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Students' Critical Thinking Skills in Solving Mathematical Problems: Systematic Literature Review

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Abstrak

Untuk mengembangkan kemampuan berpikir kritis matematis, siswa diharapkan memiliki sikap berjuang dalam menyelesaikan masalah matematika. Hal ini dapat mendukung pembelajaran yang berorientasi pada kemampuan berpikir kritis siswa. Tujuan penelitian ini adalah untuk menganalisis kecenderungan pembelajaran keterampilan berpikir kritis dalam pemecahan masalah matematika siswa. Penelitian ini menggunakan metode systematic literature review yang dilakukan dengan cara mengidentifikasi, menilai, dan menginterpretasikan seluruh bukti penelitian yang ada dengan mempelajari indikator dan cara memunculkan kemampuan berpikir kritis matematis siswa sebagai objek penelitian. Rancangan yang digunakan adalah meringkas, mengkaji, dan menganalisis 25 artikel yang sangat relevan dengan objek penelitian pada jurnal terakreditasi Sinta, terindeks Scopus dan Web of Science. Hasil tinjauan pustaka sistematik ini menyatakan bahwa aspek argumentasi dan penalaran sangat penting untuk dikembangkan dalam pemecahan masalah matematika. Penerapan pembelajaran berbasis masalah memiliki efektivitas positif terhadap peningkatan kemampuan berpikir kritis matematis dan diperlukan digitalisasi pembelajaran dalam memfasilitasi berpikir kritis siswa. Digitalisasi pembelajaran dapat berupa pengembangan modul digital berbasis masalah yang memfasilitasi konflik kognitif siswa. Kesimpulan dalam penelitian ini adalah perbedaan indikator yang digunakan untuk mengukur kemampuan berpikir kritis siswa, perbedaan aspek indikator interpretasi, penggunaan PBL, dan penggunaan TIK.

***Kata kunci*:** *Berpikir Kritis Matematis, Masalah Matematika, Pembelajaran Berbasis Masalah, Indikator Berpikir Kritis*

Abstract

To develop mathematical critical thinking skills, students are expected to have a fighting attitude in solving mathematical problems. This can support learning that is oriented towards students' critical thinking skills. The purpose of this research is to analyze the trend of studying critical thinking skills in solving students' mathematical problems. This research uses the systematic literature review method which is carried out by identifying, assessing, and interpreting all available research evidence by studying indicators and how to bring up students' mathematical critical thinking skills as the object of research. The design used is to summarize, review, and analyze 25 articles that are very relevant to the object of research in Sinta accredited journals, indexed by Scopus and Web of Science. The results of this systematic literature review state that aspects of argumentation and reasoning are very important to be developed in solving mathematical problems. Implementing problem-based learning has positive effectiveness towards improving mathematical critical thinking skills and digitalization of learning is needed in facilitating students' critical thinking. Digitalization of learning can be developing problem-based digital modules that facilitate students' cognitive conflicts. The conclusion in this research are different indicators used to measure students' critical thinking skills, different aspects of interpreting indicators, the use of PBL, and the use of ICT.

Keywords: Mathematical Critical Thinking, Mathematical Problems, Problem-Based Learning, Indicators Of Critical Thinking

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1. INTRODUCTION

The progress of the times and the rapid development of technology requires that Indonesia has human resources that are ready to compete in the global arena. Advances in civilization such as rapid changes in science and technology, increasing use of information technology, and continuing to move related to advances in science, all of which focus on education as an influential role (Pratiwi et al., 2019; Shebastian et al., 2020). Quality human resources are a reflection of an appropriate generation in continuing the relay of government that continues from generation to generation (Ferdiani, 2022). In becoming a quality generation, young people are required to have skills that are in line with global demand.

Critical thinking skills, problem solving, creativity are at the core of implementing work in the 21st century (Chai & Kong, 2017; Shahroom & Hussin, 2018).

Critical thinking is one of the most important core competencies in the 21st century. Critical thinking is an analysis and critical assessment of a problem to form a decision. With their critical thinking skills, students can develop effective communication skills as well as overcome difficult challenges in the future (Basri & As' ari, 2019; Hidayatullah et al., 2021). In the Indonesian academic context, the ability to think critically is one of the domains of mathematics that is contained in learning mathematics. Therefore, teachers need to assist students in developing critical thinking skills in solving mathematical problems through the process of learning mathematics (Imam et al., 2018; Putri & Irwan, 2019). Previous study stated that indicators of critical thinking ability include the following: 1) Understand problems and be diligent in solving problems 2) Can think abstractly and quantitatively 3) Make mathematical models, and 4) Look for and use structures and framework (Musdi et al., 2020). From the description above it can be concluded that the ability to think critically is the ability to analyze, create and use criteria objectively and carry out objective evaluations.

With critical thinking students are required to explore types of convergent thinking in learning mathematics. Mathematics is a subject that can develop students' thinking skills and problem solving abilities, because in this subject students are required to seek the truth and in the truth it is necessary to analyze and test its truth. Previous study states that problem solving abilities can support students in making decisions, thinking analytically, and cultivating critical thinking skills to deal with new situations (Chong et al., 2019). The same thing was also expressed by other study that problem solving is an individual activity that involves knowledge, skills, and understanding that has been acquired to obtain solutions to new situations (Epçaçan, 2019).

Currently the learning process still tends to use conventional learning models such as lectures and assignments, so that the learning process takes place monotonously and students are less able to explore the abilities that exist in them. In addition, the use of learning media is still very rare. This shows that the learning process used has not been able to accommodate and facilitate all the learning abilities of each student which are different from one another. There needs to be improvement and creativity so that learning can be more interesting to students as the main subject of learning and to develop students' critical thinking skills.

To develop mathematical critical thinking skills, students are expected to have a fighting attitude in solving mathematical problems. This can support learning that is oriented towards students' critical thinking skills (Munawwarah et al., 2020; Seftiani et al., 2021). Problem solving abilities and critical thinking skills will increase if there are efforts to manage learning by providing opportunities for students to be actively involved in learning. To achieve these efforts, there must be innovation in learning mathematics, for example by applying models, methods, strategies or learning media that are renewable (Darmayasa, 2018; Raharjo, 2022). In addition, so that students' mathematical critical thinking skills can be measured with actual conditions, valid and reliable indicators of mathematical critical thinking skills are needed.

Thus, the focus of this study aims to analyze a comprehensive picture of students' mathematical critical thinking skills in solving mathematical problems, through content analysis on the development of definitions or indicators of mathematical critical thinking, as well as how to emerge or improve students' mathematical critical thinking skills. This research is a Systematic Literature Review which is conducted by identifying, reviewing, evaluating, and interpreting all available research.

2. METHODS

The method used in this research is Systematic Literature Review (SLR). SLR is a method of identifying, evaluating, and interpreting all available research that is relevant to the formulation of the problem and the topic area studied (Chalkiadaki, 2018; Liu et al., 2021). Using the SLR method will be able to systematically review and identify an article in each process following the steps or stages that have been determined.

The object of this research is an indicator of critical thinking and ways to bring up or improve students' critical thinking skills in solving mathematical problems. In this SLR, the data found is evaluated based on questions of quality assessment criteria. Thus, the inclusion and exclusion criteria used in this SLR study can be seen in Table 1.

Table 1. Inclusion and Exclusion Criteria

Criteria	Description
Inclusion	1. The data used are journal articles for the last 10 (ten) years from 2018-2022. 2. Data is taken from the accredited journal Sinta, indexed by Scopus, and Web of Science. 3. The data explains the indicators and how to bring up or improve mathematical critical thinking skills.
Exclusion	1. The data must contain indicators of students' mathematical critical thinking skills 2. The data contains ways to bring out or improve students' mathematical critical thinking skills, namely: (a) application of problem-based learning for experiments; (b) analysis of critical thinking in solving mathematical problems for qualitative research; and (c) digital products in increasing critical thinking for development research.

Researchers collected journal articles from Google Scholar, Research Gate, SINTA, DOAJ, Scopus, and Web of Science. The keywords in this research are mathematical critical thinking skills. From the results of the article search, 25 articles were found with the scope of discussing Mathematical Critical Thinking Skills in Solving Mathematical Problems. In general, there are 3 research methods or approaches used in the 25 articles, namely: 10 articles are classified as experimental research, 12 articles are classified as qualitative research, and 3 articles are classified as development research. From these articles, they are then analyzed to find the results of meta-analysis related to mathematical critical thinking skills in solving mathematical problems to find potential for the development of further studies.

Referring to the objects and inclusion and exclusion criteria that have been presented in Table 1, in this study 515 articles were identified. The identified articles will go through several processes according to the PRISM chart in Figure 1.

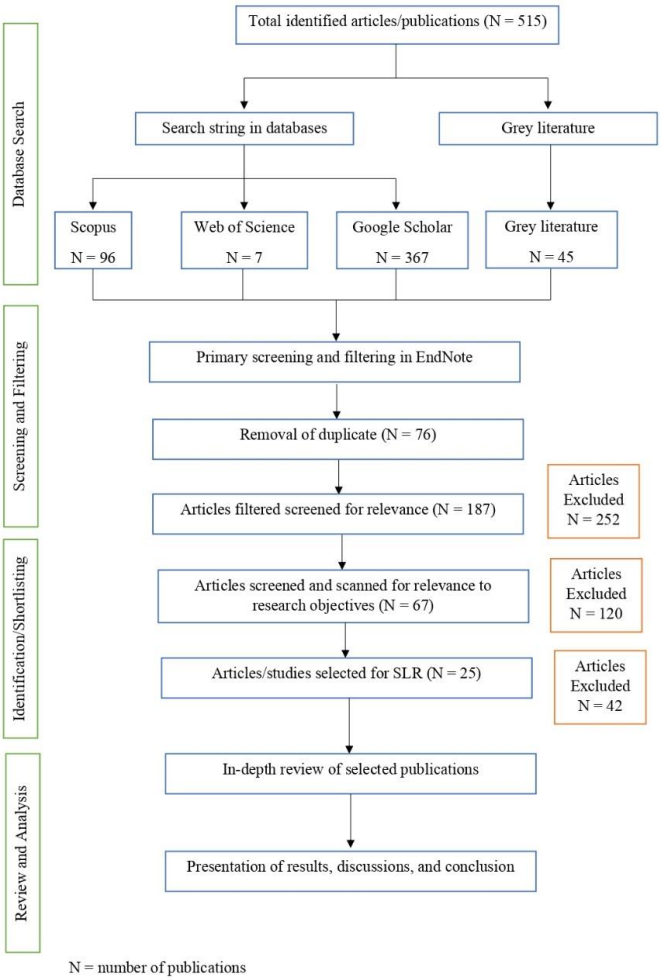

Figure 1. Article Search PRISM Chart.

3. RESULTS AND DISCUSSION

Results

Based on the search results for articles using the Publish or Perish (PoP) application with the keyword Mathematical Critical Thinking Skills, 515 articles were obtained, which then through the VosViewer application obtained visualization and descriptions of the bibliometric knowledge map exploration of these articles as shown in Figure 2.

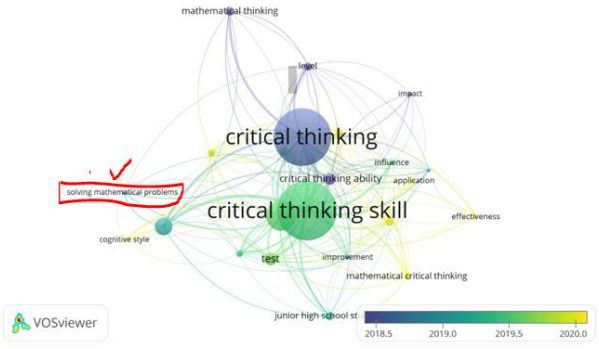

Figure 2. Visualization of Research on Critical Thinking Skills

From Figure 2 it can be seen that the study of mathematical critical thinking skills by solving mathematical problems is interesting for more in-depth analysis and needs to be studied further for potential research topics that can be carried out. This is very reasonable because in the last 10 years little has been done, and when discussing critical thinking it cannot be separated from problem solving as the spirit of learning mathematics at all levels of education. Referring to Figure 1 previously, 25 articles were obtained that were very relevant to describe the study of students' critical thinking skills in solving mathematical problems, where the results of the meta-analysis of the findings of the articles are presented in Table 2.

Table 2. Meta-Results of Mathematical Critical Thinking Concept Findings

No.	(Author Name, Year)	Research methods	Critical Thinking Indicators Used	How to Bring Up Critical Thinking
1.	(Alfayez et al., 2022)	Quasi Experiments	Referring to Facione: identifying assumptions; interpretation; discussion; deduction; and concluded	Implementation of a training program based on mathematical problem solving strategies with authentic problem types
2.	(Monrat et al., 2022)	Quasi Experiment with mixed-method approach	Referring to Facione: interpretation; analysis; evaluation; and inference	Using Open-Ended Questions and learning based on student preferences.
3.	(Samura et al., 2020)	Quasi Experiments	Referring to Ennis: compare and contrast; create categories; examine small parts and whole parts; explain why; make order; determine the source; and make predictions.	Application of Problem Based Learning with Open-Ended contextual problem types
4.	(Susilo et al., 2020)	Quasi Experiments	Referring to Faicone: analyze; giving explanation; evaluate; and choose a problem-solving strategy	Application of Problem Based Learning and submission of mathematical problems.
5.	(Ahdhianto et al., 2020)	Quasi Experiments	Referring to Ennis: ability to identify problems; reasoning ability; ability to draw conclusions; and the ability to ensure clarity of resolution	Application of Problem Based Learning with contextual problem types
6.	(Ramadhani et al., 2020)	Quasi Experiments	Referring to Facione: interpretation; analysis, evaluation, and inference.	Application of the Flip-Problem Based Learning Model with the help of the Google Classroom

No.	(Author Name, Year)	Research methods	Critical Thinking Indicators Used	How to Bring Up Critical Thinking
				LMS
7.	(Amin et al., 2020)	Quasi Experiments	Referring to Ennis: formulating the problem; provide arguments; make deductions; do induction; carry out evaluations; and implementation	Application of Problem Based Learning through activities to solve environmental problems.
8.	(Yolanda, 2019)	Quasi Experiment with mixed-method approach	Referring to Ennis: looking for similarities and differences; make generalizations; consider decisions and apply principles; give reasons; and identify problems	Application of Problem Based Learning with contextual problem types
9.	(Arifin et al., 2019)	Quasi Experiments	Referring to Facione: analysis; synthesis; evaluation; and problem solving	Application of Direct Instruction learning and Problem Based Learning with contextual problem types
10.	(Sari & Hidayat, 2019)	Quasi Experiments	Refer to Ennis: solving problems by identifying; detect given problem; and evaluate solutions	Application of the Multiple Loop Problem Solving Model with Open-Ended problem types
11.	(Aiyub et al., 2021)	Qualitative descriptive research	Refer to Watson-Glatser: inference; assumption recognition; deduction; interpretation; and evaluation of arguments	Use of contextual problems.
12.	(Tohir et al., 2021)	Qualitative research	Referring to Facione: identification; define; count; analyze; record; and re-examination	Use of contextual problems.
13.	(Munawwarah et al., 2020)	Qualitative research	Referring to Facione: identification; define; count; analyze; record; and re-examination	Use of contextual problems.
14.	(Susilo et al., 2020)	Qualitative with exploratory descriptive	Referring to Ennis: analysis; conclude and give reasons; evaluation; and choose a problem-solving strategy	Penerapan *Problem Based* Learning with Open-Ended problem types
15.	(Alifia et al., 2019)	Qualitative descriptive research	Referring to Ennis: formulating the problem; analysis and problem solving; evaluate; and draw conclusions	Use of contextual problems.

No.	(Author Name, Year)	Research methods	Critical Thinking Indicators Used	How to Bring Up Critical Thinking
16.	(Basri & As' ari, 2019)	Qualitative descriptive research	Refer to Facione: interpretation; analysis; evaluation; inference; explanation; and re-examination	Use of contextual problems.
17.	(Martiani & Juandi, 2019)	Qualitative descriptive research	Refers to Ennis: answers questions; check the correctness of the solution; analysis and clarification of questions, answers, and opinions; evaluate and determine reliable sources and arguments.	Use of contextual problems.
18.	(Aini et al., 2019)	Qualitative with a Single Case Study approach.	Refer to Ennis: basic clarification; basic support; inference; further clarification; and strategy and tactics	Application of Problem Based Learning with Open-Ended problem types l
19.	(Susanti & Hartono, 2019)	Qualitative descriptive research	Referring to Facione: interpretation; analysis, evaluation, and inference	Use of contextual problems.
20.	(Ismail, 2018)	Qualitative research	Refer to Facione: interpretation; analysis; evaluation; inference; explanation; and re-examination	Use of contextual problems.
21.	(Ismail et al., 2018)	Qualitative research	Refer to Facione: interpretation; analysis; evaluation; inference; explanation, and re-examination	Use of contextual problems.
22.	(Nugroho et al., 2018)	Qualitative with exploratory descriptive	Refers to Taube: solving problems; formulate conclusions; calculating probabilities; and make a decision	Use of Ill-Structured Mathematics problems.
23.	(Musdi et al., 2020)	Development	Referring to Ennis: identification; connect; and evaluate	Learning media based on Van Hiele's theory.
24.	(Harjo et al., 2019)	Development	Referring to Ennis & Weir and Facione: interpretation; analysis; evaluation; inference; and explanation	Online instrument for critical thinking skills.
25.	(Putri & Irwan, 2019)	Development	Referring to Facione : interpretation; analysis, evaluation, and inference.	Quantum Learning Model-based learning media.

Based on Table 2, it can be seen that all research themes are related to critical thinking skills in solving mathematical problems. All of these articles were published in the last five years, between 2018 and 2022 to be precise. From Table 2, it can be seen that the research trend of critical mathematical thinking is dominated by experimental research in the form of quasi-experiments and qualitative descriptive research. In addition, the topics of discussion that appear in the majority of each article and the potential for further research studies can be summarized as shown in Table 3.

Table 3. Summary of Discussion Topics and Opportunities for Further Study

No.	The majority of discussions appear in the article	An Analysis of the Implications and Limitations	Further Study Opportunities
1.	Critical thinking indicators refer to the opinions of Ennis and/or Facione.	92% of articles use critical thinking indicators according to Ennis and/or Facione. In more detail, as many as 48% of the articles used the Facione critical thinking indicator and 44% used the Ennis critical thinking indicator. Interestingly, articles that refer to the same critical thinking indicators (using Ennis and/or Facione indicators), have differences or variations in the aspects of the critical thinking indicators. In this case, the interpretation of one article to another on the indicators referred to is different.	1. It is necessary to test the consistency and/or effectiveness of each aspect of the critical thinking indicator by Ennis or Facione. 2. It is necessary to develop indicators by modifying critical thinking indicators according to both Ennis and Facione, referring to the strengths and weaknesses of the two critical thinking indicators, so that valid and reliable mathematical critical thinking indicators can be produced.
2.	Raising Mathematical Critical Thinking through Problem Based Learning.	As many as 88% of the articles use Problem Based Learning by utilizing contextual, realistic, authentic, open-ended, ill-structured, or metacognitive problem types, as starting points in learning. With problem-based learning, students will be directed to develop Higher Order Thinking Skills (HOTS) through a thought process in solving the problems presented. The limitations of the articles presented in table 2 are the types of problems used only to motivate students to learn and make learning more meaningful.	It is necessary to develop and apply problems that can develop Higher Order Thinking Skills (HOTS), so that learning is not only meaningful, but can also train students' higher order thinking skills.

No.	The majority of discussions appear in the article	An Analysis of the Implications and Limitations	Further Study Opportunities
3.	Bringing up critical thinking mathematically through the use of contextual, realistic, or authentic problem types.	As many as 48% of articles use contextual problem types, 8% of articles use authentic problem types, and 4% of articles use realistic problems. These three types of problems can lead students towards more meaningful learning. However, the use of contextual, authentic, and realistic problem types has not provided space for students to think critically (the realm of analysis and evaluation).	Efforts are needed to combine the types of problems, one of which is by combining contextual, authentic, and realistic problems with problems that provide cognitive conflict, for example a combination of contestual problem types and open ended problem types.
4.	Raising mathematical critical thinking through the use of open-ended, ill-structured, or metacognitive problem types.	From all the articles reviewed, it can be seen that the percentage of using open-ended, ill-structured, or metacognitive problem types is only 24% with 20% of them using open-ended problem types and 4% using ill-structured problem types. In principle, these three types of problems have accommodated critical thinking skills (the realm of analysis and evaluation) with differences of opinion and problem solving given by students. However, the types of open-ended, ill-structured, or metacognitive problems have not provided space for cognitive conflict in students due to contradictions.	It is necessary to provide controversial issues that can cause cognitive conflict in students due to cognitive conflicts.
5.	Bringing up critical thinking through the use of information and communication technology (ICT).	There are 4% of articles which in their research make use of information and communication technology (ICT) to improve students' critical thinking skills. From 4% of the articles using ICT, it can be seen that the use of IT can provide a new atmosphere and ideas to improve critical thinking skills in the digital era. However, these articles are limited to the development of learning media and instruments that cannot stand alone completely for independent learning for students.	It is necessary to develop a problem-based mathematics electronic module (E-module) that can facilitate students' critical thinking in independent learning.

Discussion

Of the 25 articles that have been identified, it is known that most of the critical thinking indicators used refer to the opinions of Ennis and Facione. Even though it refers to the same critical thinking indicators (using Ennis and/or Facione indicators), there are differences or variations in the aspects of the critical thinking indicators. This is due to the different interpretations of one article to another on the indicators of critical thinking referred to. Another thing that can be identified is that most of the articles above use Problem Based Learning to bring up critical thinking. Problem Based Learning is said to be an effective model for improving students' critical thinking skills (Munawwarah et al., 2020; Sumarno, 2019). With problem-based learning, students will be directed to develop Higher Order Thinking Skills (HOTS) through thought processes in solving the problems presented (Antara & Dewantara, 2022; Takko et al., 2020).

The use of contextual, realistic, and authentic problems in the article can motivate students in learning and is able to lead students towards more meaningful learning. However, the use of contextual, authentic, and realistic problem types in the above article has not provided space for students to think critically and has not been able to optimize development in the realm of analysis and evaluation in accordance with the objectives of Problem Based Learning (Hidayati et al., 2020; Muslimahayati et al., 2020). On the other hand, the above article also uses open-ended, ill-structured, or metacognitive problem types. In principle, these three types of problems have accommodated critical thinking skills (the realm of analysis and evaluation) through differences of opinion and problem solving given to students. However, the types of open-ended, ill-structured, or metacognitive problems do not yet provide students with cognitive conflict due to contradictions. Therefore, it is necessary to provide controversial issues that can cause cognitive conflict in students due to cognitive conflicts.

Apart from using Problem Based Learning, the method used to bring up critical thinking is through the use of information and communication technology (ICT). The use of ICT-based media tends to be better than conventional media. This is supported by research which states that the use of Adversity Quotient-based Geogebra software can improve students' critical thinking skills (Hidayat & Sariningsinh, 2018). However, the article above is limited to the development of instructional media and instruments that cannot stand alone completely for independent learning for students. Thus, it is necessary to develop a problem-based mathematics electronic module (E-module) that can facilitate students' critical thinking in independent learning (Priyonggo et al., 2021; Putri & Irwan, 2019).

From the results of the Systematic Literature Study (SLR) which elaborated on 25 articles, there were four topics that were highlighted, namely the differences in indicators used to measure students' critical thinking abilities, aspects used to translate indicators of critical thinking, the use of Problem Based Learning can bring out mathematical critical thinking skills students, and the use of ICT in generating mathematical critical thinking.In terms of theory, the results of the Systematic Literature Review (SLR) that were conducted turned out to have relevance which is in line with the results of the Systematic Literature Review (SLR). From these two studies, it can be seen that in critical thinking, aspects of argumentation and reasoning are very important to develop. This is because argumentation can describe cognitive activity, while reasoning is the key to developing critical thinking. Apart from comparing it with the relevant Systematic Literature Review (SLR), a comparison was also made with the results of the meta-analysis. From the results of this comparison, it was found that the results of the Systematic Literature Review (SLR) which were carried out were in line with the results of the meta-analysis in terms of implementing Problem Based Learning which turned out to have a positive effect on improving students' mathematical thinking skills (Azizah et al., 2018; Munawwarah et al., 2020).

Based on a comprehensive description of these students' mathematical critical thinking skills with their indicators, implications, and limitations, it can be recommended for further studies regarding the digitization of mathematics learning which is able to bring up indicators of students' critical thinking skills as a whole and independently. The digitalization of learning can be in the form of developing problem-based digital modules that facilitate students' cognitive conflicts which not only raise differences in views but also provide conflict in students' cognition so that students' analysis and evaluation processes are more optimally developed to improve students' mathematical critical thinking.

4. CONCLUSION

The topic of study on critical thinking skills in solving students' math problems includes various discussions. The aspects used to translate critical thinking indicators are different, the use of Problem Based Learning can bring up students' mathematical critical thinking skills. However the use of the majority of problem types is contextual, authentic, and open-ended problems which are still limited to more meaningful learning conditioning that does not facilitate cognitive conflict or conflict in students, and the utilization of ICT in generating mathematical critical thinking already exists but its existence is still minimal and only limited as a learning supplement or in other words it is not optimal to facilitate students' independent learning in sowing students' critical thinking.

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