



The Effectiveness of Problem-Based Learning Models to Improve Students' Mathematical Critical Thinking Skills: A Literature Study

Ali Usman¹, Rhahma Wati¹, Rino Richardo*¹

¹ Universitas Alma Ata, Yogyakarta, Indonesia
rinorichardo@almaata.ac.id

Abstract. One of the efforts to improve mathematical critical thinking is to replace the usual learning model with an activity-based learning model that emphasizes the active role of students in learning. One of the most effective learning models and is expected to improve students' mathematical critical thinking skills is the problem-based learning (PBL) model. Several studies have been conducted to evaluate problem-based learning models in improving students' mathematical critical thinking. However, there is still debate about the effectiveness of this model. Therefore, this study aims to evaluate the effectiveness of problem-based learning models in improving students' mathematical critical thinking skills. It is expected that the results of this study can make a positive contribution to the development of education in Indonesia, especially in the field of mathematics. This research is a qualitative study with descriptive analysis techniques with library research where this research seeks to describe existing phenomena, which are currently taking place. This article highlights the concept of problem-based learning in mathematics. This article uses the literature review method of knowledge, ideas, or findings contained in the literature. So that it can provide theoretical and scientific information related to students' mathematical thinking skills with the Problem Based Learning (PBL) learning model. The problem-based learning model is effective in improving students' mathematical critical thinking skills both at the elementary, middle and high school levels, which is like the result of existing research on several materials such as enumeration rules, fractions, building space, the nature of congruence and symmetry, the trigonometric problem, and opportunities. Thus in general it can be concluded that this model is effective for improving mathematical critical thinking skills.

Keywords: Problem-based learning, mathematical critical thinking, effectiveness.

1 Introduction

Education is an effort to help learners perform independent and responsible life tasks verbally and morally. Education is a process of changing the behavior of learners to become adults who are able to live independently and as members of society in the environment that surrounds them. With the help of education, students can carry out

their own activities according to personal and social needs and develop their skills optimally. Therefore, the most effective step to improve the morals and character of a student is to improve education [1]. The education curriculum in Indonesia makes mathematics a compulsory subject for students at school. As one of the teaching materials, mathematics plays an important role in developing the thinking skills of Indonesian students. These abilities such as critical, logical and creative thinking in facing all kinds of challenges of modern times [2]. Of these abilities, critical thinking is one of the abilities to be achieved because people who are mathematical critical thinkers tend to have a positive attitude towards mathematics, so they try to reason and find strategies to solve mathematical problems. Critical thinking is the mathematical ability and tendency to combine prior knowledge, mathematical reasoning, and cognitive strategies to generalize, prove, and evaluate mathematical situations [3].

The Regulation of the Minister of National Education No. 23/2006 confirms that for mathematics lessons at the primary to secondary school level, the expected graduation standards are that students show the ability to think logically, critically, creatively and innovatively, show the ability to learn independently according to their potential, and show the ability to analyse and solve problems in everyday life. The above student graduation standards are used in measuring the abilities obtained by students after learning mathematics [4]. This shows that critical thinking skills are one of the important skills to be developed starting from the most basic level of education to the secondary level. Knowing the importance of critical thinking skills, it is necessary to provide information to students and educators about the characteristics, stages, and indicators of critical thinking. "The benefits of critical thinking are lifelong, supporting students in the regulation of their study skills and subsequently empowering individuals to contribute creatively", the benefits of critical thinking are long-term allowing to support learners in learning skills, besides that it also allows individuals to be creative, so critical thinking can help students to develop learning abilities and spur students to contribute creatively [5]. So that in learning students can apply critical thinking skills and educators can find out students who have critical thinking skills.

Critical thinking is very important for learners as [5] states "critical thinking is important, students who are able to think critically are able to solve problems". Peter stated that critical thinking is important because students who have critical thinking skills can solve the problems faced.[6] stated that critical thinking and mathematics are inseparable. Mathematical material is understood through critical thinking and critical thinking is trained through a series of processes in mathematics learning. Both skills and critical thinking skills need to be developed in mathematics learning. Knowing the importance of mathematics learning and critical thinking skills, educators and students must know and understand that critical thinking skills and mathematics learning are interconnected and continuous. In order to carry out the process of learning mathematics, both students and educators know that critical thinking skills are also needed to support the learning process.

TIMSS and PISA results define that students' critical thinking skills in Indonesia are still unsatisfactory. Based on the PISA 2018 results, Indonesian education is ranked 72 out of 79 countries. The low TIMSS and PISA scores indicate that Indonesian students

do not know advanced perspective questions, which are questions that require application and reasoning. TIMSS research results show that Indonesian students are weak in thinking about non-routine problems related to reasoning or proof, solving problems that require mathematical reasoning, finding problems that require generalizations or assumptions, and finding relationships between information or facts. Given that in the PISA study, Indonesian students are weak in solving mathematical literacy problems, which is reflected in the ability of students to use the mathematics they learn to solve everyday problems.

The results of research [2] in 16 secondary schools in several provinces in Indonesia show that math test results are very low, especially in math application tasks. The ability to apply belongs to the lower cognitive domain than the ability to analyse, synthesize, and evaluate. Although Bloom categorizes the three skills into critical skills [2]. One of the student requirements is 4C (Creativity, Critical Thinking, Communication, and Collaboration) or the so-called life skills in the 21st century. These skills are also contained in the Pancasila Learner Profile which is the vision and mission of the Ministry of Education and Culture as stated in the Minister of Education and Culture Regulation Number 22 of 2020 concerning the Ministry of Education and Culture's Strategic Plan for 2020-2024. Pancasila learners are the realization of Indonesian students as lifelong learners who have global competence and behave in accordance with the values of Pancasila, with six main characteristics, namely faith, devotion to God Almighty, and noble character, global diversity, mutual cooperation, independence, critical reasoning, and creativity (<http://ditpsd.kemdikbud.go.id/hal/profil-pelajar-pancasila> accessed on May 28, 2023). In addition, the skills of critical thinking, reasoning, creativity, communication, collaboration, and problem-solving skills in arithmetic or mathematical literacy is one of the skills that students must master in facing the development of today's world.

Based on the above facts, it can be said that students' ability to solve problems, think critically, creatively and reflectively is generally still weak. The low participation and learning outcomes of students in learning mathematics are caused by the weak thinking skills of students, especially the ability to think critically when solving mathematical problems. This is due to learning that is still mostly done through traditional learning that only emphasizes the demands of the curriculum in such a way that students are passive in practice and narrow the way students think about the problems to be studied. As a result, students are unable to develop higher thinking skills in solving mathematical problems [7]. This is in accordance with the statement [2] that traditional or conventional approaches usually have certain characteristics, for example, prioritizing memorization over understanding, emphasis on arithmetic, prioritizing results over process, and instructed teaching. Student involvement is usually minimized, so students' critical skills in mathematics are not well developed.

Therefore, teachers must be able to strive for learning that can overcome difficulties and improve students' mathematical critical thinking. One of the efforts to improve mathematical critical thinking is to replace the commonly used learning model with an activity-based learning model that emphasizes the active role of students in learning. One of the most effective learning models and is expected to improve students' mathematical critical thinking skills is the problem-based learning model.

Several studies have been conducted to evaluate problem-based learning models in improving students' mathematical critical thinking. However, there is still debate about the effectiveness of this model.

Therefore, this research aims to see the effectiveness of the problem-based learning model in improving students' mathematical critical thinking skills. It is hoped that the results of this study can make a positive contribution to the development of education in Indonesia, especially in the field of mathematics, so there needs to be in-depth research on what is meant by mathematical critical thinking skills and there needs to be certainty that problem-based learning is effective in improving students' mathematical critical thinking skills

2 Methods

This type of research is library research. This study examines the thoughts or findings contained in the article so as to produce scientific information related to the effectiveness of problem learning models in improving students' mathematical critical thinking skills. The source of data taken through literature research is a pure literature research by reviewing 12 articles. While the technique in collecting data used, namely Library Technique, consists of collecting and collecting data through searching for relevant research references from journals related to improving mathematical critical thinking skills through a problem-based learning approach. The stages in conducting data analysis are taken based on stages developed [6] which consists of several activities, including: 1. Summarizing data so that it is easy to understand and interpret logically and objectively, data can be related and have relationships with other topics of discussion. 2. The data that has been collected from reading and studying is then drawn patterns, themes or topics in the discussion chapter. 3. Develop data obtained based on their importance to avoid errors in drawing conclusions. 4. Expand the findings by cross-checking the available sources and data so that they are not stacked. 5. The data that has been collected, presented as is, according to the source obtained. 6. Compile conclusions from the results of the literature studied.

3 Result and Discussion

3.1 Mathematical Critical Thinking

Preseason defines thinking as a mental activity to gain knowledge. Therefore, thinking is a cognitive process that cannot be seen physically. The results of thinking can be ideas, information, procedures, arguments and decisions [7]. Critical thinking is the ability to think through systematic reasoning and systematically evaluate the quality of reasoning and reduce beliefs. According to [1], critical thinking is a thinking process that aims to make rational decisions that lead to a decision to believe or do something. Critical thinking considers and evaluates information that ultimately allows students to

make active decisions. It can be said that critical thinking is a form of mental activity or an active human mind. According to [1], critical thinking is the activity or process of analysing, explaining, developing or selecting ideas, including categorizing, comparing, contrasting, testing arguments and assumptions, concluding and evaluating conclusions from induction and inference, setting priorities and making choices. According to [3], critical thinking in mathematics is an ability that involves prior knowledge, mathematical reasoning, and cognitive strategies to generalize, prove, or evaluate less familiar mathematical situations effectively. Teachers in mathematics learning should facilitate students in developing critical thinking processes, meaning that teachers should take actions that reflect the abilities recommended by the Glazer family.

To develop critical thinking in mathematics, students must face new and conflicting problems in search of truth and clear reasons. So that students can draw the correct conclusions to solve problems in learning mathematics. Critical thinking in mathematics is the ability and tendency to use prior knowledge, mathematical reasoning, and cognitive strategies to generalize, prove, and evaluate mathematical situations [1]. Mathematical critical thinking ability is the cognitive process of students in analyzing problems consistently and concretely, in separating problems carefully and thoroughly, and in identifying and analyzing information needed to plan problem-solving strategies [8].

When students think critically, they get the right strategies. Because students need to get actionable information. Because students need to find information to use, they also learn the necessary materials. Because in math learning, learning materials are related to each other. So when students solve a problem, they have to recall material relevant to the problem. Using critical thinking also helps students remember the subject matter, as well as what has been learned and what remains to be learned. Indicators of mathematical critical thinking skills used in this study include: (a) finding relationships, namely the ability of students to reconstruct the elements of the problem and formulate relationships in the solution; (b) analyzing data, namely the ability of students to identify and make decisions on the problems at hand; (c) analyzing elements, namely the ability of students to identify the elements contained in a relationship; (d) analyzing relationships, namely the ability of students to examine the relationship and interaction between the elements of the problem and then make decisions for its solution; (e) criticizing evidence, namely the ability of students to comment, peel, add, reduce, or rearrange the mathematical evidence they have learned; (f) problem solving, namely the ability of students in the test results or answers in solving problems (3)..

3.2 Problem Based-Learning

In PBL students are encouraged to analyse a problem and consider alternative analysis. Therefore, PBL places students as the main actors in learning and thinking skills. Students are trained to think independently and develop confidence and respect for the activities that are taking place. Thus, PBL creates an atmosphere that supports students in improving their thinking skills. Problem-Based Learning is considered as one of the effective strategies and contributes to developing students' cognitive and metacognitive thinking skills.

Problem-based learning is a learning approach that challenges students to learn through problem solving conducted cooperatively in small groups. According to [3] in PBL students' thinking skills are truly optimized through a systematic group or team work process, so that students can empower and float their capacity to think sustainably. Thus, in PBL, teachers and students are required to be able to display issues that aim to achieve mastery of concepts covered through thinking skills and creativity, achievement of learning resources. [3] recommends that PBL is a learning approach used to stimulate students' higher-order thinking in situations oriented to real-world problems, including thinking how to learn. Furthermore, [8] proposed that PBL is a learning approach that uses real-world problems as a context for students to learn about critical thinking and problem-solving skills. [3] stated that math and science can achieve success by implementing PBL.

In addition, according to [3] through PBL, students are conditioned to be able to think flexibly, make conjectures, solve problems and find general rules. So that in its application, PBL requires the readiness of teachers and students to be able to collaborate in solving the problems raised. Teachers must be prepared to be supervisors as well as tutors for students who can provide motivation, encouragement and assistance in mastering problem-solving skills. The objectivity of PBL according to [4] is the ability to think and solve problems, and adult modelling which provides a rationality for how PBL helps students to perform in real-life situations and learn the importance of adult roles. In addition, [5] argues in detail the purpose of PBL is to help students develop thinking skills and problem-solving skills, learn various adult roles through their involvement in real experiences, and become autonomous students. Therefore, PBL can be used depending on the objectives to be achieved, whether related to: (a) acquisition of multidisciplinary content knowledge; (b) acquisition of heuristic disciplinary skills and processes; (c) learning problem-solving skills; (d) learning broader life skills. Consequently, the broader the objectives of PBL, the more complex the problems, and also the more important PBL steps or cyclical processes require.

3.3 Results of Previous Research on the Relationship between Problem-Based Learning Models in Improving Students' Mathematical Critical Thinking Skills

To see how the effectiveness of problem-based learning models in improving students' mathematical critical thinking skills, the author takes some relevant research results in various regions, levels and different conditions in order to obtain conclusions that are truly appropriate.

The following table presents the results of research related to problem-based learning models to improve students' mathematical critical thinking skills

Table 1. Researchs about Students' mathematical critical thinking skills.

No.	Title	Researcher	Name of Education Unit	Material	Result
1	Improving Mathematical Critical Thinking Ability of Vocational Students through Problem-Based Learning Model	Marwan And M. Ikhsan	SMKN 5 Banda Aceh (11 th grade)	Enumeration rules	It can be concluded that the improvement of mathematical critical thinking ability of students who get learning with problem-based learning model is significantly better than the mathematical critical thinking ability of students who get conventional learning when viewed from the whole and based on the level (high, medium, and low) of students' ability .
2	Mathematical Critical and Creative Thinking Ability of Junior High School Students through Problem-Based Learning	Dasa Ismailmuza	All junior high school students in Palu city, Central Sulawesi (8 th grade)		The mathematical creative thinking ability of students who follow PBLKK learning is better than students who follow KV learning [9].

- | | | | | |
|---|---|---------------|--|--|
| | with Cognitive Conflict Strategy | | | |
| 3 | A Problem-Based Learning Model to Improve Critical and Creative Thinking Skills of High School Students in Tasikmalaya City | Yoni Sunaryo | SMAN 3 Tasikmalaya (10 th grade) | Based on the results of hypothesis testing, it is concluded that the improvement of students' mathematical critical thinking skills using problem-based learning models is better than the improvement of students' mathematical critical thinking skills using direct learning [10] |
| 4 | Effectiveness of Problem Based Learning for Teaching Critical Thinking Skills of Junior High School Students | Marzuki Ahmad | SMPN 1 Padangsidempuan (7 th grade) | Fraction
The conclusion that can be drawn from the results and discussion of the research is that problem-based learning is effective for teaching fraction topics in grade VII. This is shown by: (a) Students' learn- ing complete- ness after learning |

					meets the criteria of classical completeness (b) Students' activities in learning are more effective (c) Students' positive response to learning .
	Meta Analysis of the Effectiveness of Problem Based Learning and Problem Solving Models on Critical Thinking Skills in Mathematics Subjects for Elementary School Students	Tika Evi And Endang Indriani	Elementary School in Indonesia (4 th grade)		Problem Based Learning and Problem Solving models can improve critical thinking skills, and are classified as very large in terms of influencing the mathematical critical thinking skills of elementary school students [11].
5	Application of Problem-Based Learning Model to Improve Students' Critical Thinking Ability and Mathematical Disposition	1. Husnidar 2. M. Ikhsan 3. Syamsul Rizal	SMPN 3 Peusangan Aceh (8 th grade)	Building space	The improvement of mathematical critical thinking ability of students taught with problem-based learning model on the material of building space is higher than students taught conventionally
6					

			on the same material. In the grouping of students according to rank, the increase in mathematical critical thinking ability of students taught with problem-based learning model is higher than students taught conventionally occurs in the high group and medium group only [1].
7	Improving Mathematical Critical Thinking Ability and Learning Independence of Junior High School Students through Problem-Based Learning	T. Jumaisyaroh, Napitupulu and Hasratuddin	SMP Swasta Ar-rahman Per-cut Sumatera Utara (8 th grade)
			The increase in mathematical critical thinking skills of students who were given problem-based learning was higher than those given direct learning. The increase in learning independence of students who were given problem-based learning was better than

	Development of Mathematics Learning Tools Oriented to Problem-Based Learning Model (PBM) to Improve Critical Thinking Ability of High School Students Se-Kuala Nagan Raya Aceh	Henra Saputra Tanjung And Siti Aminah Nababan	SMA in Kuala Nagan Raya Aceh	those given direct learning [12]. The average increase in students' critical thinking skills from trial I to trial II was 0.32 points with an increase in classical learning completeness of 21.4% [13].
8	The Impact Of Problem-Based Learning Approach Tosenior High School Students' Mathematics Critical Thinking Ability	Reviandari Widyatiningtyas, Yaya S. Kusumah, Utari Sumarmo and Jozua Sabandar	All students in high school (SMA) from two schools in Kotamadya Bandung	Students who follow the problem-based learning approach has better mathematics critical thinking ability than student who take conventional learning. Problem-based learning should be developed in the field and can be used as an alternative option for the implementation of

				learning mathematics and making the suggested teaching materials in form of more challenging for students and in order to exist trigger for cognitive conflict (14).
The Effect of Problem Based Learning Model on Student Mathematics Learning Outcomes Viewed from Critical Thinking Skills	1. Heri Mulyanto 2. Gunarhadi 3. Mintasih Indriayu	Private primary school students in five sub-districts of Surakarta city	The nature of congruence and symmetry	Concluded as follows (1) There are significant differences in mathematics learning outcomes between students who following Problem Based Learning model with conventional model of fifth grade students of the private primary school in Surakarta Region Year 2016/2017. Students who following Problem Based Learning model get higher learning outcomes than students

who following conventional model

(2) There is a significant difference in mathematics learning outcomes between students who have high and low critical thinking skills of fifth grade students of the private primary school in Surakarta Region Year 2016/2017. Students who have high critical thinking skills achieve higher learning outcomes than students with low critical thinking skills.

(3) There is no interaction effect between learning model and critical thinking skills on mathematics learning outcomes of fifth grade students of the

11	The Implementation of Mathematical Problem-Based Learning Model as an Effort to Understand the High School Students' Mathematical Thinking Ability	1. Sriyanti Mustafa 2. Vernita Sari 3. Baharullah	High school students in Parepare	The trigonometric problem	private primary school in Surakarta Region Year 2016/2017. There is no difference in mathematics learning outcomes in both learning models in students with high or low critical thinking skills [15] The mathematical problem-based learning model can help to understand the high school students' mathematical thinking ability. Each phase of the learning model has an impact on students' ability to uncover students' ideas towards mathematical problems, so they can illustrate the thinking process of the students. Phase consists of Orientation
----	--	---	----------------------------------	---------------------------	---

Development of Problem-Based Learning Device to Grow Students' Mathematical Critical Thinking Ability	1. Muhamad Julianto 2. Elfis Suanto 3. Syarifah Nur Siregar	SMP IT Aufia Global Islamic Boarding School (9 th grade)	Opportunities	Phase, Organizing Phase, Mentoring Phase, Developing Phase, and Analysis Phase [16].
				The validation results from three validators show that the syllabus, lesson plans, and student worksheets are very valid, with the average score in a row 3.82, 3.74, and 3.55. Student worksheets practicality shows an average percentage of 92,06% with efficient criteria. The results of this study indicate that the learning) based on Model Problem Based Learning (PBL) on the probability material is very valid and very to grow stu-

dents' mathe-
matical criti-
cal thinking
skills [17]

From the table 1, we can know that at the elementary school level there are other learning models with higher effectiveness than problem-based learning in improving students' mathematical critical thinking skills. However, this problem-based learning model is still effective in improving students' mathematical critical thinking skills. At the Junior High School and Senior High School levels, this learning model is still more effective than other learning models in improving students' mathematical critical thinking skills.

Critical thinking in mathematics is improved because of the problem-based learning (PBL) model which provides opportunities for students to face real problems and find solutions independently [18]-[20] (. In the problem-based learning model, there is a problem-solving process that encourages students to identify and formulate appropriate solutions, which in turn improves their critical thinking skills [20]-[22]. Problem solving in problem based learning not only involves understanding mathematical concepts, but also requires students to think critically in evaluating various alternative solutions [23]-[24]. Students who engage in problem-based learning will be more accustomed to facing complex mathematical challenges, so their critical thinking skills will continue to develop along with the problem solving process [25]-[26]. By applying the problem-based learning model, students not only learn how to solve maths problems, but are also trained to think critically in developing effective and efficient problem-solving strategies [27]-[28]

4 Conclusion

Mathematical critical thinking is the ability to think using mathematical logic flow with cognitive strategies to generalize, prove, or evaluate unfamiliar mathematical situations effectively. In order to improve this ability, an appropriate learning model is needed, one of which is a problem-based learning model which focuses on learning to challenge students to solve problems cooperatively and systematically by dividing students in each small group so as to optimize the student's thinking process in a sustainable manner. By looking at some of the research that has been done we can conclude that the problem-based learning model is effective in improving students' mathematical critical thinking skills both at the elementary, middle and high school levels, which is like the results of existing research on several materials such as enumeration rules, fractions, building space, The nature of congruence and symmetry, The trigonometric problem, and opportunities. Thus in general it can be concluded that this model is effective for improving mathematical critical thinking skills.

Acknowledgments. This research article is funded by the Institute for Research and Community Service, Universitas Alma Ata

References

1. Didaktik, J., Husnidar, M., Kemampuan, M., Kritis, B., Matematis, D., Husnidar, S., et al.: Penerapan Model Pembelajaran Berbasis Masalah.
2. Marwan: Meningkatkan Kemampuan Berpikir Kritis Matematis Siswa SMK melalui Model Pembelajaran Berbasis Masalah. *Didaktik Matematika* 3, 9–18 (2016).
3. Widyatiningsy, R., Kusumah, Y.S., Sumarmo, U., Sabandar, J.: The Impact of Problem-Based Learning Approach to Senior High School Students' Mathematics Critical Thinking Ability.
4. Ahmad, M.: Efektivitas Penerapan Pembelajaran Berdasarkan Masalah untuk Membelajarkan Kemampuan Berpikir Kritis Matematika Siswa SMP. *Jurnal Education and Development STKIP Tapanuli Selatan* 6(4), 34–40 (2017).
5. Kurniawati, D., Ekayanti, A.: Pentingnya Berpikir Kritis Dalam Pembelajaran Matematika. *Jurnal Penelitian Tindakan Kelas dan Pengembangan Pembelajaran* 3(2), 112 (2020).
6. Abdullah, I.H.: *Delta-Pi: Jurnal Matematika dan Pendidikan Matematika*, (2013).
7. Kritis, K.B., Matematis, K., SMP, S., Pembelajaran, M., Masalah, B., Konflik, S., et al.: *Jurnal Teknologi*, (2013). Available from: www.jurnalteknologi.utm.my.
8. Annet, N., Naranjo, J.: Title. *Appl Microbiol Biotechnol* 85(1), 2071–2079 (2014).
9. Ismailmuza, D.: Kemampuan berpikir kritis dan kreatif matematis siswa SMP melalui pembelajaran berbasis masalah dengan strategi konflik kognitif. *Sains Humanika* 63(2), (2013).
10. Sunaryo, Y.: Model pembelajaran berbasis masalah untuk meningkatkan kemampuan berpikir kritis dan kreatif matematik siswa SMA di Kota Tasikmalaya. *Jurnal Pendidikan dan Keguruan* 1(2), 209679 (2014).
11. Evi, T., Indarini, E.: Meta analisis efektivitas model Problem-Based Learning dan Problem Solving terhadap kemampuan berpikir kritis mata pelajaran matematika siswa sekolah dasar. *Edukatif: Jurnal Ilmu Pendidikan* 3(2), 385–395 (2021).
12. Jumaisyaroh, T., Napitupulu, E.E., Hasratuddin, H.: Peningkatan kemampuan berpikir kritis matematis dan kemandirian belajar siswa SMP melalui pembelajaran berbasis masalah. *Kreano: Jurnal Matematika Kreatif-Inovatif* 5(2), 157–169 (2015).
13. Tanjung, Nababan, S.A.: Pengembangan Perangkat Pembelajaran Matematika Berorientasi Model Pembelajaran Berbasis Masalah (PBM) untuk Meningkatkan Kemampuan Berpikir Kritis Siswa SMA Se-Kuala Nagan Raya Aceh. *Genta Mulia* 9(2), 56–70 (2018).
14. Widyatiningsy, R., Kusumah, Y.S., Sumarmo, U., Sabandar, J.: The impact of Problem-Based Learning approach to senior high school students' mathematics critical thinking ability. *Indonesian Mathematical Society Journal on Mathematics Education* 6(2), 30–38 (2015)..
15. Mulyanto, H., Gunarhadi, G., Indriayu, M.: The effect of Problem-Based Learning model on student mathematics learning outcomes viewed from critical thinking skills. *International Journal of Educational Research Review* 3(2), 37–45 (2018).
16. Mustafa, S., & Sari, V. (2019). The Implementation of Mathematical Problem-Based Learning Model as an Effort to Understand the High School Students' Mathematical Thinking Ability. *International Education Studies*, 12(2), 117-123.
17. Julfianto, M., Suanto, E., Siregar, S.N.: Developing Problem-Based Learning device to grow students' mathematical critical thinking ability. *Jurnal Gantang* 7(2), 173–184 (2022).

18. Ahdhianto, E., Marsigit, H., Nurfauzi, Y.: Improving fifth-grade students' mathematical problem-solving and critical thinking skills using Problem-Based Learning. *Universal Journal of Educational Research* 8(5), 2012–2021 (2020).
19. Wardana, A., Sukestiyarno, Y.L., Suyitno, A.: Analysis of high school students' critical thinking ability in solving mathematical problems with Independence Problem-Based Learning (IPBL) model: A case study on middle class students. *Educational Administration: Theory and Practice* 30(4), 7137–7147 (2024).
20. Masruro, S., Sudibyo, E., Purnomo, T.: Profile of Problem-Based Learning to improve students' critical thinking skills. *IJORER: International Journal of Recent Educational Research* 2(6), 682–699 (2021).
21. Magaji, A.: Promoting problem-solving skills among secondary science students through Problem-Based Learning. *International Journal of Instruction* 14(4), 549–566 (2021).
22. Shanta, S., Wells, J.G.: T/E design based learning: Assessing student critical thinking and problem solving abilities. *International Journal of Technology and Design Education* 32(1), 267–285 (2022).
23. Benedicto, P.N., Andrade, R.: Problem-based learning strategies and critical thinking skills among pre-service teachers. *International Journal of Science, Technology, Engineering and Mathematics* 2(2), (2022).
24. Nilimaa, J.: New examination approach for real-world creativity and problem-solving skills in mathematics. *Trends in Higher Education* 2(3), 477–495 (2023).
25. Purba, U.A., Azis, Z.: The effectiveness of Problem-Based Learning model on the ability to solve mathematical problems in terms of students' analytical thinking ability. *JMEA: Journal of Mathematics Education and Application* 1(2), 73–80 (2022).
26. Wahyudi, A., Ariyani, Y.D., Putri, H.E.: Analisis perbedaan gaya berpikir mahasiswa menggunakan Yan-Piaw Critical-Creative Thinking Style Test. *Metodik Didaktik: Jurnal Pendidikan Ke-SD-an* 18(2), 47–53 (2023).
27. Choir, R.M., Abdullah, A.A.: Pengaruh penggunaan media pembelajaran interaktif berbasis Android dengan pendekatan matematik realistik terhadap hasil belajar matematika siswa kelas VII MTS Assalafiyah Mlangi. *Literasi: Jurnal Ilmu Pendidikan* 12(2), 85–91 (2021).
- Richardo, R., Martyanti, A., Suhartini, S.: Analisis kebutuhan pengembangan Subject Specific Pedagogy Etnomatematika untuk meningkatkan kemampuan berpikir kritis. *Journal of Mathematics and Mathematics Education* 8(2), 138–144 (2018)

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

