
Systematic literature review steps

1. Research Question

   Research Questions is defining questions according to the research topic. The research questions in this study are: (RQ1) whether self-regulated learning has an influence on mathematical critical thinking ability?; (RQ2) How is the description of mathematical critical thinking ability reviewed from self-regulated learning?; and (RQ3) how the research trends in 2019-2023 regarding mathematics critical think skills are reviewed of self-regulated learning?

2. Research Process

   Research Process is implemented to obtain resources that are directly related to the problem being studied so that it can answer the Research Question (RQ) and other related references. To support this research, the researchers compiled articles related to critical thinking skills and self-regulated learning. The collected articles are accredited publications published between 2019-2023, obtained through searches in the Google Scholar search engine using Publish or Perish, and based on inclusion criteria.

3. Inclusion and Exclusion

   Criteria The inclusion and exclusion criteria are used to assess whether the data found is worthy to be used as a source of information in research or not. The following in Table 1 are the inclusion criteria set for this study.

   Table 1
   The inclusion criteria

Criteria	Type
Literature is a national or international journal that discusses mathematical critical thinking and self-regulated learning skills of students in mathematics subjects.	Inclusion
Literature published in 2019-2023.	Inclusion
Literature in Indonesian or English	Inclusion

4. Quality Assessment

   The following evaluation criteria questions will be taken into consideration while evaluating the data discovered in SLR research:

   QA 1. Is the journal published in 2019-2023?

   QA 2. Does the journal explain how students' mathematical critical thinking ability are reviewed from self-regulated learning?

5. Data Collection

   At this stage the data for research is collected. In this study the data collected is secondary and obtained from several stages namely: 1) Library study, carried out by reviewing the journals relevant to the SLR method and obtaining through Publish or Perish. 2) Documentation, the data obtainable will be stored in the Mendeley software. Information about the literature that is the research data is presented in Table 2, after which the literatures are grouped according to the criteria of inclusion that have been established.

Table 2
Research journal

Number	Journal
1	Al-Hikmah
2	*Mathline Journal of Mathematics and Mathematics Education*
3	Cendekia: Jurnal Pendidikan Matematika
4	*Indonesian Journal of Science and Mathematics Education*
5	*Pegem Journal of Education and Instruction*
6	GAUSS: Jurnal Pendidikan Matematika
7	Imajiner: Jurnal Matematika dan Pendidikan Matematika
8	*Electronic Journal of Social Sciences*
9	Analisa
10	*Journal of Physics: Conference Series*
11	PYTHAGORAS: Jurnal Pendidikan Matematika
12	Edueksos

Table 3
Grouping literature into research data

Inclusion Criteria	Group	Total
Types of Literature	Journal Article	13
Types of Research Methods	Quantitative	3
	Qualitative	6
	Mix Method	4
Indexing	Q1	0
	Q2	0
	Q3	1
	Q4	1
	Sinta 1	0
	Sinta 2	2
	Sinta 3	3
	Sinta 4	3
	Sinta 5	1
	Sinta 6	0
	Google Scholar	2
Year of Publication	2019	0
	2020	3
	2021	3
	2022	3
	2023	4
Educational Level	Elementary School	2
	Junior High School	3
	Senior High School	5
	University	3

6. Data Analysis

   At this stage, previously collected data will be analyzed. The results that have been analyzed will answer all the Research Questions that have previously been determined. At this stage, the data that has been collected will be analyzed to show:

   a. Journals published in 2019-2023

   b. The journal discusses mathematical critical thinking skills in terms of self-regulated learning.

7. Deviation from Protocol

   The final phase is deviation from protocol by improving the matching of keywords in the database.

FINDINGS

In the search process using Publish or Perish, as many as 200 articles were obtained based on inclusion and exclusion criteria. However, the paper used in the study comprises 13 articles obtained from national and international journals published between 2019 and 2023 and related to mathematical critical thinking and self-regulated learning. The data obtained is then classified into Table 4 as shown below.

Table 4
Classification of selected literature

Author	Journal	Types of Research	Educational Level	Indexing
Bali & Tartila (2023)	Al-Hikmah	Quantitative	Elementary School	Sinta 4
Nashrullah *et al.,* (2023)	*Mathline Journal of Mathematics and Mathematics Education*	*Mix method*	Junior High School	Sinta 3
Khishaaluhussaniyyati *et al.,* (2023)	Cendekia: Jurnal Pendidikan Matematika	Qualitative	Senior High School	Sinta 3
Bastian *et al.,* (2022)	*Indonesian Journal of Science and Mathematics Education*	Quantitative	Junior High School	Sinta 2
Nizaruddin & Kusmaryono (2023)	*Pegem Journal of Education and Instruction*	*Mix method*	Senior High School	Q4
Winda & Hendro (2022)	GAUSS: Jurnal Pendidikan Matematika	Qualitative	Senior High School	Sinta 5
Prabawati *et al.,* (2022)	Imajiner: Jurnal Matematika dan Pendidikan Matematika	*Mix method*	Junior High School	*Google Scholar*
Öz & Şen (2021)	*Electronic Journal of Social Sciences*	*Mix method*	Elementary School	*Google Scholar*
Rahmawati & Alaydrus (2021)	Al-Hikmah	Quantitative	University	Sinta 4
Gusmawan *et al.,* (2021)	Analisa	Quantitative	Senior High School	Sinta 3
Susanti *et al.,* (2020)	*Journal of Physics: Conference Series*	Qualitative	University	Q3
Miatun & Khusna (2020)	PYTHAGORAS: Jurnal Pendidikan Matematika	Quantitative	University	Sinta 2
Wayudi *et al.,* (2020)	Edueksos	Quantitative	Senior High School	Sinta 4

Based on the analysis of 13 literatures used as research data, it shows that there is a relationship between mathematical critical thinking ability and self-regulated learning, namely the level of mathematical critical thinking ability is influenced by students' self-regulated learning. The research results from 13 literatures are shown in Table 5.

Table 5
Literature research results demonstrating mathematical critical thinking ability revised from SRL

Author	Result
Bali & Tartila (2023)	Through the application of the self-regulated learning model to students at Madrasah Ibtidaiyah Miftahul Islam, the benefits obtained include being able to direct the mind of students during the learning process, regulate the emotions and motivation of students in learning, enable students to take actions necessary to a specific goal, as well as building student confidence when carrying out certain actions.
Nashrullah *et al.*, (2023)	The results showed that (1) students with high self-regulated learning have critical thinking capabilities in categories that meet all critical-thinking indicators i.e., interpretation, analysis, inference, and evaluation; (2) students with self-regulated learning are meeting three critical thought indicators, i. e. interpretations, analyses, and inferences; and (3) students with low self-Regulated Learning only meet two critical think indicators that are at the stage of interpretation and analysis.
Khishaaluhus saniyyati *et al.*, (2023)	Subjects with self-regulated learning are very good at meeting the four critical thinking indicators, namely interpretation, analysis, evaluation, and inference. Subject with self-regulated learning is well able to meet the three critical-thinking indicators that are interpretations, analyses, and evaluations.
Bastian *et al.*, (2022)	Based on the results of the study conducted in the 8th grade of the State High School, Tungkal Ulu found that there was a significant influence of the selection of learning models on critical thinking skills reviewed from self-regulated learning.
Nizaruddin & Kusmaryono (2023)	Study results show that there is a significant relationship between self-regulated learning and independent learning with critical thinking skills. Self-regulation learning and autonomy learning can improve critical learning skills of students. Students who have good self-regulated learning are included in the category of students who have the ability to think critically.
Winda & Hendro (2022)	The study's findings demonstrated that: (1) subjects with high levels of self-regulation can meet four indicators of mathematical critical thinking ability, namely analysis, conclusion, strategy, and tactic; (2) subjects with high levels of self-regulation can meet three indicators of mathematical critical thinking abilities, namely analysis, strategy, and tactic; and (3) subjects with low levels of self-regulation can meet one indicator of mathematical critical thinking.
Prabawati *et al.*, (2022)	The results of the study explained several categories of self-regulated learning that students have: (1) students with the category regulation of cognition meet each critical thinking stage; (2) students with regulations of motivation meet two critical thought stages namely clarification and assessment but belong sufficiently to two other critical think stages; (3) students with categories Regulation of behavior only meet one critical Thinking stage namely at the clarification stage.
Öz & Şen (2021)	Based on research findings, students' critical thinking skills can be enhanced through self-regulated learning. As a result, self-governing learning can help high school students become more skilled critical thinkers.
Rahmawati & Alaydrus (2021)	Students with low self-regulated learning and those with high self-regulated learning differ from one another. Students with high levels of self-regulated learning are also more adept at critical thinking. In blended learning, students' critical thinking skills increase with their level of self-regulated learning.
Gusmawan *et al.*, (2021)	Students who have a high level of self-regulated learning also show high critical thinking abilities, likewise students who have a moderate level of self-regulated learning will have critical thinking abilities at a medium level. Students with low self-regulated learning also have critical thinking skills in the low category. This indicates that there is a proportional relationship between students' level of self-regulated learning and their ability to think critically.
Susanti *et al.*, (2020)	The results of the research show that students with high and moderate levels of self-regulated learning both have good abilities in making generalizations, identifying and justifying concepts, while students with low levels of self-regulated learning only have good abilities in making generalizations, but have poor performance. in terms of identifying and justifying the concept of algorithm analysis.
Miatun & Khusna (2020)	The study's findings indicate that pupils with high levels of self-regulated learning are more adept at critical thinking than those with moderate or low levels of self-regulation. Aside from that, students who exhibit a moderate level of self-regulated learning are more adept at critical thinking than those who do not.
Wayudi *et al.*, (2020)	The research results show that there is an influence of self-regulated learning on students' critical thinking abilities through the application of the guided discovery learning method. This was proven through a simple regression test which obtained an F value of 16,548 with a significance figure of 0.000, which means it is smaller than 0,05.

Quality Assessment Results

1. Studies Based on Year of Publication
   Studies of Literature used as data SLR is a journal published from the year 2019-2023. The following is a detailed dissemination of studies of literature based on the year of publication presented in Figure 2.

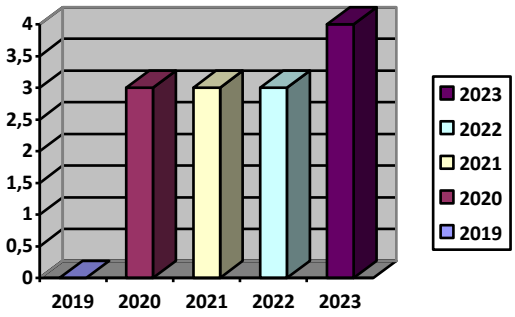

Figure 2
Studies based on year of publication

2. Study Based on Research Type
   The literature studies that SLR data relates to mathematical critical thinking and self-regulated learning is a study that is done using qualitative, quantitative, and mix methods.

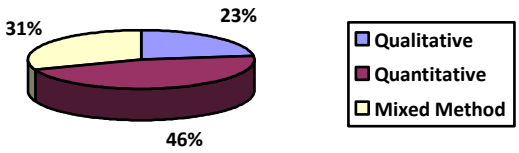

Figure 3
Research type

3. Studies Based on Education
   The literature study that SLR data relates to the ability to think critically mathematical and self-regulated learning is done from the age of elementary school to college. Here is a detail of the study of literature based on the level of education presented in Figure 4.

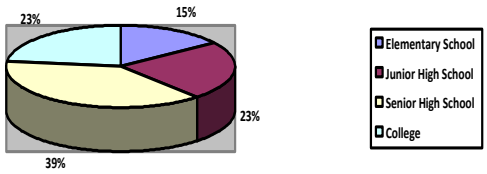

Figure 4
Education level

DISCUSSION

(RQ1) Does self-regulated learning have an impact on mathematical critical thinking?

Mathematical critical thinking is an ability to think effectively and reflectively that can help a person to make, evaluate, and make decisions about what is believed or done (Jumaisyaroh et al., 2014). The ability to think critically mathematically is crucial in learning because it helps students think logically when making decisions, formulating conclusions, and choosing the best option for them. Therefore, many researchers are starting to do research related to critical mathematical thinking in students. Abdullah, as quoted by Gusmawan et al., (2021) explains that self-management and environmental skills, known as self-regulated learning, can affect students' cognitive abilities in critical thinking.

Self-regulated learning is the ability of individuals to consistently regulate and manage their minds, emotions, behaviors, and environments to academic goals (Gusmawan et al., 2021). According to Roslinda et al., (2022), self-regulated learning allows students to plan learning strategies and set goals to be achieved during the learning process. Self-regulation also makes students responsible for their learning process, so they are more aware of conceptual reasons, relationships, and explanations of questions that arise during learning (Sudarman, 2014).

Based on studies by Bali & Tartila (2023), Bastian et al., (2022), and Wayudi et al., (2020) show that self-regulated learning significantly affects mathematical critical thinking. According to Nizaruddin & Kusmaryono (2023), students who have good self-regulated learning are students who fall into the category of critical thinkers. This is due to the fact that students who apply self-regulated learning will tend to have the confidence to express their views, do critical thinking, and be able to solve problems independently. The attitude of self-learning makes the student trained and has the habit of regulating every action without relying on the learning of others. Miatun & Khusna (2020) explains that students with higher self-regulated learning will have better mathematical critical thinking skills than students with moderate and low self-regulated learning, while students with self-Regulated Learning are having better critical thought skills than those with low self-reformed learning. The higher a student has, the higher his or her ability to think mathematically critically (Rahmawati & Alaydrus, 2021). Asmar & Delyana (2020) also confirms that the students with high levels of self- Regulated Learning also have higher mathematic critical think skills.

(RQ2) How is the description of mathematical critical thinking ability reviewed from self-regulated learning?

Out of the study of 13 articles on mathematical critical thinking and self-regulated learning, there are 5 articles that study the types or indicators of mathematic critical thought skills. Of the 5 research papers that study or investigate the ability to think mathematically critically are Nashrullah et al., (2023), Khishaaluhussaniyyati et al. (2022), Nizaruddin & Kusmaryono (2023), Winda & Hendro (2022), and Prabawati et al., (2022). The results of the research carried out by Nashroullah et al., (2023), Nizarudin and Kusmariono (2023), and Khishaluhusussaniyati et al., (2023) use the critical think skills indicators according to Facione which consist of interpretation, analysis, conclusion, evaluation, explanation, and self regulation. Then in the research conducted by Winda and Hendro et al., (2027) and Prawati et al., (2021) use the indicators and Perkins Murphy to measure critical minding skills that students are able to comprehend, clarify, analyze, evaluate, expound.

Further, based on the results of literature research contained in Table 5, it shows that students' ability to think critically mathematically varies depending on the level of self-regulated learning that each student has. Gusmawan et al., (2021) revealed that there are significant differences in the ability to think critically mathematically between students with high, moderate, and low self-regulated learning (Budiwiguna et al., 2022).

In the study Winda & Hendro (2022) explained that students with high self-regulated learning meet four critical thinking indicators when solving problems ranging from clarification, assessment, conclusion, and strategy/tactic. Students with higher self-regulated learning are able to identify problems in questions, define ideas or concepts used in answering questions accurately, generalize summaries according to facts, as well as plan the right strategy or step in solving questions. This is in line with research Nashrullah et al., (2023) which revealed that the students with a high self regulation learning are capable of solving critical mathematical thinking tests according to the entire indicator of mathematic critical thought ability. Studers with high Self-regulation learning will be able to solve questions by using each of the critical thinking skills indicators and can explain the problem solving process correctly (Susanti et al., 2020). But they haven't been able to make an accurate conclusion. Based on this, it appears that students in mathematical critical thinking still have difficulties with critical-thinking indicators so that students with self-regulated learning are meeting only three critical thought indicators: clarification, assessment, and strategy/tactic (Winda & Hendro, 2022). However, they are still incapable of defining the ideas or concepts used in answering questions accurately, are unable to present conclusions in accordance with the results obtained and are not able to generalize on the basis of facts, have not been able to write a solution strategy well and students finish issues without clear and inappropriate sequence (Winda & Hendro, 2022). According to Susanti et al., (2020), students with low self-regulated learning do not have the desire to try to solve problems and feel desperate when they do not find the answer to the problem, so in the end they cannot solve the given problem.

(RQ3) What are the research trends in 2019-2023 regarding mathematical critical thinking skills in terms of self-regulated learning?

The data presented in Fig. 2 is a study that deals with students' mathematical critical thinking and self-regulated learning skills over the last five years, starting from 2019-2023. The search restriction is only in the past five years because there is a lot of research on students' critical mathematics thinking skills and self-regulated learning. From Fig. 2, it can be concluded that the number of studies related to students' Mathematical Critical Thinking skills published from 2019 to 2023 has relatively increased from year to year.

Research on mathematical critical thinking and self-regulated learning using various types of research, including qualitative, quantitative, and mix-methods. From 2019 to 2023, research on the ability to think critically mathematically and self-regulated learning more using mix methods as shown in Figure 3, has presentations of 46%, whereas research using mix and qualitatively methods in sequence has presentation of 31% and 23%.

Research on mathematical critical thinking and self-regulated learning has been carried out at various levels of education, ranging from elementary school, junior high school, senior high school, up to college. Figure 4 shows that research conducted at the level of junior high school and college has a presentation of 23%, while at senior high school level it dominates with a percentage of 39%. However, research at the elementary school level is still rare, so there is a need for further efforts by researchers to conduct more in-depth research at that level.

CONCLUSION

From the study of several articles on the ability to think critically mathematically, to enhance mathematical critical thinking, this study recommends critical-thinking indicators according to Perkins and Murphy, which are clarifications, assessments, conclusions, and strategies/tactics because they describe the phases of critical thought of other experts but in a simpler, clearer, and easier to understand way. Based on the results of the study using SLR of 13 articles reviewed and analyzed, it can be concluded that self-regulated learning has an influence on students' ability to think mathematically critically and has a positive relationship. The findings also indicate that depending on the degree of self-regulated learning, there are variations in students' mathematical critical thinking skills. There are three classifications for the self-regulated learning level: high, medium, and low. Higher levels of self-regulated learning are associated with stronger critical thinking skills in mathematics.

RECOMMENDATIONS

To improve mathematical critical thinking skills, it is important to strengthen students' self-regulated learning skills by helping them plan their learning strategies and monitor their learning process. However, research results show that there are still few studies linking mathematical critical thinking skills with self-regulated learning at the elementary school level. Therefore, further research is needed to gain a deeper understanding of the relationship at the elementary level.

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