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Effectiveness of Problem-Based Learning to Improve Critical Thinking Ability of Chemistry Students on Acid-Base Material

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Abstract: This study aims to determine the improvement of critical thinking skills of chemistry students through a problem-based learning (PBL) learning model on acid-base titration material. The method used is analytical descriptive research based on categorizing critical thinking skills with the research subject of chemistry education students in a regular class in 2022, consisting of 35 students. Data collection of critical thinking skills using essay tests reveals critical thinking skills in interpretation, analysis, inference, deduction, and evaluation. Research data were obtained from pretest and post-test results. The results showed the lowest N-gain value on the interpretation indicator and the highest on the deduction indicator, with an average N-gain value of 0.59 in the moderate category. This shows increased critical thinking skills after being treated using the PBL learning model.

Keywords: Acid base; Critical thinking skill; Problem-based learning

Introduction

One of the demands of today's modern society is to be able to think critically to face global challenges. To prepare superior and highly competitive human resources, education must equip them with the qualifications needed in the 21st century. Developments have changed the paradigm that demands an increase in the quality of education. Higher education, as one of the educational institutions, plays a vital role in producing competent graduates based on the demands of 21st-century competencies, namely 4C competencies (Taufiqurrahman, 2023). 4C competencies include creativity, critical thinking, communication, and collaboration, which are relevant to current developments. 4C competencies will make individuals able to compete in the future technological era (Partono et al., 2021).

Critical thinking skills are one of the competencies needed by today's millennial generation. Rapidly developing technology provides easy internet access to information from various sources. Strong critical thinking skills will help individuals evaluate the information obtained (P. A. P. Devi et al., 2023). In addition, critical thinking skills will help individuals become independent learners who are prepared to face changes that occur in society (Prayogi et al., 2022; Rahayu et al., 2020; Rimiene, 2002). Oktariani et al. (2020) also expressed the same thing, stating that critical thinking skills in chemistry align with the importance of critical thinking skills in global understanding of information.

Efforts to develop critical thinking skills are essential in achieving holistic educational goals because these skills focus not only on acquiring knowledge but also on the importance of thinking effectively (Rimiene, 2002). However, the facts in the field show that the critical thinking skills of students in Indonesia are still relatively low. This condition can be caused by many factors, including using learning models that do not actively involve students. The emphasis on memorization rather than investigation contributes to

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Indonesian students' lack of critical thinking skills (Hamdani et al., 2022). Criticism of the education system in Indonesia, which prioritizes the acquisition of knowledge rather than its application in life, so that educators focus more on how students can master concepts rather than on efforts to develop critical thinking skills (Putri et al., 2021; Salsabilla et al., 2022).

Several studies in Indonesia show that students' critical thinking skills in chemistry material still need to be higher. Manik et al. (2020) concluded that students' critical thinking skills in solving two-tier problems were still at the inference level. Lusi et al. (2023) concluded that students' critical thinking skills with an average of 37.92 were included in the low criteria, especially in the ability to make assumptions. Students' low critical thinking skills can be improved by applying a learner-centered learning model that will provide meaningful learning experiences that will encourage the development of critical thinking skills (Dharmawati et al., 2018).

Critical thinking skills allow students to evaluate and reflect on facts and data; critical thinking is not just a tool for solving academic problems (Huber et al., 2016). The same thing was expressed by van Brederode et al. (2020), who stated that critical thinking skills are a deep understanding of information that helps students become independent and responsible learners. In addition, it helps prepare students to face changes that occur in society. Facts on the ground show that students' critical thinking skills in Indonesia are still relatively low. Many factors cause this condition to occur. Teaching methods that do not actively involve students in the learning process, emphasizing memorization rather than investigation, have been identified as factors contributing to the lack of critical thinking skills among Indonesian students (Solihati et al., 2018). In addition, direct teaching strategies, which place teachers as the main focus in the classroom, have hampered the development of critical thinking skills among students (Fajari, 2021). Other factors, such as students' self-efficacy, interest in learning, and the ability to express ideas that are lacking, influence their critical thinking skills (Hyytinen et al., 2018). Several studies in Indonesia have shown low critical thinking skills in chemistry subjects (Purwanto et al., 2022).

Problem-Based Learning (PBL) is a learning model or constructivist strategy that involves a real-life problem as a learning activator. This strategy provides opportunities for students to learn to understand problems, design solutions, carry out problem-solving, and improve problem-solving (Olaniyan et al., 2018). According to research conducted by Pohan et al. (2022), the critical thinking ability of engineering students of the Civil Engineering Study Program, Faculty of Engineering UGN Padangsidimpuan, increased by 30% after applying the problem-based learning model. Liu et al. (2022) concluded that applying the problem-based learning model effectively improves critical thinking skills.

Chemical materials can be found in daily activities/problems. Therefore, it is necessary to improve students' critical thinking skills. Acid-base is an important material to understand thoroughly because it is the basis for understanding related materials such as salt hydrolysis, buffer solution, and solubility products (Voska et al., 2000). However, most students still need help understanding the concept of acid-base, which is thought to be related to the characteristics of the material, which is generally a defined concept. Defined concepts are ideas derived from abstract objects or events (Ertmer et al., 2014; Fajarianingtyas et al., 2018). Optimal efforts are needed in the learning process to provide a complete understanding. One of them is the implementation of innovative learning models. Implementing the PBL model is expected to improve students' critical thinking skills. This research will identify and analyze the effectiveness of Problem-Based Learning in improving the critical thinking skills of chemistry students.

Gagne (1970) and Priansa (2010) state that problem-based learning can be viewed as finding a combination of formulas/rules/concepts that have been learned and then applied so that students can find ways to solve problems in new situations and conditions. Devi et al. (2020) added that Problem-Based Learning (PBL) is a learning model that focuses on solving real problems through the stages of the scientific method so that students will gain knowledge and skills in solving problems. Another reference states that PBL is a learning model that uses problems as a learning context so that students learn to think critically, have the skills to solve problems, and gain essential knowledge and concepts from the material being taught. Arends (2009) argues that Problem-Based Learning (PBL) is a learning process that focuses on authentic problems so that students can compile knowledge, develop inquiry and higher-order thinking skills, and have independence and confidence. Through PBL Learning, learners will construct knowledge through structured real-world problem-solving efforts. Learning will lead learners to conduct investigations to solve problems actively. The learning process will shape higher-order thinking skills and improve students' ability to think critically.

According to Arends (2009), the steps or syntax in the PBL learning model can be seen in Table 1. Applying the PBL model in learning can develop higher critical thinking skills for students. Susanti et al. (2017) stated that PBL learning is learning that can develop critical thinking skills through asking and answering questions and analyzing and solving problems individually or in

groups. Critical thinking is one of the most essential skills, and the Next Generation Science Standard (NGSS) emphasizes that students must possess critical thinking and communication skills for their future. Critical thinking includes cognitive processes that involve analyzing and evaluating information and ideas in a systematic and disciplined manner. It includes the ability to engage in reflective and independent thinking and make sound judgments and decisions based on evidence and sound reasoning. Critical thinking involves open-mindedness, considering alternative perspectives, and a willingness to revise one's own beliefs and opinions, considering new information (Ghanizadeh et al., 2012).

Table 1. Syntax of PBL Model

Phase	Educator Activity
Stage 1: Orient learners to the problem	Discuss learning objectives and describe and motivate students to engage in problem-solving activities.
Stage 2: Organizing students in learning	Help learners define and organize learning tasks related to the problem
Stage 3: Assist individual and group investigations	Encourage learners to gather appropriate information, conduct experiments, and seek explanations and solutions.
Stage 4: Develop and present work	Assist learners in planning and preparing appropriate outcomes such as reports, video recordings, and models and help communicate with others.
Stage 5: Analyze and evaluate the problem-solving process.	Helping learners *to* reflect on their investigations and the processes they used

The American Philosophical Association outlines six essential skills in critical thinking, including interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 1990). These skills form the basis for further development, as the proposed skill categories are predominantly: (a) focusing on the problem; analyzing arguments; asking questions and answering; clarifying and challenging questions; assessing the credibility of sources; and observing and assessing assumptions (Ennis, 1985); (b) verifying hypotheses; providing verbal reasoning; identifying uncertainty and making decisions; and offering solutions to problems and creativity (Halpern, 1998); (c) utilizing creative thinking and critical thinking; practicing decision making; and solving every day and mathematical problems (Perkins et al., 1993). These skills are identified as essential elements of critical thinking. Critical thinking involves thinking seriously, actively, and accurately in analyzing any information received with rational reasoning (Liberna, 2015). Critical thinking is used in assessing information and explaining the reasons for solving problems (Thomas, 2011). Critical thinking is essential in determining decisions and overcoming problems during learning and everyday life (Snyder et al., 2008). Critical thinking is necessary to overcome the problems faced in life.

The indicators of critical thinking skills by several experts are described in Table 2.

Table 2. Critical Thinking Indicators

Ennis (1985)	Krulik et al. (1995)	Facione (1990)	Synthesis Result
Providing simple explanations	Identifying and interpreting information	Interpretation: clarifying meaning through categorization and translation.	Interpretation
Building basic skills	Analyzing information	Analysis: Identifying and examining ideas, arguments, or procedures	Analysis
Summarizing	Evaluating evidence and arguments	Self-regulation: Self-assessment and reflection	Inference
Providing advanced explanations			Deduction
Organizing strategies and techniques			Evaluation

Method

The method used in this research is descriptive-analytic research based on categorizing critical thinking skills. The categorization refers to the N-gain score, according to Meltzer (2018). The categories of critical skills include interpretation, analysis, inference, deduction, and evaluation. Calculation of normalized average gain score data (N-gain) using the equation 1.

$$g = \frac{Score_{posttest} - Score_{pretest}}{Score_{ideal} - Score_{pretest}} \quad (1)$$

The average N-gain score obtained is then interpreted based on Table 3.

Table 3. N-gain Score Categories

N – Gain Score	Category
g> 0.7	High
0.3 < g < 0.7	Medium
G < 0.3	Low

The instrument used is a structured essay test of 6 items on acid-base titration. This instrument reveals critical thinking skills in the interpretation aspect of 2 items and the aspects of analysis, inference, deduction, and evaluation of 1 item each. The validity of the content of the question is proven by presenting it to a chemist. In line with Gregory's (2007) statement, checking content validity can be done by asking experts in their fields to assess the items that have been made.

Result and Discussion

The scores obtained based on the respective question indicators show increased critical thinking skills for each indicator. The following is the n-gain value of the increase in critical thinking skills indicators, which can be seen in Figure 1.

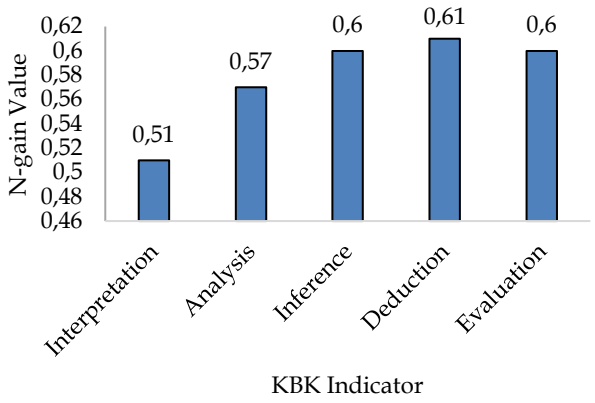

Figure 1. N-gain results for each critical thinking indicator

Figure 1. shows that the lowest N-gain value is on the interpretation indicator and the highest on deduction ability. This shows that students already have the initial ability to identify the information provided but still need to improve in solving problems.

Table 4. N-gain Score

Indicators of critical thinking skills	N-Gain	Category
Interpretation	0.51	Medium
Analysis	0.57	Medium
Inference	0.60	Medium
Deduction	0.61	Medium
Evaluation	0.60	Medium
Average	0.58	Medium

On average, there was an increase in N-gain on all indicators of 0.59 in the medium category, indicating an increase in critical thinking skills after being given treatment using the PBL learning model. This is in line with other research that students' critical thinking skills have increased after learning activities using PBL-based e-modules by 51.41% (Sulhan et al., 2023). Problem-based learning can improve critical thinking skills (Adhelacahya et al., 2023). With the application of problem-based learning, critical thinking skills can develop. Based on this, learning activities using problem-based learning models can be a good enough solution to improve students' critical thinking skills.

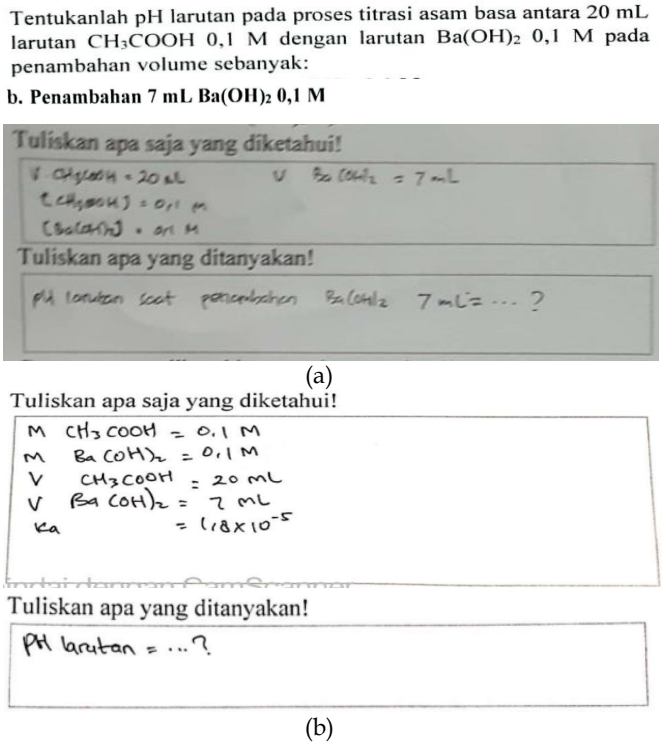

Figure 2. Documentation of student answers on interpretation indicators. a) Correct answer; b) Wrong answer

The interpretation indicator is the first thing that students need to do. In interpretation, students identify information in the form of what data is known from a problem and the problem to solve. The learning process with PBL trains students to make initial identification at the orientation stage. Students are trained to interpret the data in a problem statement at this stage. Based on the results of student work, generally, students have been able to interpret the data well, as in Figure 2a. Some students still need to write about the pH condition of the solution, namely before or after adding the reagent. In addition, some have written the value of the weak acid/base equilibrium constant (Ka/Kb), which needs to be mentioned in the problem, like Figure 2b.

For analysis indicators, students must know what data is needed to solve the problem. Organizing students to learn in PBL trains students to further analyze the data needed for problem-solving. In solving problems related to acid-base material, students need to analyze whether acids and bases are classified as weak or strong acids and bases have reacted or not. Based on the results of the analysis, students will know what

things are needed to solve the problem. Based on student answers, some students have yet to be able to write formulas or stages in solving problems like Figure 3a. Some directly collate, and the number of moles that react and remain like in Figure 3b.

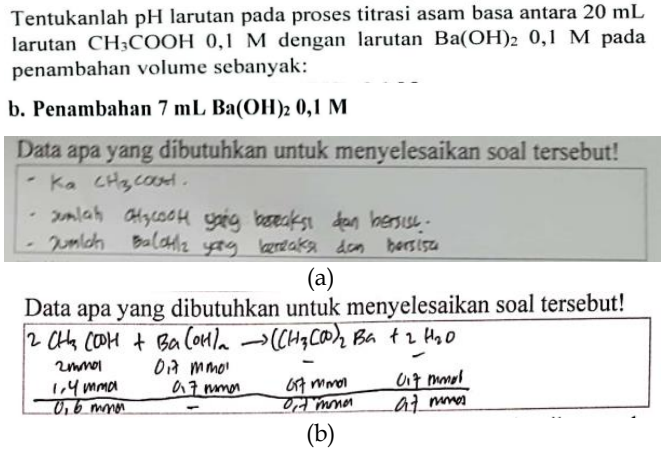

Figure 3. Documentation of student answers on analysis indicators. a) Correct answer; b) Wrong answer

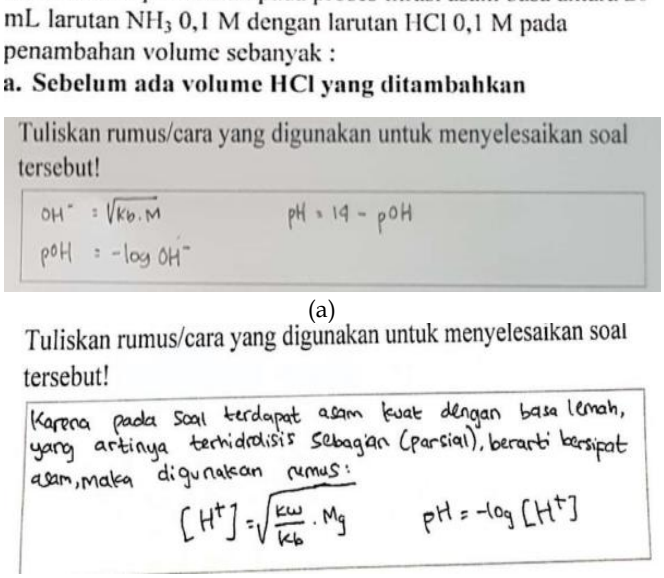

Figure 4. Documentation of student answers on inference indicators. a) Correct answer; b) Wrong answer

Indicators of inference: Students then determine the formula, method, and stages that must be taken to solve the problem. The guiding inquiry stage in PBL helps students to conclude the formula, method, and stages of problem-solving according to the analysis that has been done before. Students are guided to gather appropriate information by conducting further literature studies at this stage before finally determining the appropriate formula, method, and stage. There are several criteria in solving acid-base titration, including the formula for determining the pH of acids/bases (strong and weak) if they have not reacted, the formula for acid/base hydrolysis if what remains from the reaction is salt, and the acid/base buffer formula if what remains is weak acid/base and its conjugates. So that students can choose the right formula according to the reaction conditions. Based on students' answers, some students have been able to write the formula correctly, like in Figure 4a, and some still need to be correct. Some students still write the hydrolysis formula when NH3 and HCl have yet to react, like in Figure 4b.

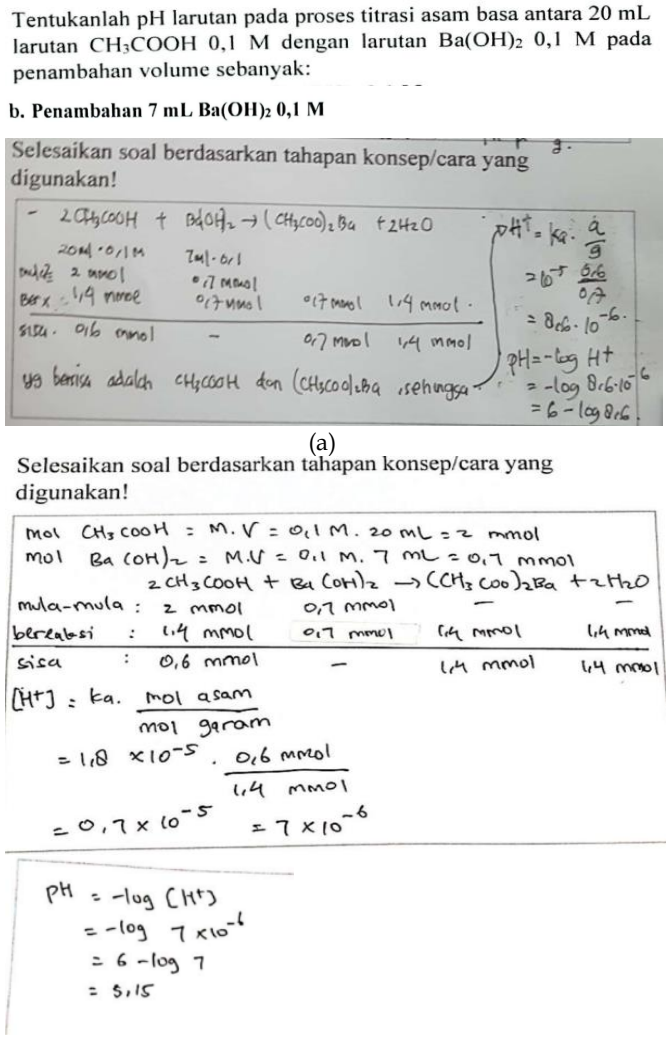

Figure 5. Documentation of student answers on deduction indicators. a) Correct answer; b) Wrong answer

Indicators of deduction: Students solve problems based on formulas, methods, and stages selected at the inference stage. The stage of developing and presenting work in PBL trains students to present the results of solving a problem in a structured manner. Some students used the right formula in their answers like figure 5a, but the solution process needed to be corrected. Students need clarification about the amount

of salt produced by 1.4 mmol, which should only be 0.7 mol because it has a coefficient of 1 in Figure 5b.

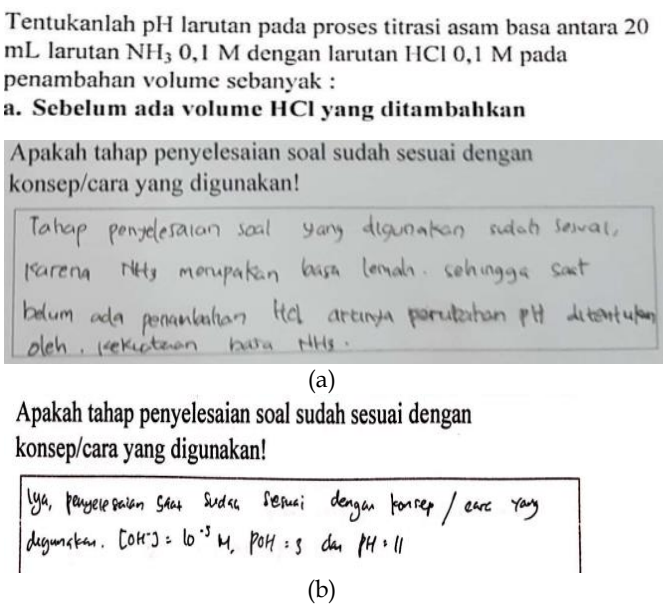

Figure 6. Documentation of student answers on evaluation indicators. a) Correct answer; b) Wrong answer

Evaluation indicators: Students then evaluate whether the stages chosen to solve the problem are appropriate. The analyzing and evaluating stage in PBL trains students to assess the work steps they have set. After going through the presentation stage, if the stage chosen is correct, it will be given reinforcement, but if it is not appropriate, it will be given correction. Based on this, students can then conclude that solving a problem. In the answers, students generally only write the conclusion yes and the pH results obtained, like Figure 6b, but need to express the logical reasons for the results obtained, the formula, and whether the solution used is correct, like Figure 6a.

The effectiveness of applying the PBL model can be proven through documentation of student work in solving problems based on critical thinking indicators. The stages of problem-solving show students' ability to identify and analyze information, select logical arguments, evaluate arguments, and make conclusions. Documentation of student work shows students' ability to organize and communicate their ideas clearly and structured.

The results that have been obtained prove the effectiveness of the PBL model in improving students' critical thinking skills. Learning using the PBL model will lead to increased curiosity and motivation so that it can be a medium for developing critical thinking (Kusumawati et al., 2020). One of the advantages of the PBL learning model is that it can train students to use various concepts, principles, and skills that they have learned to solve the problems at hand.

In addition, PBL has been shown to have a high level of influence (Standardized Mean Difference [SMD] = 0.640, $p < 0.001$) on critical thinking ability with heterogeneity ($I2 = 82.9\%$) (Liu et al., 2022). In another study, PBL improved nursing students' critical thinking (overall critical thinking score SMD = 0.33, 95% CI = 0.13-0.52, P = 0.0009) compared to traditional lectures (Kong et al., 2014). The integration of PBL in learning can be a systematic effort to increase the potential of adult critical thinking skills to be applied in the world of work (Santos-Meneses et al., 2023).

Conclusion

The results showed that the PBL learning model can improve critical thinking skills based on the N-gain value obtained on each critical thinking indicator, with the lowest N-gain value on the interpretation indicator and the highest N-gain value on deduction ability. The average N-gain value on all indicators is in the medium category. The findings of this study add knowledge and information about the effectiveness of PBL learning models in improving critical thinking skills. Critical thinking is one of the abilities in the 4Cs that students need to have to face the 5.0 era.

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Author Contributions
J. J. and S. S., conceptualized the research idea, methodological, design, data analysis, funding acquisition, writing-original draft, software, management and coordination for the research activity planning and execution. Z. S., M. M., and K. S. guided, directed, helped the process of processing and analyzing data, provided ideas and suggestions in writing research, wrote-reviewed and edited.

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Conflicts of Interest
The author declares no conflict of interest.

References

Adhelacahya, K., Sukarmin, S., & Sarwanto, S. (2023). Impact of Problem-Based Learning Electronics Module Integrated with STEM on Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 4869–4878. https://doi.org/10.29303/jppipa.v9i7.3931

Arends, R. (2009). *Learning to teach*. New York: McGraw-Hill.

Devi, P. A. P., Wulan, T. S., & Sampoerno, M. R. (2023). Peningkatan Kompetensi Creative, Communication, Colaboration Dan Critical Thinking (4C) Generasi Milenial. *AMMA: Jurnal Pengabdian Masyarakat*, *2*(9), 1094–1098. Retrieved from https://journal.mediapublikasi.id/index.php/amma/article/view/3657

Devi, P. S., & Bayu, G. W. (2020). Berpikir kritis dan hasil belajar IPA melalui pembelajaran problem based learning berbantuan media visual. *Mimbar PGSD Undiksha*, *8*(2), 238–252. Retrieved from https://ejournal.undiksha.ac.id/index.php/JJPGSD/article/view/26525

Dharmawati, I., Prayogi, S., & Hidayat, S. (2018). Pengaruh Model Pembelajaran Aktif Berbasis Inkuiri (ABI) Terhadap Kemampuan Berpikir Kritis Siswa. *Lensa: Jurnal Kependidikan Fisika*, *6*(1), 8. https://doi.org/10.33394/j-lkf.v6i1.930

Ennis, R. H. (1985). Educational leadership. *A Logical Basis for Measuring Critical Thinking Skills*, *43*(2), 44–48. Retrieved from https://jgregorymcverry.com/readings/ennis1985assessingcriticalthinking.pdf

Ertmer, P. A., Driscoll, M. P., & Wager, W. W. (2014). The Legacy of Robert Mills Gagné. In *Educational Psychology: A Century of Contributions: A project of Division 15 (Educational Psychology) of the American Psychological Association* (pp. 303–330). Lawrence Erlbaum Associates, Inc. https://doi.org/10.4324/9781315734255-15

Facione, P. A. (1990). Critical Thinking : A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction Executive Summary " The Delphi Report. *The California Academic Press*, *423*, 1–19. Retrieved from http://www.insightassessment.com/pdf_files/DEXadobe.PDF

Fajari, L. E. W. (2021). Critical Thinking Skills and Their Impacts On Elementary School Students. *Malaysian Journal of Learning and Instruction*, *18*. https://doi.org/10.32890/mjli2021.18.2.6

Fajarianingtyas, D. A., Herowati, H., & Yuniastri, R. (2018). Gaya Belajar Dan Miskonsepsi Siswa Pada Konsep Redoks Di SMA Negeri I Sumenep. *LENSA (Lentera Sains): Jurnal Pendidikan IPA*, *7*(1), 1–19. https://doi.org/10.24929/lensa.v7i1.21

Gagne, R. M. (1970). Learning Theory, Educational Media, and Individualized Instruction. *1970*, 1–23. Retrieved from https://eric.ed.gov/?id=ED039752

Ghanizadeh, A., & Mizaee, S. (2012). EFL Learners' Self-regulation, Critical Thinking and Language Achievement. *International Journal of Linguistics*, *4*(3), 451–468. https://doi.org/10.5296/ijl.v4i3.1979

Gregory, R. J. (2007). *Psychological testing: history, principles, and applications* (5th ed.). New York: Pearson Education Group, In.

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. *American Psychologist*, *53*(4), 449–455. https://doi.org/10.1037/0003-066X.53.4.449

Hamdani, M., Mulyono, A., & Habiburrahman, L. (2022). Keefektifan Kemampuan Berpikir Kritis Terhadap Hasil Belajar Kognitif Siswa. *Jurnal Ilmiah Mandala Education*, *8*(3). https://doi.org/10.58258/jime.v8i3.3720

Huber, C. R., & Kuncel, N. R. (2016). Does College Teach Critical Thinking? A Meta-Analysis. *Review of Educational Research*, *86*(2), 431–468. https://doi.org/10.3102/0034654315605917

Hyytinen, H., Toom, A., & Postareff, L. (2018). Unraveling the complex relationship in critical thinking, approaches to learning and self-efficacy beliefs among first-year educational science students. *Learning and Individual Differences*, *67*, 132–142. https://doi.org/10.1016/j.lindif.2018.08.004

Kong, L.-N., Qin, B., Zhou, Y., Mou, S., & Gao, H.-M. (2014). The effectiveness of problem-based learning on development of nursing students' critical thinking: A systematic review and meta-analysis. *International Journal of Nursing Studies*, *51*(3), 458–469. https://doi.org/10.1016/j.ijnurstu.2013.06.009

Krulik, S., & Rudnick, J. A. (1995). *The New Sourcebook for Teaching Reasoning and Problem Solving in Elementary School: A Longwood Professional Book*. Allyn & Bacon.

Kusumawati, R., & Kurniawan, P. (2020). Development of Algebraic Structure Teaching Materials with Guided Discovery to Improve Abstraction and Writing Mathematical Proof Skills. *Journal of Medicine : Journal of Mathematics Education IKIP Veteran Semarang*, *4*(1), 197–204. https://doi.org/10.31331/medicivesveteran.v4i1.1010

Liberna, H. (2015). Peningkatan Kemampuan Berpikir Kritis Matematis Siswa Melalui Penggunaan Metode Improve pada Materi Sistem Persamaan Linear Dua Variabel. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, *2*(23), 190–197. Retrieved from https://rb.gy/rr4iw1

Liu, Y., & Pásztor, A. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis.

Thinking Skills and Creativity, *45*(May), 101069. https://doi.org/10.1016/j.tsc.2022.101069

Lusi, Y., Sahputra, R., Rasmawan, R., Sartika, R. P., & Ulfah, M. (2023). Profil Kemampuan Berpikir Kritis Mahasiswa Pendidikan Kimia dalam Menyelesaikan Permasalahan Kontekstual pada Materi Termokimia. *Jurnal Pendidikan Dan Pembelajaran (JPPK)*, *12*(3), 876–885. https://doi.org/10.26418/jppk.v12i3.63598

Manik, A. C., Suryaningsih, S., & Muslim, B. (2020). Analisis Berpikir Kritis Kimia dalam Menyelesaikan Soal Two-Tier Berdasarkan Level Kemampuan Mahasiswa. *Jambura Journal of Educational Chemistry*, *2*(1), 28–39. https://doi.org/10.34312/jjec.v2i1.2999

Meltzer, L. (2018). *Executive function in education: From theory to practice*. Guilford Publications.

Oktariani, O., Febliza, A., & Fauziah, N. (2020). Keterampilan Berpikir Kritis Calon Guru Kimia sebagai Kesiapan Menghadapi Revolusi Industri 4.0. *Journal of Natural Science and Integration*, *3*(2), 114. https://doi.org/10.24014/jnsi.v3i2.8791

Olaniyan, A. O., & Govender, N. (2018). Effectiveness of polya problem-solving and target-task collaborative learning approaches in electricity amongst high school physics students. *Journal of Baltic Science Education*, *17*(5), 765–777. https://doi.org/10.33225/jbse/18.17.765

Partono, P., Wardhani, H. N., Setyowati, N. I., Tsalitsa, A., & Putri, S. N. (2021). Strategi Meningkatkan Kompetensi 4C (Critical Thinking, Creativity, Communication, & Collaborative). *Jurnal Penelitian Ilmu Pendidikan*, *14*(1), 41–52. https://doi.org/10.21831/jpipfip.v14i1.35810

Perkins, D. N., Jay, E., & Tishman, S. (1993). Beyond Abilities: A Dispositional Theory of Thinking. *Merrill-Palmer Quarterly*, *39*(1), 1–21. Retrieved from http://www.jstor.org/stable/23087298

Pohan, R. F., & Rambe, M. R. (2022). Penerapan Model Pembelajaran Problem Based Learning (PBL) dalam Kimia Teknik untuk Meningkatkan Kemampuan Berpikir Kritis Mahasiswa Prodi Teknik Sipil Fakultas Teknik UGN Padangsidimpuan Tahun Akademik 2020/2021. *JagoMIPA: Jurnal Pendidikan Matematika Dan IPA*, *2*(1), 14–25. https://doi.org/10.53299/jagomipa.v2i1.138

Prayogi, S., & Verawati, N. N. S. P. (2022). Science and Technology Transmission for Society: Training on Development of Learning Tools for Teachers to Train Students' Critical Thinking Skills. *Lumbung Inovasi: Jurnal Pengabdian Kepada Masyarakat*, *7*(1), 65–71. https://doi.org/10.36312/linov.v7i1.689

Priansah, D. J. (2010). *Menumbuhkan jiwa Entrepreneur Dalam Diri Siswa*. Bandung: PT Setia Purna Inves.

Purwanto, A., Rahmawati, Y., Rahmayanti, N., Mardiah, A., & Amalia, R. (2022). Socio-critical and problem-oriented approach in environmental issues for students' critical thinking skills development in Chemistry learning. *Journal of Technology and Science Education*, *12*(1), 50. https://doi.org/10.3926/jotse.1341

Putri, F. A. E., Syaiful, S., & Siburian, J. (2021). Kemampuan Berpikir Kritis Siswa pada Pembelajaran Online Inquiry dan Problem Based Learning Ditinjau dari Kemampuan Awal. *Jurnal Cendekia : Jurnal Pendidikan Matematika*, *5*(1), 274–285. https://doi.org/10.31004/cendekia.v5i1.450

Rahayu, S. D., Ashadi, & Dwiastuti, S. (2020). Analysis of Students' Critical Thinking Skills in Secondary Schools on Plants' Structure and Functions Material. *Proceedings of the 3rd International Conference on Learning Innovation and Quality Education (ICLIQE 2019)*. https://doi.org/10.2991/assehr.k.200129.131

Rimiene, V. (2002). Assessing and Developing Students' Critical Thinking. *Psychology Learning & Teaching*, *2*(1), 17–22. https://doi.org/10.2304/plat.2002.2.1.17

Salsabilla, T. M., Darmiany, D., & Setiawan, H. (2022). Keterampilan Mengajar Guru Mengembangkan Kemampuan Berpikir Kritis Siswa Kelas IV Dalam Pembelajaran di SDN 3 Labuhan Lombok Tahun Ajaran 2022/2023. *Jurnal Ilmiah Profesi Pendidikan*, *7*(3c), 1811–1816. https://doi.org/10.29303/jipp.v7i3c.842

Santos-Meneses, L. F., Pashchenko, T., & Mikhailova, A. (2023). Critical thinking in the context of adult learning through PBL and e-learning: A course framework. *Thinking Skills and Creativity*, *49*, 101358. https://doi.org/10.1016/j.tsc.2023.101358

Snyder, L. G., Snyder, L. G., Snyder, M. J., & Snyder, M. J. (2008). Teaching Critical Thinking and Problem Solving Skills. *The Delta Pi Epsilon Journal*, *2*, 90–100. Retrieved from https://rb.gy/mzg54p

Solihati, N., & Hikmat, A. (2018). Critical Thinking Tasks Manifested in Indonesian Language Textbooks for Senior Secondary Students. *SAGE Open*, *8*(3), 215824401880216. https://doi.org/10.1177/2158244018802164

Sulhan, A. S., Wilujeng, I., & Prasetyo, Z. K. (2023). Improving Critical Thinking Skills Students Through Problem Based Learning E-Module. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9481–9486. https://doi.org/10.29303/jppipa.v9i11.5231

Susanti, A. E., & Suwu, S. E. (2017). Penerapan pembelajaran berbasis masalah untuk meningkatkan ketrampilan berpikir kritis siswa Kelas IX dalam pelajaran Ekonomi. *Polyglot: Jurnal Ilmiah*, *12*(1), 66. Retrieved from

http://ojs.uph.edu/index.php/PJI/article/view/383

Taufiqurrahman, M. (2023). Pembelajaran Abad 21 Berbasis Kompetensi 4C di Perguruan Tinggi. *PROGRESSA: Journal of Islamic Religious Instruction*, *7*(1), 78–90. https://doi.org/10.32616/pgr.v7.1.441.78-90

Thomas, T. A. (2011). Developing First Year Students' Critical Thinking Skills. *Asian Social Science*, *7*(4). https://doi.org/10.5539/ass.v7n4p26

van Brederode, M. E., Zoon, S. A., & Meeter, M. (2020). Examining the effect of lab instructions on students' critical thinking during a chemical inquiry practical. *Chemistry Education Research and Practice*, *21*(4), 1173–1182. https://doi.org/10.1039/D0RP00020E

Voska, K. W., & Heikkinen, H. W. (2000). Identification and Analysis of Student Conceptions Used to Solve Chemical Equilibrium Problems. *Journal of Research in Science Teaching*, *37*(2), 160–176. https://doi.org/10.1002/(SICI)1098-2736(200002)37:2<160::AID-TEA5>3.0.CO;2-M