Meta Analysis: Analysis of Students' Mathematical Critical Thinking Ability Through the Inquiry Learning Model

Bayu Murti Suryonegoro[1,*], Wardono[1], Tri Sri Noor Asih[1], Scolastika Mariani[1], Isnaini Rosyida[1], Aulia Hurual Aini[1]
[1]Department of Mathematics, Universitas Negeri Semarang, Jawa Tengah, Indonesia

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ABSTRACT

Purpose of the study: The importance of critical mathematical thinking skills in mathematics learning in the current era of the industrial revolution and globalization has encouraged research to evaluate the impact of learning models, one of which is the inquiry model, on students' critical mathematical thinking skills.

Methodology: This meta-analysis review was conducted using the stages of data collection, literature review using PRISMA, statistical analysis, qualitative study, and conclusions. Data were collected through national and international journals and proceedings indexed by Sinta or Scopus to make the information obtained more credible. This study uses the PRISMA framework with the steps identification, screening, eligibility, and inclusion to help transparency, consistency, and completeness of reporting the results of the meta-analysis review.

Main Findings: Based on the research results, inquiry learning significantly influences students' critical mathematical thinking skills. This is evidenced by increased motivation, curiosity, and student involvement in learning. However, this finding requires follow-up in the future, for example, the development of innovations in textbook learning in the form of textbooks or other learning media.

Novelty/Originality of this study: The study analysis of the process of students' critical mathematical thinking skills towards the inquiry learning model in this study was conducted by citing various cross-disciplinary studies and studies from multiple countries or regions to balance more detailed analysis perspectives globally.

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Corresponding Author:
Bayu Murti Suryonegoro,
Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Gunungpati, Semarang, Jawa Tengah, 50229, Indonesia
Email: bayusuryonegoromat23@students.unnes.ac.id

1. INTRODUCTION

The increasingly dynamic and complex global development requires individuals to possess relevant capabilities for competitive advantage. Literacy, as one fundamental ability, encompasses not only reading and writing skills but also critical thinking abilities, information comprehension, and effective communication. It serves as the primary foundation for addressing modern life challenges, particularly in the digital era characterized by extensive information flows. However, literacy proficiency levels among individuals, especially children, are diverse. Various studies have indicated that literacy abilities are influenced by multiple factors, including socioeconomic conditions, health status, community involvement, and educational environment [1], [2]. Children with limited access to learning resources or inadequate social support tend to demonstrate lower literacy abilities than those in supportive environments [3]. Considering literacy's importance as a determinant of future success, developing literacy skills from an early age becomes crucial. Literacy development must be initiated in preschool through various approaches involving family, school, and community participation. Establishing strong literacy foundations early enables children to understand their environment better, utilize opportunities, and confidently address future challenges [4]. Therefore, literacy development represents not merely an individual responsibility but a collective task in creating a literate generation prepared for global competition.

Literacy capabilities play an essential role in individual development, as mastering literacy facilitates the acquisition of more complex skills in the future [5]. Literacy serves as the foundation for knowledge comprehension and mastery and supports critical thinking abilities, enabling individuals to analyze information thoroughly and make appropriate decisions [6], [7]. Furthermore, literacy contributes to developing significant life values such as responsibility, empathy, and cooperation. Additionally, strong literacy capabilities can enhance sensitivity to environmental issues, helping individuals understand the importance of maintaining ecosystem balance and promoting environmentally responsible behavior [8]. Thus, literacy functions not only as a tool for knowledge acquisition but also as a means of developing superior character and making positive societal contributions. Numeracy literacy represents a crucial component of literacy capabilities. The development of numeracy literacy skills influences higher-order abilities [2], [9], [10] and impacts future policy development and targeted interventions [11], [12]. These findings indicate that literacy represents an essential capability for global competitiveness.

Environmental issues have emerged alongside numeracy literacy concerns, with numerous environmental degradation and coastal erosion, among other environmental challenges. One contributing factor is the low level of environmental awareness attitudes. This is evidenced by children and adults disposing of waste inappropriately, such as along beaches and drainage channels [13], [14]. Environmental awareness attitude serves as a key determinant of environmental preservation; consequently, various methods have been implemented to develop environmental awareness attitudes. Several implemented approaches include enhancing environmental awareness attitudes through environmentally-oriented school culture [15], integrating moral values into learning to shape students' environmentally conscious character [16], and applying learning models that impact environmental awareness attitudes [14], [17], [18]. These findings suggest that habituating students to environmental activities can develop environmental awareness attitudes that positively impact environmental preservation.

These explanations highlight that, despite the implementation of numerous methods, significant challenges persist in certain areas, particularly concerning numeracy skills and environmental awareness. The low level of students' numeracy skills is reflected in behaviors such as littering, which is still common among school-aged children. Research findings indicate that students' numeracy literacy skills are categorized as low, as evidenced by the individual scores obtained by the students. The study also revealed that among the six components of numeracy literacy measurement, the indicator requiring the most attention is the use of measurement tools, which includes topics such as measuring length, time, area, and others [19]. Additionally, the practice of burning grass during the dry season, still prevalent in some regions, not only degrades air quality but also negatively affects food chains and ecosystem balance. If these conditions are left unaddressed, they could lead to further deterioration in the quality of education and the environment. One contributing factor to the failure of certain methods is their lack of alignment with local environmental conditions. Therefore, an initial assessment is necessary to understand the current state of numeracy skills and environmental awareness, ensuring that solutions implemented are both effective and contextually appropriate..

Previous research has primarily focused on implementing learning models, developing educational media, and applying cultural frameworks to enhance literacy capabilities and environmental awareness attitudes. However, this study aims to analyze numeracy literacy capabilities and attitudes toward environmental awareness. This focus derives from the observation that each region demonstrates varying levels of numeracy literacy capabilities and attitudes toward environmental awareness. The results of this research are expected to provide appropriate solutions for developing these abilities effectively according to regional characteristics. Several studies have produced diverse findings regarding students' numeracy literacy capabilities and environmental awareness attitudes. Research at a private junior high school in Batam reported students' numeracy literacy capabilities in the good category, with an average score of 84.7 [20]. Other studies indicated that junior high school students' numeracy literacy capabilities during the independent learning era remained at a low level of 37% [21]. Additional research demonstrated that numeracy literacy capability among 22 participants achieved a very good category with an average score of 84.7 [22]. Studies also indicated that first-grade students' numeracy literacy capabilities in mathematics demonstrated satisfactory performance aligned with existing numeracy literacy indicators, with students showing increased enthusiasm for mathematics learning [23]. Regarding environmental attitudes, research has indicated that students' environmental awareness attitudes meet good criteria [24], [25]. These varied findings regarding students' numeracy literacy capabilities and environmental awareness attitudes indicate that while some research demonstrates positive outcomes, with students achieving very good categories in both domains, other studies reveal persistent challenges, such as low numeracy literacy levels among some students. This variation suggests that more strategic and contextual approaches are needed to enhance students' numeracy literacy capabilities and environmental awareness attitudes tailored to specific regional or group requirements and conditions.

2. SYSTEMATIC REVIEW

2.1. Inquiry Learning Model

Inquiry can be interpreted as the process of asking and finding out the answers to the scientific questions that are asked. The inquiry learning model is a process to obtain and build knowledge by conducting observations and/or experiments to find answers or solve problems to questions. This learning model is able to make students learn more actively to find the knowledge that will be built through discovery. Therefore, learning with the inquiry model is oriented towards guidance and instructions from the teacher so that it can facilitate students in understanding learning materials when solving mathematical problems and drawing conclusions according to learning objectives [17].

The inquiry learning model has several syntaxes consisting of five phases, namely observation, manipulation, generalization, verification, and application [18]. The inquiry model is designed by considering the cognitive levels of students and various teacher activities including discovery learning, interactive demonstration, inquiry lesson, inquiry lab, real word application, and hypothetical inquiry [19]. The level of inquiry is based on experience and investigation aimed at improving students' ability to find what they want in learning at school, because in essence, mathematics or science-based learning should not only require students to accept and use existing concepts but they can find and prove them through their own experiences. Therefore, the level in the inquiry learning model needs to be adjusted to the experience gained by students in the learning process. This is certainly in accordance with the development of problem-based learning models that have been developing for a long time, with learning phases that are also suitable for application in this modern era, only at the inquiry level considering the cognitive level and experience of students in learning [20].

Inquiry lesson is one of the levels of inquiry where at this stage it is included in the medium or intermediate level for students who already have little experience in finding concepts independently. The learning steps taken for inquiry lessons include Student observation to observe something explained by the teacher until a question arises that will be solved. Manipulation where students are asked to find as much information as possible related to the phenomenon explained by the teacher. This search for information is based on scientific investigation or without depending on the learning context. Generalization where at this phase students are asked to generalize from previous findings using appropriate theories, the next stage is Verification where students are asked to verify the truth of their findings to be integrated at the Application stage, namely students are directed and explained about the truth of the findings and then can be used in everyday life.

Therefore, the inquiry learning model itself emphasizes improving students' high-level thinking skills through scientific investigations in solving mathematical problems, so that teachers can maximize this opportunity to guide students in conducting investigations so that the desired learning objectives can be achieved properly through their own understanding process [21], [22].

2.2. Mathematical Critical Thinking Ability

Critical thinking skills are an individual's ability to carry out learning activities so that they become more complex and critical in solving mathematical problems [23]. Critical thinking skills themselves can also be interpreted as a complex concept and involve cognitive skills and self-confidence in them, so that they can influence various learning methods carried out in the classroom [24]. The ability to think critically mathematically is generally considered to be a major component that supports other abilities such as creativity and others to solve a problem [25]. On the other hand, mathematically critical thinking skills can also be defined as the ability to understand a problem by carrying out analysis to produce new ideas that can be developed into logical thinking [26]. Therefore, it can be concluded that the ability to think critically in mathematics is an ability that involves an individual both cognitively and affectively in understanding a mathematical problem intellectually which is influenced by various methods in learning, thus producing new ideas or concepts in each problem that can be developed into a logical thought.

Several studies have stated that there are various indicators in identifying the level of students' mathematical critical thinking ability. There are several indicators to assess students' mathematical critical thinking ability as stated by [27] which includes: (1) clarification; (2) assessment; (3) inference; (4) strategies. In addition, there are several indicators of mathematical critical thinking skills to assess the level of ability, including: (1) the ability to identify and justify concepts, namely the ability to provide reasons for mastery of concepts; (2) the ability to generalize, namely the ability to complete data or supporting information; (3) the ability to analyze algorithms, namely the ability to evaluate or check an algorithm. Then, there are also several indicators that state the process of students' mathematical critical thinking skills, including interpretation, analysis, evaluation, inference, explanation, and self-regulation [28].

3. RESEARCH METHOD

This paper used the systematic literature review method to conduct with a meta analysis approach. This review is a form of secondary study that includes various approaches to build, explore, and summarize accessible evidence related to a particular research question. This meta-analysis review was conducted by surveying secondary data consisting of basic research results on the analysis of students' mathematical critical thinking skills through the inquiry learning model. The research stages is data collection, literature review using PRISMA, statistical analysis, qualitative study, and conclusions. The data collected is primary research published in journal articles and national and international conference proceedings indexed by Sinta and Scopus, for further extraction of all identified articles, so that more valid and more credible data will be obtained.

This literature review used a review procedure that complies with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, to answer the research question through four steps: identification, screening, eligibility, and inclusion (final selection of articles), thereby helping to improve transparency, consistency, and completeness of reporting the results of systematic reviews and meta-analyses. Journals obtained from Sinta and Scopus used the keywords "inquiry learning model and mathematical critical thinking ability." The literature selection process followed the inclusion and exclusion criteria, which were applied to the selection of primary literature. The purpose of these criteria is to minimize ambiguity and reduce the possibility of bias in the literature review. These criteria are detailed in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• The literature used consists of academic-philosophical, theoretical, and educational practice studies on the intervention of the influence of inquiry learning models on students' critical mathematical thinking abilities. • Literature refers to publications in reputable journals or conference proceedings. • The population/research subjects consist of students, teachers, and prospective teachers. • Literature published in the last 10 years in reputable journals indexed by Sinta and Scopus. • Literature is published in Indonesian and English.	• Literature published within the last 10 years. • Literature in book form. • Literature is not in Indonesian and English. • Literature is not related to the study of mathematics.

The search flow and number of literature identified in the PRISMA framework are shown in Figure 1. The literature selection process is carried out in four steps, namely keyword search then selecting literature based on title and abstract, inclusion and exclusion criteria, and references from the referred literature.

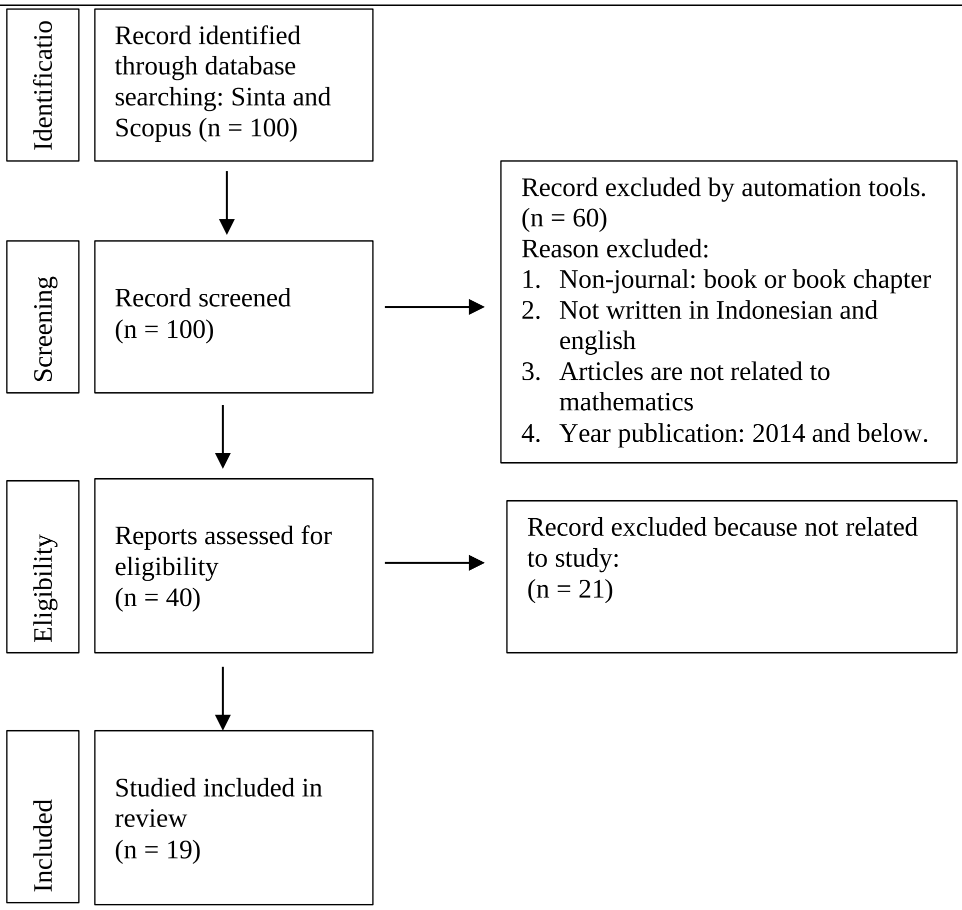


Figure 1. PRISMA Flow Diagram

Furthermore, to find out the analysis of students' critical mathematical thinking skills with the inquiry learning model, it can be calculated using the effect size value with the Cohen's d formula, namely as follows.

$$d = \frac{\overline{x_1} - \overline{x_2}}{s_{gab}} \ldots (1)$$

with

$$s_{gab} = \sqrt{\frac{(n_1 - 1){s_1}^2 + (n_2 - 1){s_2}^2}{n_1 + n_2 - 2}} \ldots (2)$$

Information:

d	: *Effect size*
$\overline{x_1}$	: experimental class average
$\overline{x_2}$	: control class average
s_{gab}	: combined class standard deviation
n_1	: number of students in experimental class
n_2	: number of students in control class
${s_1}^2$	: standard deviation of experimental group
${s_2}^2$	: standard deviation of control group

The effect size results obtained are interpreted based on the classification in Table 2 below.

Table 2. Interpretation of Effect Size

d (*Effect Size*)	Interpretation
$0 \leq d \leq 0{,}2$	Weak
$0{,}2 < d \leq 0{,}5$	Medium
$0{,}5 < d \leq 1$	Big
$d > 1$	Very Big

In addition, the purpose of this study is to determine the analysis of students' mathematical critical thinking skills using the inquiry learning model, so that hypothesis testing is needed using the t-test. The hypothesis used in this study is as follows.

$H_0: \mu_1 \leq \mu_2$ (the average critical mathematical thinking ability of students with inquiry model learning is lower than the average critical mathematical thinking ability of students with expository learning)

$H_1: \mu_1 > \mu_2$ (the average critical mathematical thinking ability of students with inquiry model learning is higher than the average critical mathematical thinking ability of students with expository learning)

The formulation used to test hypothesis is as follows.

$$t_{hitung} = \frac{\overline{x_1}gab - \overline{x_2}gab}{s_{gab}\sqrt{\left(\frac{1}{n_1 gab} - \frac{1}{n_2 gab}\right)}} \ldots (3)$$

where:

t : grade of t_{hitung}

$\overline{x_1}gab$: combined experimental group average

s_{gab} : combined standard deviation of experimental class and control class

$\overline{x_2}gab$: combined control group average

$n_1 gab$: number of samples in the combined experimental group

$n_2 gab$: number of samples in the combined control group

with the testing criteria, namely rejection H_0 if $t_{hitung} > t_{tabel}$, where $t_{tabel} = t_{1-\frac{1}{2}\alpha}$ with $\alpha = 0{,}05$ and $dk = (n_1 + n_2 - 2)$.

4. RESULTS AND DICUSSION

Based on flow PRISMA framework in Figure 1, at the identification stage using the keywords “inquiry learning model and mathematical critical thinking skills.” in the Sinta and Scopus databases, initially 100 studies were identified. Furthermore, at the screening stage, 60 studies in the form of books and book chapters, studies that were not related to mathematics, not in Indonesian and English, and published before 2014 were eliminated. Thus, the articles included at this stage were articles published in journals or conference proceedings indexed by Sinta and Scopus. Then, at the feasibility stage, 40 articles were obtained. Furthermore, at the final inclusion stage, the author excluded 21 articles that were not relevant to the study. Thus, 19 articles were identified that met all inclusion criteria for analysis in this systematic literature review. The articles obtained are grouped in Table 3 as follows [29-47].

Table 3. Articles used as primary references

Title	Author	Journal
Effect of Inquiry Model on Mathematical Critical Thinking Ability of Primary School Students.	Pratiwi, H. S., & Prabawanto, S. (2020).	The 2nd International Conference on Elementary Education.
The effectiveness of STEM based inquiry learning packages to improving students’ critical thinking skill.	Isdianti, M., Nasrudin, H., & Erman, E. (2021).	Journal for the Education of Gifted.
Developing Students’ Critical Thinking Skills in Mathematics Using Online-Process Oriented Guided Inquiry Learning (O-POGIL).	Artuz, J. K. A., & Roble, D. B. (2021).	American Journal of Educational Research.
Inquiry-Based Learning Implementation to Improve Critical Thinking of Prospective Teachers.	Dewi, D. K., Ardhana, W., Irtadji, T. C., & Sulianti, A. (2021).	International Journal of Information and Education Technology.
The Effectiveness of Science, Technology, Engineering, and Mathematics-Inquiry Learning for 15-16 Years Old Students Based on K-13 Indonesian Curriculum: The Impact on the Critical Thinking Skills.	Pahrudin, A., Alisia, G., Saregar, A., Asyhari, A., Anugrah, A., & Susilowati, N. E. (2021).	European Journal of Educational Research.

Title	Author	Journal
The Influence of Inquiry Learning Model towards Students' Mathematical Critical Thinking Ability.	Pujiastuti, H., Haryadi, R., & Ayatullah, F. (2019).	Unnes Journal of Mathematics Education.
The Influence of Inquiry Learning Model Implementation on Students Critical Thinking Ability in Class Learning Activities.	Mohzana, M., Bahansubu, A., Ramdani, H. T., Syahrul, M., & Vanchapo, A. R. (2023).	Journal on Education.
Enhancing students' critical thinking skills through inquiry-based learning model.	Rahmi, Y. L., Alberida, H., & Astuti, M. Y. (2019).	IOP Conf. Series: Journal of Physics: Conf. Series.
Promoting Critical Thinking and Problem Solving Skills of Preservice Elementary Teachers through Process-Oriented Guided-Inquiry Learning (POGIL).	Saputro, A. D., Rohaeti, E., & Prodjosantoso, A. K. (2018).	International Journal of Instruction.
Development of Guided Inquiry-Based Mathematical E-Module in Improving Critical Thinking Ability and Mathematical Disposition Ability.	Zulfa, N. I., & Zaenuri, W. (2023).	International Journal of Research and Review.
The Effect of Guided Inquiry-Based Strategy on Students' Academic Achievement in Mathematics.	Odupe, T. A., & Opeisa, O. Z. (2019).	Abacus (Mathematics Education Series).
Comparative Analysis of Guided Discovery and Guided Inquiry Models: Their Impact on High School Students' Analytical Thinking Abilities.	Sandi, A. F., & Prasetyo, A. T. (2024).	Future Space: Studies in Geo-Education.
Pengaruh model inquiry learning terhadap kemampuan berpikir kritis matematis siswa pada materi fungsi kuadrat kelas X SMA Negeri 3 Singkawang.	Prameswari, G., Apriana, R., & Wahyuni, R. (2018).	JPMI (Jurnal Pendidikan Matematika Indonesia).
The impact of inquiry-based learning approach on critical thinking skill of EFL students.	Ghaemi, F., & Mirsaeed, S. J. G. (2017).	Efl Journal.
Peningkatan Kemampuan Berpikir Kritis Matematis Siswa dengan Menggunakan Model Pembelajaran Inquiri pada Siswa Kelas VII MTsS Jabal Nur.	Amellia, Z., Fonna, M., & Isfayani, E. (2022).	Ar-Riyadhiyyat: Journal of Mathematics Education.
Kemampuan berpikir kritis matematis serta habits of mind menggunakan model inquiry learning dan model creative problem solving.	Nurdiansyah, S., Sundayana, R., & Sritresna, T. (2021).	Mosharafa: Jurnal Pendidikan Matematika.
Pembelajaran Inkuiri Terbimbing Untuk Peningkatan Kemampuan Berpikir Kritis, Komunikasi Matematis, Efikasi Diri Matematis.	Sopari, Y. W., Daniarsa, Y., & Ulfatushiyam, N. (2022).	Pasundan Journal of Mathematics Education Jurnal Pendidikan Matematika.
Penerapan Model Pembelajaran Inkuiri dengan Strategi Konflik Kognitif untuk	Hanggara, W., & Widyatiningtyas, R. (2019).	INTERMATHZO Journal.

Title	Author	Journal
Meningkatkan Kemampuan Berpikir Kritis Matematis Siswa SMK.		
Keefektifan problem solving dan guided inquiry dalam setting TAI ditinjau dari prestasi belajar, kemampuan berpikir kritis, dan kedisiplinan diri.	Setianingsih, H. (2016).	Jurnal Riset Pendidikan Matematika.

Based on the results of the main study analysis of 19 articles obtained, it can be seen that the analysis of students' mathematical critical thinking abilities using the inquiry learning model is as in the statistical analysis in Table 4 below.

Table 4. Statistical Analysis Results

Article Code	Experimental Class			Control Class			*Effect Size*	Criteria
	n	$\bar{x}$	s	n	$\bar{x}$	s		
A1	21	78,29	5,86	21	68,05	6,26	1,30	VB
A2	28	20,82	1,98	28	20,79	1,85	0,003	M
A3	33	37,59	6,89	31	33,87	5,91	0,47	M
A4	38	11,08	1,92	38	9,68	1,16	0,17	M
A5	25	76,20	5,65	25	70,00	4,41	0,79	M
A6	32	7,72	5,35	37	3,95	2,03	0,48	M
A7	32	85,74	13,95	31	70,65	12,76	1,92	VB
A8	32	78,05	8,11	32	68,38	10,09	1,23	VB
A9	24	17,96	1,33	24	14,75	1,51	0,40	M
A10	96	74,36	4,61	96	55,18	19,6	2,44	VB
A11	90	39,15	9,42	90	37,26	10,81	0,24	M
A12	34	84,70	9,58	34	80,20	9,18	0,57	B
A13	32	66,19	12,72	33	56,15	11,19	1,27	VB
A14	20	111,69	11,92	20	88,38	11,63	2,97	VB
A15	28	13,93	3,39	30	11,07	2,77	0,36	M
A16	35	7,69	4,04	35	5,44	3,82	0,28	M
A17	20	60,00	0,21	20	42,00	0,16	2,29	VB
A18	35	62,14	13,01	32	41,28	15,59	2,65	VB
A19	30	75,94	4,46	30	72,74	4,81	0,40	M
	n_e= 685	$\overline{x_e}$= 50,46	$s_{gab\ eksp}$ = 6,04	n_k= 687	$\overline{x_k}$= 42,49	$s_{gab\ kontrol}$ = 9,40	1,00	B
s_{gab} = 7,90								

Therefore, the effect size can be calculated as follows.

$$d = \frac{\overline{x_1} - \overline{x_2}}{s_{gab}} = \frac{50,46 - 42,49}{7,90} = 1,00$$

Then, a statistical analysis was conducted to see whether the inquiry learning model had an impact on students' critical mathematical thinking skills.

1) Determine the hypothesis
   $H_0: \mu_1 \leq \mu_2$ (The average critical mathematical thinking ability of students with inquiry model learning is lower than the average critical mathematical thinking ability of students with expository learning.)
   $H_1: \mu_1 > \mu_2$ (The average critical mathematical thinking ability of students with inquiry model learning is higher than the average critical mathematical thinking ability of students with expository learning.)
2) Determine the level of significance
   The level of significance used is $\alpha = 0,05$
3) Testing criteria
   Reject H_0, if $t_{hitung} > t_{tabel}$
4) Determining t_{tabel} and t_{hitung}
   $t_{tabel} = t_{1-\frac{1}{2}(0,05)} = t_{0,975}$ and
   $dk = n_1 + n_2 - 2 = 685 + 687 - 2 = 1370$ obtained $t_{tabel} = 1,645$

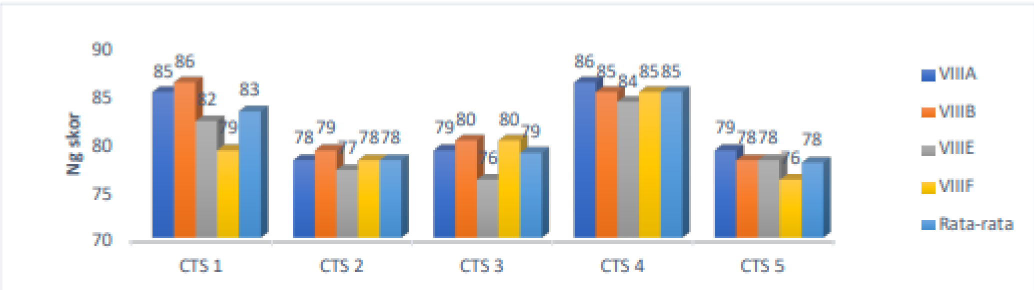
Then count t_{hitung} as follows.

$$t_{hitung} = \frac{\overline{x_1}gab - \overline{x_2}gab}{s_{gab}\sqrt{\left(\frac{1}{n_1 gab} - \frac{1}{n_2 gab}\right)}} = \frac{50{,}46 - 42{,}49}{7{,}90\sqrt{\left(\frac{1}{685} - \frac{1}{687}\right)}} = \frac{7{,}79}{7{,}90\,.\,2{,}06}$$

$$= \frac{7{,}79}{16{,}27} = 0{,}47$$

Based determine t_{tabel} and t_{hitung} we obtained $t_{hitung} = 0{,}47 < 1{,}645 = t_{tabel}$ so that H_0 accept. This means that the average critical mathematical thinking ability of students with inquiry learning model is lower than the average critical mathematical thinking ability of students with expository learning. This implies that the inquiry learning model does not have a significant impact on students' critical mathematical thinking ability. Then, based on the results of statistical analysis, it was found that the inquiry learning model did not have a statistically significant impact compared to the expository learning model, but the average effect size showed a figure of 1.07 so that there was a large influence. Based on this, we get the results that the inquiry learning model emphasizes practical benefits with a large influence in the process of improving students' critical mathematical thinking skills.

Based on the research results, although there are still several categories of effect sizes with a moderate category on critical mathematical thinking skills, the results of the research also show that each indicator of students' critical mathematical thinking skills has increased with the inquiry learning model [48], [49]. This is influenced by the learning approach that is a driving factor in the process of improving mathematical critical thinking skills, one of which is the STEM approach and the implementation of Online Process Oriented Guided in the inquiry learning model. The STEM approach to the inquiry learning model will help the process of improving students' mathematical critical thinking skills because the use of real contexts in everyday life in STEM will increase student motivation to learn, conduct experiments, think critically, and be active in the learning process [50], [51]. This is also shown in Figure 1 which shows that by implementing STEM learning, students experience a high increase in each indicator of mathematical critical thinking skills [52]. Meanwhile, the implementation of Online Process Oriented Guided Inquiry (O-POGIL) has a significant influence on students' critical mathematical thinking skills compared to conventional models and minimizes the occurrence of misconceptions about the material and students' motivation in solving mathematical problems [53], [54]. However, it should be noted that each individual student who becomes a critical thinker with adequate indicators has the challenge of changing the tendency of his/her thought process to be better than before in handling a mathematical problem with another approach that is in accordance with each student's criteria [55], [56].



Note: CTSI 1 (basic clarification); CTSI 2 (decision); CTSI 3 (inference); CTSI 4 (advanced clarification); CTSI 5 (assumption and integration)

Figure 1. N-gain Score Critical Thinking Skills Indicator

In addition, based on the research results, it is known that the factors that influence students critical mathematical thinking skills using the inquiry learning model are media development, one of which is e-modules and the implementation of technology as well as the process of using learning language in the inquiry learning model [57]. Another factor that influences students' critical mathematical thinking skills through the inquiry learning model is the team assisted individualization (TAI) setting, which causes the ability to think and reason in solving mathematical questions or problems to increase, thereby triggering students' critical thinking continuously over a relatively long period of time [58]. Therefore, we can see that the inquiry model is a very good recommendation in the process of improving students' critical mathematical thinking skills.

Furthermore, based on the results of the research conducted, it can be seen that the student-centered approach provides a fairly large contribution to the process of students' critical mathematical thinking skills using the inquiry model. This is supported by the findings stating that the inquiry model through the student-centered approach will be more effective when compared to the problem-based learning model with the traditional approach [59], [60]. In addition, this also has an impact on students' curiosity about the process of analyzing and reconstructing mathematical problems in learning [61], [62]. The cognitive conflict strategy of students’ critical mathematical thinking skills through the inquiry learning model has a significant impact which is very important to improve, especially in mathematics learning, for example in solving problems, students will start to search and justify and start to find a balance between the initial knowledge they have obtained and the new knowledge they have obtained so that students will be more interested in searching and finding the answer [63]. This certainly requires a more complex process by involving students directly in the problems they encounter, because students with ideal critical thinking tend to try to understand a problem clearly, to “fix it,” in finding the truth, and presenting a problem clearly, so that thinking skills are still needed and integrating them imaginatively into a view [64].

The improvement of habits of mind on students’ critical mathematical thinking skills has a positive impact of 60.98%, and also has an effect on students' generalization skills of 42.50% [65]. In addition, according to [66] revealed that habits of mind greatly influence the process of students’ critical mathematical thinking skills through the implementation of the inquiry learning model. There are several things that cause differences in critical mathematical thinking skills and Habits of Mind between students who receive the Inquiry Learning model including physiological factors and psychological factors, as well as factors originating from outside the student including environmental factors (family, school, community, time), and instrumental factors [67].

This result is also proven from the implication that the inquiry learning model does not have a significant impact on students' critical mathematical thinking skills, but there is a positive student response to the inquiry learning model. This is in line with the opinion that several factors, one of which is the response and motivation of students to solving mathematical problems and ongoing learning. Students' responses to learning are very good so that students are directly involved in applying concepts and reasoning critically to the problems they learn in everyday life [68]. This fact is also in line with the statement that inquiry learning will provide good stimulation for motivation, conducting experiments, thinking critically, discussing and being more active in learning activities [69]. This is also in accordance with David Ausubel’s learning theory (meaningful learning) which states that meaningful learning will provide good stimulation for motivation, conducting experiments, thinking critically, discussing and being more active in learning activities, one of which is learning with the inquiry model [70]. In line with the learning principles in Vygotsky’s theory [71], [72] that social interaction can trigger students’ cognitive development. Through discussion and exchange activities, it will encourage group interaction in collaboration that can help in critical thinking [73]. Therefore, although the inquiry learning model does not have a significant impact on students’ critical mathematical thinking skills, the inquiry learning model has a large influence on students’ critical mathematical thinking skills.

5. CONCLUSION

Based on the results of data collection, it was found that although the inquiry learning model may not produce significant results in significance testing, it has a large effect and positive student responses, and of course this shows that the inquiry learning model is a promising learning model innovation to foster students' critical mathematical thinking skills. In addition, the results of this study underline the importance of continuous exploration and innovation in teaching strategies to maximize their potential. Therefore, these findings certainly require future follow-up to conduct research related to the development of innovative teaching resources, for example by developing textbooks as an innovative step to improve students' critical mathematical thinking skills by integrating the inquiry learning model.

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REFERENCES

[1] S. A. Vong and W. Kaewurai, “Instructional model development to enhance critical thinking and critical thinking teaching ability of trainee students at regional teaching training center in Takeo province, Cambodia,” *Kasetsart Journal of Social Sciences*, vol. 38, no. 1, pp. 88–95, Jan. 2017, doi: 10.1016/j.kjss.2016.05.002.

[2] P. A. Facione and N. C. Facione, “Critical thinking for life: valuing, measuring, and training critical thinking in all its forms,” *Inquiry: Critical thinking across the disciplines*, vol. *28*, no. 1, pp. 5-25, 2013.

[3] Y. Ariany, A. Ardi, and Y. L. Rahmi. “Analisis pemahaman guru IPA se-kecamatan Lima Kaum terhadap pelaksanaan standar proses dan standar penilaian kurikulum 2013,” *Jurnal Eksakta Pendidikan (Jep)*, vol. 2, no. 1, pp. 56-63, 2018.

[4] O. L. U. Enciso, D. S. U. Enciso and M. D. P. Daza, “Critical thinking and its importance in education: Some reflections,” *Rastros Rostros*, vol. 19, no. 34, pp. 78-88, 2017.

[5] F. Kalelioğlu and Y. Gülbahar, “The effect of instructional techniques on critical thinking and critical thinking dispositions in online discussion,” *Journal of Educational Technology & Society*, vol. 17, no. 1, pp. 248-258, 2014.

[6] T. W. Luke, “What is critical?,” *Critical Policy Studies*, vol. 10, no. 1, pp. 113-116, 2016.

[7] M. T. Braza and S. S. Supapo, *Effective solutions in the implementation of the K to12 mathematics curriculum*. West Visayas State University. Iloilo City, 2014.
[8] S. ŽivkoviL, "A model of critical thinking as an important attribute for success in the 21st century," *Procedia Soc Behav Sci*, vol. 232, pp. 102–108, Oct. 2016, doi: 10.1016/j.sbspro.2016.10.034.
[9] Y. M. Heong, L. C. Sern, T. T. Kiong, and M. M. Binti Mohamad, "The role of higher order thinking skills in green skill development," *MATEC Web of Conferences*, vol. 70, Aug. 2016, doi: 10.1051/matecconf/20167005001.
[10] S. Hadi and Novaliyosi, "TIMSS INDONESIA (TRENDS IN INTERNATIONAL MATHEMATICS AND SCIENCE STUDY)," *Prosiding Seminar Nasional & Call For Papers*, pp. 562–529, Dec. 2019.
[11] I. Agus and A. N. Purnama, "Eksplorasi kemampuan berpikir kritis matematika berdasarkan keyakinan (belief) siswa," *Jurnal Tadris Matematika*, vol. 5, no. 1, pp. 17-28, 2022.
[12] J. Shara, G. Kadarisma, and W. Setiawan, "Analisis kemampuan berpikir kritis matematis siswa SMP pada materi fungsi kuadrat," *Journal on Education*, vol. 1, no. 2, pp. 450-456, 2019.
[13] X. Jia *et al.*, "The influence of teaching methods on creative problem finding," *Think Skills Creat Journal*, vol. 24, pp. 86–94, Jun. 2017, doi: 10.1016/j.tsc.2017.02.006.
[14] Y. L. Rahmi, E. Novriyanti, A. Ardi and R. Rifandi, "Developing guided inquiry-based student lab worksheet for laboratory knowledge course," In *IOP Conference Series: Materials Science and Engineering*, vol. 335, no. 1, pp. 012082, 2018.
[15] Y. L. Rahmi, H. Alberida and M. Y. Astuti, "Enhancing students' critical thinking skills through inquiry-based learning model," In *Journal of Physics: Conference Series*, vol. 1317, no. 1, pp. 012193, 2019.
[16] N. P. Murnaka, Q. Almaisurie and S. Arifin, "Method on guided inquiry learning to improve students' critical thinking abilities in facing the industrial revolution 4.0," *International Journal Science Technology Research.*, vol. 8, no. 9, 2019.
[17] J. McNew-Birren and L. A. Van den Kieboom, L. A, "Exploring the development of core teaching practices in the context of inquiry-based science instruction: An interpretive case study," *Teaching and Teacher Education*, vol. 66, pp. 74-87, 2017.
[18] C. J. Wenning, "The levels of inquiry model of science teaching," *Journal of Physics Teacher Education Online*, vol. 6, no. 2, pp. 9-16, 2011.
[19] C. J. Wenning, "Levels of inquiry: hierarchies of pedagogical practices and inquiry processes," *Journal of physics teacher education online*, vol. 2, no. 3, pp. 3-11, 2005.
[20] C. J. Wenning and M. A. Khan, "Levels of inquiry model of science teaching: learning sequences to lesson plans," *Journal of Physics Teacher Education Online*, vol. 6, no. 2, pp. 17-20, 2011.
[21] L. S. Vygotsky, "Mind in society: the development of higher psychological processes vol. 86," USA: Harvard university press, 1978.
[22] L. B. Flick and N. G. Lederman, "Scientific inquiry and nature of science," Kluwer Academic Publishers, 2006.
[23] A. Danaryanti and A. T. Lestari, "Analisis kemampuan bepikir kritis dalam matematika mengacu pada watson-glaser critical thinking appraisasl pada siswa kelas VIII SMP Negeri di Banjarmasin Tengah tahun pelajaran 2016/2017," *EDU-MAT Jurnal Pendidikan Matematika*, vol. 116, no. 2, pp. 116–115, 2017.
[24] F. Noor and M. G. Ranti, "Hubungan antara kemampuan berpikir kritis dengan kemampuan komunikasi matematis siswa SMP pada pembelajaran matematika," *Math Didactic: Jurnal Pendidikan Matematika*, vol. 5, no. 1, pp. 75–82, May 2019, doi: 10.33654/math.v5i1.470.
[25] E. Aizikovitsh-Udi and D. Cheng, "Developing critical thinking skills from dispositions to abilities: mathematics education from early childhood to high school," *Creative education*, vol. 6, no. 4, pp. 455-462, 2015.
[26] T. Jumaisyaroh, E. E. Napitupulu, and Hasratuddin, "Peningkatan kemampuan berpikir kritis matematis dan kemandirian belajar siswa SMP melalui pembelajaran berbasis masalah," *KREANO: Jurnal Matematika Kreatif-Inovatif*, vol. 5, no. 2, pp. 157–169, Dec. 2015, doi: https://doi.org/10.15294/kreano.v5i2.3325.
[27] C. Perkins and E. Murphy, "Identifying and measuring individual engagement in critical thinking in online discussions: An exploratory case study," *Educational Technology & Society*, vol. 9, no. 1, pp. 298–307, 2006.
[28] D. K. Filsaime "Menguak kemampuan berpikir kritis dan kreatif," Jakarta: Buku Berkualitas Prima, 2008.
[29] H. S. Pratiwi and S. Prabawanto, S, "Effect of inquiry model on mathematical critical thinking ability of primary school students," In *International Conference on Elementary Education*, vol. 2, no. 1, pp. 312-323, March, 2020.
[30] M. Isdianti, H. Nasrudin and E. Erman, "The effectiveness of STEM based inquiry learning packages to improving students' critical thinking skill," *Journal for the Education of Gifted Young Scientists*, vol. 9, no. 3, pp. 223-232, 2021.
[31] J. K. A. Artuz and D. B. Roble, "Developing students' critical thinking skills in mathematics using online-process oriented guided inquiry learning (O-POGIL)," *American Journal of Educational Research*, vol. 9, no. 7, pp. 404-409, 2021.
[32] D. K. Dewi, W. Ardhana, T. C. Irtadji and A. Sulianti, "Inquiry-based learning implementation to improve critical thinking of prospective teachers," *International Journal of Information and Education Technology*, vol. 11, no. 12, 2021.
[33] A. Pahrudin, G. Alisia, A. Saregar, A. Asyhari, A. Anugrah and N. E. Susilowati, "The effectiveness of science, technology, engineering, and mathematics inquiry learning for 15-16 years old students based on K-13 Indonesian curriculum: the impact on the critical thinking skills," *European Journal of Educational Research*, vol. 10, no. 2, pp. 681-692, 2021.
[34] H. Pujiastuti, R. Haryadi and F. Ayatullah, "The influence of the inquiry learning model on students mathematical critical thinking skill," *Unnes Journal Of Mathematics Education*, vol. 8, no. 3, pp. 216-223, 2019.
[35] M. Mohzana, A. Bahansubu, H. T. Ramdani, M. Syahrul and A. R. Vanchapo, "the influence of inquiry learning model implementation on students critical thinking ability in class learning activities," *Journal on Education*, vol. 6, no. 1, pp. 725-731, 2023.

[36] Y. L. Rahmi, H. Alberida and M. Y. Astuti, “Enhancing students’ critical thinking skills through inquiry-based learning model,” In *Journal of Physics: Conference Series*, vol. 1317, no. 1, pp. 012193, 2019.

[37] A. D. Saputro, E. Rohaeti and A. K. Prodjosantoso, “Promoting critical thinking and problem solving skills of preservice elementary teachers through process-oriented guided-inquiry learning (POGIL),” *International Journal of Instruction*, vol. 11, no. 4, pp. 777-794, 2018.

[38] N. I. Zulfa, Zaenuri and W. Wardono, “Development of guided inquiry-based mathematical e-module in improving critical thinking ability and mathematical disposition ability,” *International Journal of Research and Review*, vol. 10, no. 4, pp. 456-464, 2023.

[39] T. A. Odupe and O. Z. Opeisa, “The effect of guided inquiry-based strategy on students’ academic achievement in mathematics,” *Abacus (Mathematics Education Series)*, vol. 44, no. 1, 2019.

[40] A. F. Sandi and A. T. Prasetyo, “Comparative analysis of guided discovery and guided inquiry models: their impact on high school students' analytical thinking abilities,” *Future Space: Studies in Geo-Education*, vol. 1, no. 3, pp. 277-285, 2024.

[41] G. A. Prameswari, R. Apriana and R. Wahyuni, “Pengaruh model inquiry learning terhadap kemampuan berpikir kritis matematis siswa pada materi fungsi kuadrat kelas X SMA Negeri 3 Singkawang,” *JPMI (Jurnal Pendidikan Matematika Indonesia)*, vol. 3, no. 1, pp. 35-40, 2018.

[42] F. Ghaemi and S. J. G. Mirsaeed, “The impact of inquiry-based learning approach on critical thinking skill of EFL students,” *Efl Journal*, vol. 2, no. 2, pp. 89-102, 2017.

[43] Z. Amellia, M. Fonna and E. Isfayani, “Peningkatan kemampuan berpikir kritis matematis siswa dengan menggunakan model pembelajaran inkuiri pada siswa kelas VII MTsS Jabal Nur,” *Ar-Riyadhiyyat: Journal of Mathematics Education*, vol. 3, no. 1, pp. 1-9, 2022.

[44] S. Nurdiansyah, R. Sundayana and T. Sritresna, “Kemampuan berpikir kritis matematis serta habits of mind menggunakan model inquiry learning dan model creative problem solving,” *Mosharafa: jurnal pendidikan matematika*, vol. 10, no. 1, pp. 95-106, 2021.

[45] Y. W. Sopari, Y. Daniarsa and N. Ulfatushiyam, “Pembelajaran inkuiri terbimbing untuk meningkatkan kemampuan berpikir kritis, komunikasi matematis, self-efficacy matematis,” *Pasundan Journal of Mathematics Education Jurnal Pendidikan Matematika*, vol. 12, no. 1, pp. 60-75, 2022.

[46] W. Hanggara and R. Widyatiningtyas, “Penerapan model pembelajaran inkuiri dengan strategi konflik kognitif untuk meningkatkan kemampuan berpikir kritis matematis siswa SMK,” *INTERMATHZO*, vol. 4, no. 2, pp. 123-127, 2019.

[47] H. Setianingsih, “Keefektifan problem solving dan guided inquiry dalam setting TAI ditinjau dari prestasi belajar, kemampuan berpikir kritis, dan kedisiplinan diri,” *Jurnal riset pendidikan matematika*, vol. 3, no. 2, pp. 221-233, 2016.

[48] E. J. Byker, H. Coffey, S. Harden, A. Good, T. L. Heafner, K. E. Brown and D. Holzberg, “Hoping to teach someday? inquire within: examining inquiry-based learning with first-semester undergrads,” *Journal of Inquiry and Action in Education*, vol. 8, no. 2, pp. 54-80, 2017.

[49] A. Šorgo, B. Dojer, N. Golob, R. Repnik, S. Repolusk, I. Pesek, ... and N. Špur, “Opinions about STEM content and classroom experiences as predictors of upper secondary school students' career aspirations to become researchers or teachers,” *Journal of Research in Science Teaching*, vol. 55, no. 10, pp. 1448-1468, 2018.

[50] M. S. Rivera Maulucci, B. A. Brown, S. T. Grey and S. Sullivan, “Urban middle school students' reflections on authentic science inquiry,” *Journal of Research in Science Teaching*, vol. 51, no. 9, pp. 1119-1149, 2014.

[51] A. A. Zamista, “Increasing persistence of collage students in science technology engineering and mathematic (STEM),” *Curricula: Journal Of Teaching and Learning*, vol. 3, no. 1, 2018.

[52] S. Prayogi and L. Yuanita, “Critical-inquiry-based-learning: model of learning to promote critical thinking ability of pre-service teachers,” In *Journal of Physics: Conference Series*, vol. 947, no. 1, pp. 012013, 2018. IOP Publishing.

[53] S. Andriani, E. Nurlaelah and K. Yulianti, “The effect of process oriented guided inquiry learning (POGIL) model toward students’ logical thinking ability in mathematics,” In *Journal of Physics: Conference Series*, vol. 1157, no. 4, pp. 042108, 2019, February. IOP Publishing.

[54] Ş. Şen, A. Yılmaz and Ö. Geban, “The effects of process oriented guided inquiry learning environment on students' self-regulated learning skills,” *Problems of Education in the 21st Century*, vol. 66, no. 54, 2015.

[55] M. Kallet, “Think smarter: critical thinking to improve problem-solving and decision-making skills,” John Wiley & Sons, 2014.

[56] W. Sanjaya, “Strategi pembelajaran: berorientasi standar proses pendidikan,” Jakarta: Kencana, 2010.

[57] L. S. Amijaya, A. Ramdani and I. W. Merta, “Pengaruh model pembelajaran inkuiri terbimbing terhadap hasil belajar dan kemampuan berpikir kritis peserta didik,” *Jurnal Pijar Mipa*, vol. 13, no. 2, pp. 94-99, 2018.

[58] B. Trilling and C. Fadel, “21st century skills: learning for life in our times,” John Wiley & Sons, 2009.

[59] D. N. Marpaung and M. F. Azzajjad, “The effectiveness of student centre learning in experiment method on acid and base solution to increase student achievement,” *Journal of Applied Science, Engineering, Technology, and Education*, vol. 2, no. 1, pp. 32-36, 2020.

[60] B. C. Bruce and J. D. Wasser, “An inquiry model for literacy across the curriculum,” *Journal of Curriculum studies*, vol. 28, no. 3, pp. 281-300, 1996.

[61] J. Sıburıan, A. D. Corebıma and M. Saptasarı, “The correlation between critical and creative thinking skills on cognitive learning results,” *Eurasian Journal of Educational Research*, vol. 19, no. 81, pp. 99-114, 2019.

[62] H. Husni, “The effect of inquiry-based learning on religious subjects learning activities: an experimental study in high schools,” *Jurnal Penelitian Pendidikan Islam*, vol. 8, no. 1, pp. 43-54, 2020.

[63] G. Dwirahayu, D. Kustiawati and I. Bidari, “Pengaruh habits of mind terhadap kemampuan generalisasi matematis,” *Jurnal Penelitian dan Pembelajaran Matematika*, vol. 11, no. 2, 2018.

[64] R. H. Ennis, “The Palgrave handbook of critical thinking in higher education,” New York: Palgrave Macmillan US, 2015.

[65] N. Nurmala, E. E. Rohaeti and R. Sariningsih, "Pengaruh habits of mind (kebiasaan berpikir) terhadap pemecahan masalah matematik siswa SMP," *Journal on Education*, vol. 1, no. 2, pp. 163-168, 2019.
[66] A. Burrows and T. Slater, "A proposed integrated STEM framework for contemporary teacher preparation," *Teacher Education and Practice*, vol. 28, no. 2/3, pp. 318-330, 2015.
[67] P. Griffin and E. Care, "Assessment and teaching of 21st century skills: methods and approach," Springer, 2014.
[68] D. A. Tillman, S. A. An, J. D. Cohen, W. Kjellstrom and R. L. Boren, "Exploring wind power: Improving mathematical thinking through digital fabrication," *Journal of Educational Multimedia and Hypermedia*, vol. 23, no. 4, pp. 401-421, 2014.
[69] M. A. Priadi and A. R. Riyanda, "Pengaruh model guided discovery learning berbasis e-learning terhadap kemampuan berpikir kritis," *IKRA-ITH Humaniora: Jurnal Sosial dan Humaniora*, vol. 5, no. 2, pp. 1-13, 2021.
[70] P. Ernest., O. Skovsmose., J. P. Van Bendegem., M. Bicudo., R. Miarka., L. Kvasz., and R. Moeller, "The philosophy of mathematics education," Springer Nature, 2004.
[71] R. E. Slavin, "Psikologi pendidikan teori dan praktik jilid 1," Jakarta: PT. Indeks, 2011.
[72] Moll, L. C., & Greenberg, J. B. (1992). 14 Creating zones of possibilities: Combining social contexts for instruction. *Vygotsky and education: Instructional implications and applications of sociohistorical psychology*, *319*.
[73] D. Lee, Y. Huh and C. M. Reigeluth, "Collaboration, intragroup conflict, and social skills in project-based learning," *Instructional science*, vol. 43, pp. 561-590, 2015.