Jurnal Iqra' Kajian Ilmu Pendidikan

OPEN ACCESS

Volume 10, Number 2, August 2025

Interaction Profile of Problem Solving and Logical Thinking in Teaching Materials for Inheritance of Traits in Schools

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ARTICLE INFO
Article history:
Received
May 04, 2025
Revised
July 29, 2025
Accepted
August 24, 2025

ABSTRACT

Problem solving and logical thinking are essential 21st-century skills that are highly relevant to science learning, particularly in biology. The purpose of this study is to present the interaction profile between problem solving and logical thinking in teaching materials for the topic of inheritance of traits in schools. This research employed a descriptive qualitative method with indicator reduction. A total of 66 indicators were developed based on problem-solving aspects—Identify the problem; Define and represent the problem; Explore possible strategies; Act on the strategies; and Look back and evaluate the effects of your activities—and logical-thinking aspects, namely proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. The findings show that the teaching materials tend to emphasize the IPPR aspect (Identify – Proportional Reasoning) with an average of 4.77%, while the APBR aspect (Act – Probabilistic Reasoning) is less accommodated, with an average of 0.53%. Based on these results, the interaction profile of problem-solving and logical-thinking aspects in inheritance of traits materials in schools is presented unevenly and requires improvement. Therefore, further research is needed to develop and test problem-solving- and logical-thinking-based teaching materials through a classroom experimental approach to measure their impact on student learning outcomes. The findings of this study contribute to the field by providing an empirical basis for curriculum developers, textbook authors, and educators to design teaching materials that integrate higher-order thinking skills more evenly and effectively.

Keywords: Problem Solving, Logical Thinking, Inheritance of Traits

Published by Institut Agama Islam Ma'arif NU (IAIMNU) Metro Lampung
Website https://journal.iaimnumetrolampung.ac.id/index.php/ji/index
E-ISSN 2548-7892

INTRODUCTION

Problem solving is one of the essential skills in developing 21st-century competencies (Setiawati et al., 2024; Giang et al., 2024; Antonio & Prudente, 2024; Ioannidou, & Erduran, 2022; Shek, Chau, & Lee, 2025). These skills not only support academic success but also serve as a foundation for addressing complex and dynamic real-life challenges (Hoskinson et al., 2013; Rahman, 2019). Problem solving is defined as a systematic thinking process involving the identification of problems, evaluation of alternative solutions, and reflective action (Ahghar, 2012; Lu & Xie, 2024).

The problem-solving process consists of several aspects, reflecting its structured and high-level cognitive nature (Zakiah et al., 2019). These aspects are: (1) Identify the problem, which involves understanding the nature and conditions of the problem situation; (2) Define and represent the problem, which involves determining the objectives of problem-solving from various perspectives; (3) Explore possible strategies, which involves using prior experience and knowledge to identify potential solutions; (4) Act on the strategies, which involves implementing chosen strategies and anticipating the results to achieve problem-solving goals; and (5) Look back and evaluate the effects of your activities, which involves assessing solutions,

reflecting on the methods used, and reviewing the solved problems (Bransford & Stein, 1993; Brookhart, 2010). These stages, abbreviated as IDEAL, can be implemented in learning through teaching materials (Bransford & Stein, 1993; Annizar et al., 2020; Arifin, Saputro, & Kamari, 2025; Tan et al, 2023; Luthfia, 2023).

All aspects of problem solving follow a systematic process that requires sound reasoning and factual evidence (Punia et al., 2022). Reasoning that is both logically sound and factually supported forms the basis of logical thinking (Prasetyono & Hariyono, 2020; Garcia-Carmona, 2023). Logical thinking is the ability to think step-by-step, analyze, and compare facts to reach a conclusion (Mukimzhonovich, 2022). It influences academic achievement, making it a crucial component in science education (Fah et al., 2019; Ramirez & Monterola, 2022). According to Tobin and Capie (1981), logical thinking comprises five aspects: (1) proportional reasoning; (2) controlling variables; (3) probabilistic reasoning; (4) correlational reasoning; and (5) combinatorial reasoning.

Proportional reasoning refers to the ability to recognize and apply patterns by understanding structured relationships between terms (Modestou & Gagatsis, 2010; Fehér, Jaruska, Szarka, & Tarová, 2023; Sevinc & Lizano, 2024). Controlling variables involves designing, conducting, and evaluating experiments by managing influential variables (Schwichow et al., 2016; Jong et al, 2023; Anggraeni, 2023). Probabilistic reasoning is the ability to make decisions under conditions of uncertainty based on probability information (Boege, 2022; Carrió, Baños, & Rodríguez, 2022). Correlational reasoning is the ability to identify relationships between variables, even when objects change or phenomena are irregular (Ongcoy, 2016; Yu & Zin, 2023). Combinatorial reasoning is the ability to identify and analyze combinations of factors to draw conclusions and generate solutions (Bello, 2014; Kaldaras & Wieman, 2023). These aspects of logical thinking are inherently linked to stages of the problem-solving process.

Logical thinking can be effectively developed through problem-solving-based learning (Çiğrik & Ergül, 2010; Adkhamjonovna, 2022). Biology is a particularly relevant subject for applying problem-solving and logical thinking skills, as many of its concepts require logical analysis and abstraction, especially in the topic of inheritance of traits (Maulida, 2016). Mastery of this topic requires a deep understanding of genetic mechanisms and the ability to connect concepts such as dominance, segregation, and probability based on Mendel's Laws (Avena & Knight, 2019; Liana et al., 2020; Subramaniam, 2025).

The relationship between problem-solving and logical thinking aspects can be illustrated through their interactions. In the "Identify the problem" stage: (1) proportional reasoning involves recognizing existing problem patterns (Rahaded & Tuasikal, 2025); (2) controlling variables involves identifying factors that influence the problem (Schwichow et al., 2016); (3) probabilistic reasoning involves identifying problems using probability and chance values (Mazfufah, 2017); (4) correlational reasoning involves identifying relationships between variables (Rimadani et al., 2017); and (5) combinatorial reasoning involves identifying combinations of variables that affect a problem (Modestou & Gagatsis, 2010; Rahman, 2019).

In the "Define and represent the problem" stage: (1) proportional reasoning involves defining objectives based on structured relationships between terms (Poernomo et al., 2021); (2) controlling variables involves specifying influential variables (DeHaan, 2009; Schwichow et al., 2016); (3) probabilistic reasoning involves defining problems based on probability values (Feronika, 2023); (4) correlational reasoning involves specifying relationships between variables (Firdausi et al., 2020); and (5) combinatorial reasoning involves defining combinations of influential variables (Price et al., 2021).

In the "Explore possible strategies" stage: (1) proportional reasoning involves recognizing problems and applying solution patterns (Mujib & Sulistiana, 2023); (2) controlling variables involves designing experiments by controlling influential factors (Brookhart, 2010); (3) probabilistic reasoning involves exploring strategies based on probability values (Muyasaroh et al., 2023); (4) correlational reasoning involves strategies based on relationships between variables (Anjani et al., 2020); and (5) combinatorial reasoning involves integrating strategies in problem-solving (Avena & Knight, 2019).

In the "Act on the strategies" stage: (1) proportional reasoning involves determining actions based on established patterns (Hadi, 2021); (2) controlling variables involves implementing actions by managing variables (Brookhart, 2010); (3) probabilistic reasoning involves acting based on probability values (Hadi, 2021); (4) correlational reasoning involves actions based on relationships between variables (Hadi, 2021); and (5) combinatorial reasoning involves combining actions to solve problems (Bello, 2014; Price et al., 2021).

In the "Look back and evaluate the effects of your activities" stage: (1) proportional reasoning involves evaluating solutions by recognizing patterns (Rahman et al., 2023); (2) controlling variables involves assessing solutions based on influential factors (Siti, 2024); (3) probabilistic reasoning involves evaluating solutions based on probability values obtained (Mazfufah, 2017); (4) correlational reasoning involves evaluation based on relationships between variables (Anjani et al., 2020); and (5) combinatorial reasoning involves evaluating combinations of actions (Rott et al., 2021).

Logical thinking is a key component of problem solving and should be deliberately developed in learning processes (Rahman, 2019; Bronkhorst et al., 2020). It can be cultivated through problem-solving-based instruction (Çiğrik & Ergül, 2010; Adkhamjonovna, 2022). One effective medium for training these skills is teaching materials (Avena & Knight, 2019).

Teaching materials that incorporate all indicators of problem-solving and logical thinking interactions can help build students' knowledge (Punia et al., 2022). In the Merdeka Curriculum, the inheritance of traits topic is included in phase F, which states that "students have the ability to apply the concept of inheritance of traits" (Kemendikbudristek, 2022). Applying concepts requires logical thinking (Sezen & Bülbül, 2011). Therefore, learning that integrates logical thinking and problem solving supports students in achieving curriculum learning outcomes.

The integration of problem-solving and logical-thinking aspects is essential for equipping students with high-level cognitive skills in accordance with 21st-century curriculum demands. Given the importance of this interaction, existing teaching materials on inheritance of traits need to be reviewed based on relevant interaction indicators. This review aims to profile the integration of problem-solving and logical-thinking aspects in school teaching materials on inheritance of traits. The findings are expected to contribute to the development of more contextual, adaptive, and cognitively engaging learning resources.

In light of the growing importance of integrating problem solving and logical thinking in science education, there remains a noticeable gap in the literature regarding the extent to which school teaching materials for inheritance of traits reflect a balanced interaction between these two competencies. This study seeks to address this issue by systematically analyzing teaching materials based on reduced indicators of both aspects, with the goal of contributing both theoretical insights and practical applications in the field of biology education. By developing a deeper understanding of the interaction profile between problem solving and logical thinking in teaching materials, this research aims to support future innovations and inform effective practices in curriculum design, teaching material development, and classroom instruction.

METHOD

Research Type and Approach

This study used a qualitative descriptive approach with the aim of analyzing the content of biology learning teaching materials on the material of inheritance of traits based on the interaction between aspects of problem solving and logical thinking. This approach was chosen to describe the integration of concepts systematically through content analysis of teaching materials, without manipulating variables.

Object of Analysis

The object of this research is teaching materials for biology learning used at the Senior High School (SMA) level, especially teaching materials that contain inheritance of traits. The teaching materials analyzed are teaching materials that are actively used in biology learning activities in the classroom. Teaching materials are available in printed and digital form and

contain a learning structure that includes objectives, student activities, core material, and evaluation questions.

Compilation and Reduction of Indicators

The problem solving aspect in this study refers to five stages according to Brookhart (2010): (1) Identify the problem; (2) Define and represent the problem; (3) Explore possible strategies; (3) Act on the strategies; and (5) Look back and evaluate the effects of your activities. Meanwhile, the logical thinking aspect refers to five aspects according to Tobin and Capie (1981): (1) Proportional reasoning; (2) Controlling variables; (3) Probabilistic reasoning; (4) Correlational reasoning; and (5) Combinatorial reasoning.

The interaction of the two aspects was used as the basis for developing the analysis indicators. The drafting process resulted in 358 initial indicator items, which were then reduced to 66 operational indicator items through meaning categorization to avoid redundancy and overlapping indicators (Szabó, Soós, & Schiller, 2025). Reduction was carried out by paying attention to the category of meaning and representation of concepts based on the content contained in the teaching materials.

Data Collection Technique

The content of the teaching materials was examined using content analysis. Each component (learning objectives, materials, student activities, and evaluation questions) was reviewed against the compiled indicators. The presence of each indicator in the materials was recorded. In addition to document analysis, classroom observations and teacher interviews were conducted to validate the contextual use of the teaching materials and clarify any ambiguities in the indicator mapping process.

Data Analysis Technique

Teaching materials were analyzed using content analysis techniques. Each part of the teaching materials (objectives, materials, student activities, and evaluation questions) was analyzed using a list of indicators that had been compiled. Researchers noted the presence of each indicator in the teaching materials and calculated the percentage level of the indicator using the following formula:

$$P = \frac{\sum xi}{\sum x} \times 100\%$$

Description :

P = assessment percentage

$\sum xi$ = the number of indicators that appear in the teaching materials

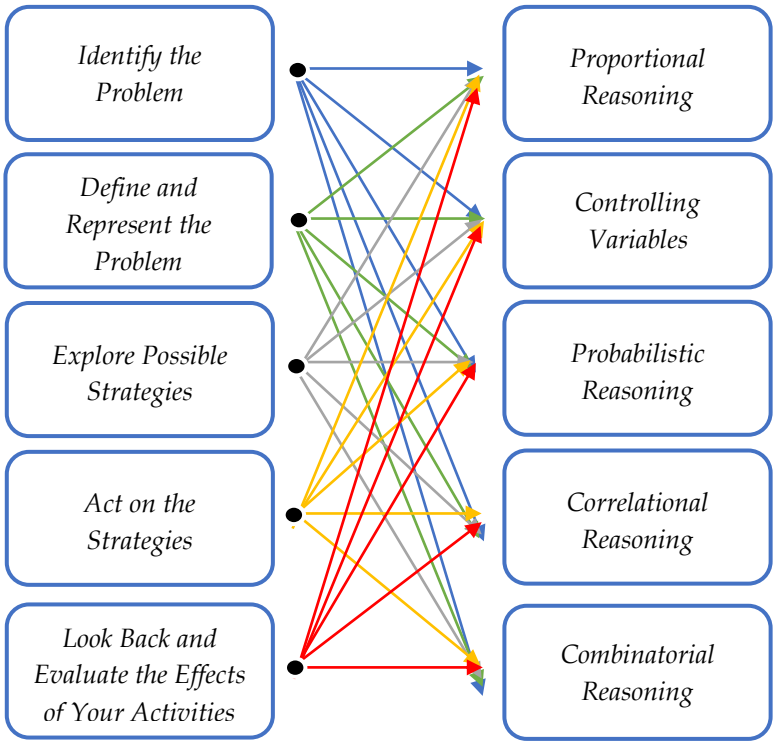
$\sum x$ = total number of indicators (66 indicators)

Visualization of aspect interactions

To strengthen the interpretation of the relationship between aspects, a visualization in the form of a network diagram was used to illustrate the relationship between aspects of problem solving and logical thinking (see Figure 1). Each colored line in the diagram shows the interaction of the problem solving aspect of each aspect of logical thinking.

RESULT AND DISCUSSION

Figure1. Interaction of problem solving aspect with logical thinking aspect

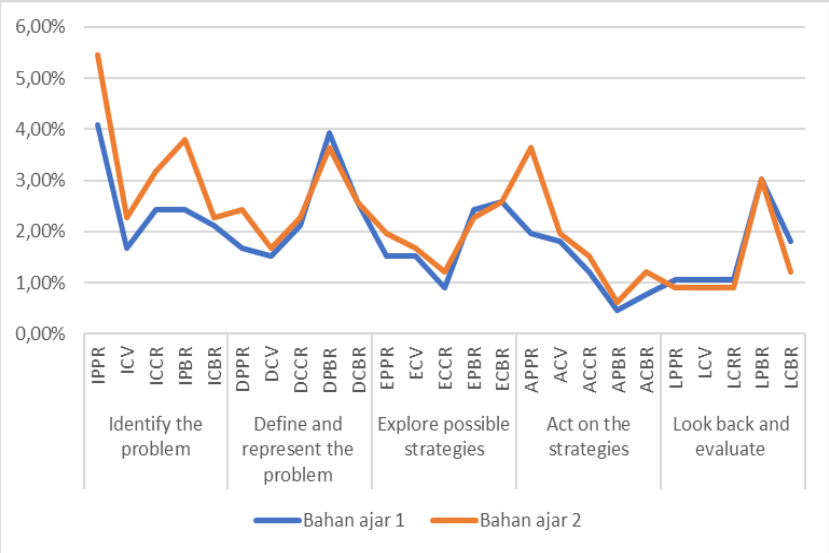


Based on the visualization of the interaction of problem solving and logical thinking aspects according to Figure 1, it indicates the interaction of each aspect contained in Table 1. Table 1 shows the interaction between the aspects of problem solving and logical thinking. Example: IPPR is the interaction of Identify the problem and Proportional reasoning aspects.

Table 1. Interaction of problem solving and logical thinking aspects

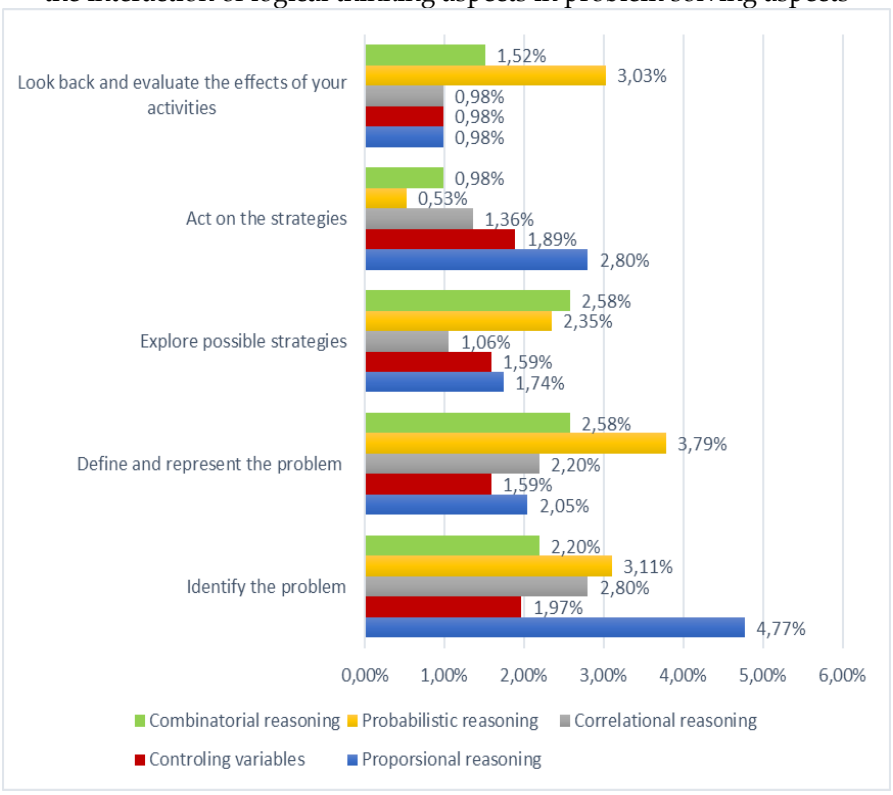
Aspek problem solving	Aspek logical thinking				
	Proportional Reasoning	*Controlling Variables*	*Probabilistic Reasoning*	*Correlational Reasoning*	*Combinatorial Reasoning*
Identify the problem	IPPR	ICV	IPBR	ICRR	ICBR
Define and represent the problem	DPPR	DCV	DPBR	DCRR	DCBR
Explore possible strategies	EPPR	ECV	EPBR	ECRR	ECBR
Act on the strategies	APPR	ACV	APBR	ACRR	ACBR
Look back and evaluate	LPPR	LCV	LPBR	LCRR	LCBR

Figure 2. Assessment of teaching materials based on
the interaction of logical thinking aspects in problem solving aspects



The results of the assessment of biology teaching materials on the material of inheritance of traits show a variation in distribution between aspects of problem solving and logical thinking. Based on Figure 2, teaching material 1 has the highest value in the IPPR aspect (4.09%) and has the lowest value in the APBR aspect (0.45%). Whereas in teaching material 2, the highest value is in the IPPR aspect (5.45%) and the lowest value is in the APBR aspect (0.61%). Based on the assessment of both teaching materials, it tends to the IPPR aspect with an average of 4.77% and less accommodates the APBR aspect with an average of 0.53%.

Figure 3. Average assessment of teaching materials based on
the interaction of logical thinking aspects in problem solving aspects

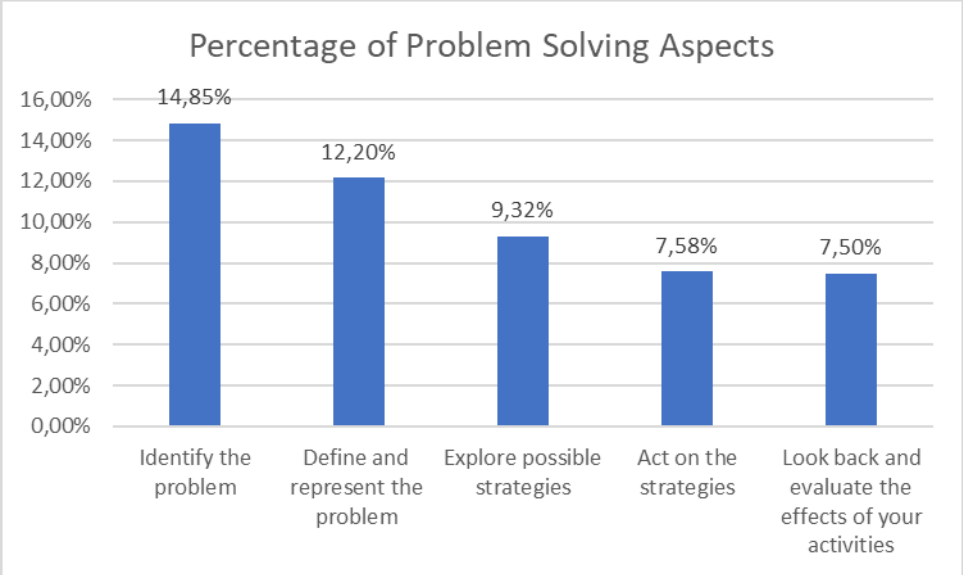


Visualization of the assessment results is shown in Figure 2, illustrating the percentage of integration of each aspect of logical thinking in each aspect of problem solving. Based on the problem solving aspects, it shows that in the Identify the problem aspect, the highest value is found in the proportional reasoning aspect with a percentage of 4.77%. In contrast, controlling variables only reached 1.97%. In the Define and represent the problem aspect, the highest interaction was found in probabilistic reasoning (3.79%). However, controlling variables became the aspect with the lowest distribution (1.59%). In the Explore possible strategies aspect, combinatorial reasoning ranks the highest (2.58%). However, the interaction with correlational reasoning is very low (1.06%). In the Act on the strategies aspect, it is most associated with proportional reasoning (2.58%). On the other hand, probabilistic reasoning appeared the lowest (0.53%). In the aspect of Look back and evaluate the effects of your activities, the highest interaction was with probabilistic reasoning (3.03%). However, the proportional reasoning, controlling variables, and correlational reasoning aspects only appeared at 0.98% each.

The results of the study show that the teaching materials have contained important elements in problem-solving-based learning but the interaction of logical thinking aspects has not been evenly distributed. The percentage results of proportional reasoning and probabilistic reasoning aspects show that teaching materials are still dominated by numerical understanding and opportunities. In contrast, the aspects of controlling variables; combinatorial reasoning and correlational reasoning, show lower percentage results so that additional learning activities are needed that help students identify variables, analyze relationships between variables, predict combinations of factors in developing solutions (Ross & Cousins, 1993; Cihlář et al., 2020).

Based on the percentage of logical thinking aspects, Proportional Reasoning (blue) dominates at the Identify the Problem and Act on the Strategies stages, with values of 4.77% and 2.80% respectively. Probabilistic Reasoning (yellow) is highest at the Identify the Problem (3.11%), Define and represent the problem (3.79%) and Look back and evaluate the effects of your activities (3.03%) stages. Combinatorial Reasoning (green) has the highest value in the aspects of Define and represent the problem and Explore possible strategies with the same value of 2.58%. Correlational Reasoning (gray) is highest in the Identify the Problem aspect with a value of 2.80% and Controlling Variables (red) tends to have low values in all aspects of problem solving, especially at the Look back and evaluate the effects of your activities stage. Thus, these results reflect the potential for further development of teaching materials to further emphasize problem solving skills to empower logical thinking.

Figure 4. Assessment of teaching materials based on problem solving aspects



Visualization of the analysis results is shown in Figure 4, illustrating the total percentage based on problem solving aspects which shows the results of the analysis of biology

learning teaching materials on inheritance of traits have an unbalanced percentage. The highest percentage value is recorded in the Identify the Problem aspect of 14.85% with a maximum percentage of 20%, while the other three aspects, namely Explore Possible Strategies (9.32%), Act on the Strategies (7.58%), and Look Back and Evaluate the Effects of Your Activities (7.50%) have a value below 10%.

Impact of Logical Thinking Interaction Limitations

The low distribution of problem solving aspects interacted with logical thinking has the potential to affect students' abilities. The problem solving aspects that are classified as low are Explore Possible Strategies, Act on the Strategies, and Look Back and Evaluate the Effects of Your Activities. In the Explore Possible Strategies aspect, students are expected to be able to choose the right approach by utilizing their experience and knowledge (Annizar et al., 2020). However, if the interaction of logical thinking in the aspects of controlling variables and correlational reasoning is poorly trained, it causes students to have difficulty in developing alternative solutions and thinking flexibly in new situations (Avena & Knight, 2019; Rott et al., 2021).

In the Act on the Strategies aspect, students are expected to be able to make decisions based on strategies to solve problems and reflect on the effectiveness of actions (Yimer & Ellerton, 2010). However, if the interaction of logical thinking aspects of probabilistic reasoning and combinatorial reasoning is not maximally trained, it causes students to tend to rely on trial and error strategies rather than using evidence-based strategies (Schwichow et al., 2016; Annizar et al., 2020).

At the Look Back and Evaluate the Effects of Your Activities stage, students are expected to be able to evaluate the solution strategies carried out, review the results and develop the next steps for improvement. The evaluation process includes the process of considering additional information, the effectiveness of the chosen solution, and possible alternative approaches (Price et al., 2021). However, if the logical thinking interaction aspects of proportional reasoning, controlling variables and correlational reasoning are not trained, then reflective activities will tend to be superficial and not produce meaningful solutions (Rott et al., 2021).

The Role of Problem Solving in Strengthening Logical Thinking

Logical thinking can be trained by applying and using problem solving in learning (Çiğrik & Ergül, 2010; Adkhamjonovna, 2022). In addition, effective problem solving requires a strong foundation of logical thinking. Logical thinking plays an important role in processing and applying information, explaining understanding, and describing relationships between concepts rationally and systematically (Prasetyono & Hariyono, 2020; Punia et al., 2022). The power of logical thinking helps students in finding the right answer through efficient solutions and can be proven rationally (Rahman, 2019). Thus, problem solving and logical thinking have a mutually influencing relationship. The aspects of problem solving, namely Identify the problem, Define and represent the problem, Explore possible strategies, Act on the strategies, Look back and evaluate the effects of your activities should be interacted in the learning process so as to improve logical thinking skills.

DISCUSSION

The results of this study indicate that the interaction between problem-solving aspects and logical-thinking aspects in biology teaching materials on the topic of inheritance of traits is not evenly distributed. The analysis revealed that the highest interaction occurs in the "Identify the problem – Proportional reasoning" (IPPR) aspect, with an average of 4.77%, while the "Act on the strategies – Probabilistic reasoning" (APBR) aspect is the least represented, with an average of 0.53%. At the problem-solving level, the "Identify the problem" stage dominates (14.85%), while "Explore possible strategies" (9.32%), "Act on the strategies" (7.58%), and "Look back and evaluate" (7.50%) remain underrepresented. These findings suggest that current teaching materials focus heavily on initial problem identification but provide limited opportunities for students to engage in higher-level reasoning processes such as strategic action, probabilistic decision-making, and reflective evaluation.

This study's findings both align with and differ from prior research in significant ways. Consistent with Çiğrik and Ergül (2010) and Adkhamjonovna (2022), the results confirm that problem-solving-based learning can facilitate logical thinking development. However, unlike Bronkhorst et al. (2020) and Ramirez and Monterola (2022), who found balanced improvements across multiple logical-thinking aspects, this study reveals a disproportionate emphasis on proportional reasoning over other reasoning types. Furthermore, Avena and Knight (2019) demonstrated the benefits of integrating probability concepts into genetics teaching, yet the current analysis shows that probabilistic reasoning remains minimal in the examined materials. Similarly, Schwichow et al. (2016) and Cihlář et al. (2020) emphasized the importance of controlling variables in science learning, but our findings indicate this aspect is underrepresented. The lack of correlational reasoning identified here contrasts with results from (Ross and Cousins (1993) and Rimadani et al. (2017), who observed that correlational reasoning could be effectively embedded in science tasks. Additionally, while (Modestou and Gagatsis (2010) and Price et al. (2021) stress the significance of combinatorial reasoning for complex problem solving, this study finds such reasoning insufficiently developed in the analyzed content. These differences highlight a persistent gap between theoretical recommendations in the literature and their practical integration into teaching materials.

The uneven representation of logical-thinking aspects in teaching materials has several educational implications. First, it suggests that while students may be guided to recognize problems effectively, they might not be sufficiently trained to generate, evaluate, and implement diverse solution strategies. This imbalance can hinder the development of adaptive expertise, a key 21st-century competency. In practical terms, curriculum developers and textbook authors should aim for a more balanced distribution of problem-solving and logical-thinking indicators to ensure that students engage in reasoning processes beyond pattern recognition. Furthermore, teacher training programs could incorporate modules that emphasize integrating underrepresented reasoning types, such as probabilistic, correlational, and combinatorial reasoning, into classroom tasks and assessments.

This study has several limitations. The scope of the data was restricted to teaching materials from a limited number of educational institutions, which may not fully represent the diversity of materials used across different regions, publishers, or curriculum levels. The content analysis relied on indicator mapping, which, while systematic, may not capture the full depth of cognitive engagement that occurs when materials are implemented in classrooms. Additionally, although interviews and observations were conducted to validate findings, these were limited in scale and may not reflect all contextual variations in instructional practices.

Future research could address these limitations by expanding the dataset to include teaching materials from various geographical areas, curriculum frameworks, and publishers. Experimental studies could be conducted to test the effectiveness of revised materials that intentionally balance all aspects of problem-solving and logical thinking. Moreover, longitudinal research could explore how sustained exposure to such balanced materials impacts students' higher-order thinking skills over time. Cross-disciplinary studies could also investigate whether similar patterns of imbalance exist in other science subjects, thereby informing broader curriculum and instructional design strategies.

CONCLUSION

The results showed that the interaction between aspects of problem solving and logical thinking in biology teaching materials on inheritance of traits was not fully optimized. The assessment of both teaching materials tends to IPPR aspects with an average of 4.77% and less accommodates APBR aspects with an average of 0.53%. Based on problem solving aspects, teaching materials show the highest interaction in the Identify the Problem aspect (14.85%) which indicates that students are sufficiently directed to recognize and understand the problem. However, the other three aspects, namely Explore Possible Strategies (9.32%), Act on the Strategies (7.58%), and Look Back and Evaluate the Effects of Your Activities (7.50%) showed low values. This finding shows that the interaction profile of problem solving aspects with

logical thinking on the material of inheritance of traits in schools is unevenly presented and needs to be improved.

This study has limitations on the scope of the data, which only includes teaching materials from certain educational units without involving the diversity of geographical contexts, publishers, or different curriculum levels. Based on these limitations, it is recommended that further research analyze teaching materials from various regions or publishers to obtain more representative results. In addition, further research is needed by developing and testing teaching materials based on problem solving and logical thinking directly through a classroom experimental approach to measure their impact on student learning outcomes quantitatively and qualitatively.

REFERENCES

Adkhamjonovna, K. M. (2022). Development of Logical Thinking of Junior School Children. *Web of Scientist: International Scientific Research Journal*, *3*(10), 914-919. https://doi.org/10.17605/OSF.IO/Y7MSA

Ahghar, G. (2012). Effect of Problem-Solving Skills Education on Auto-Regulation Learning of High School Students in Tehran. *Procedia-Social and Behavioral Sciences*, *69* (Iceepsy), 688–694. https://doi.org/10.1016/j.sbspro.2012.11.462

Anggraeni, D. M., Prahani, B. K., Suprapto, N., Shofiyah, N., & Jatmiko, B. (2023). Systematic Review of Problem Based Learning Research in Fostering Critical Thinking Skills. *Thinking Skills and Creativity*, *49*, 101334. https://doi.org/10.1016/j.tsc.2023.101334

Anjani, F., Supeno, S., & Subiki, S. (2020). Kemampuan Penalaran Ilmiah Siswa SMA dalam Pembelajaran Fisika Menggunakan Model Inkuiri Terbimbing disertai Diagram Berpikir Multidimensi. *Lantanida Journal*, *8*(1), 13-28. http://dx.doi.org/10.22373/lj.v8i1.6306

Annizar, A. M., Masrurotullaily, Jakaria, M. H. D., Mukhlis, M., & Apriyono, F. (2020). Problem Solving Analysis of Rational Inequality Based on IDEAL Model. *Journal of Physics: Conference Series*, *1465*(1). https://doi.org/10.1088/1742-6596/1465/1/012033

Antonio, R. P., & Prudente, M. S. (2024). Effects of Inquiry-Based Approaches on Students' Higher-Order Thinking Skills in Science: A Meta-Analysis. *International Journal of Education in Mathematics, Science and Technology*, *12*(1), 251-281. https://doi.org/10.46328/ijemst.3216

Arifin, Z., Saputro, S., & Kamari, A. (2025). The Effect of Inquiry-Based Learning on Students' Critical Thinking Skills in Science Education: A Systematic Review and Meta-Analysis. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(3), em2592. https://doi.org/10.29333/ejmste/15988

Avena, J. S., & Knight, J. K. (2019). Problem Solving in Genetics: Content Hints Can Help. *CBE Life Sciences Education*, *18*(2), 1–13. https://doi.org/10.1187/cbe.18-06-0093

Bello, A. (2014). Students' Acquisition of The Formal Reasoning Ability in Kaduna State, Nigeria. *International Journal of Science, Mathematics and Technology Learning*, *2*(6), 613–628. https://doi.org/10.18848/2327-7971/cgp/v21i01/49044

Boege, T. (2022). *Algebra in Probabilistic Reasoning*. Cornell University: arXiv preprint. https://doi.org/10.48550/arXiv.2211.04164

Bransford, J. D., & Stein, B. S. (1993). *The IDEAL Problem Solver: A Guide for Improving Thinking, Learning, and Creativity*. New York, NY: Freeman

Bronkhorst, H., Roorda, G., Suhre, C., & Goedhart, M. (2020). Logical Reasoning in Formal and Everyday Reasoning Tasks. *International Journal of Science and Mathematics Education*, *18*(8), 1673–1694. https://doi.org/10.1007/s10763-019-10039-8

Brookhart, S. (2010). How to Assess Higher-Order Thinking Skills in Your Classroom. In *ASCD*. https://doi.org/10.1177/002205741808801819

Carrió, M., Baños, J. E., & Rodríguez, G. (2022). Comparison of The Effect of Two Hybrid Models of Problem-Based Learning Implementation on the Development of Transversal and Research Skills and the Learning Experience. In *Frontiers in Education*, *7*, 875860. Frontiers Media SA. https://doi.org/10.3389/feduc.2022.875860

Çiğrik, E., & Ergül, R. (2010). The Investion Effect of Using WebQuest on Logical Thinking

Ability in Science Education. *Procedia-Social and Behavioral Sciences*, *2*(2), 4918–4922. https://doi.org/10.1016/j.sbspro.2010.03.795

Cihlář, J., Eisenmann, P., Hejnová, E., & Přibyl, J. (2020). Problem Solving in Mathematics and Scientific Reasoning. *New Educational Review*, *61*, 97–108. https://doi.org/10.15804/tner.2020.61.3.08

Hadi, W. P. (2021). Identifikasi Kemampuan Penalaran Ilmiah Berdasarkan Gender. *Wahana Matematika dan Sains: Jurnal Matematika, Sains, dan Pembelajarannya*, *15*(2), 133-142. https://doi.org/10.23887/wms.v15i2.34047

DeHaan, R. L. (2009). Teaching Creativity and Inventive Problem Solving in Science. *CB-Life Sciences Education*, *8*, 172–181. https://doi.org/10.1187/cbe.08–12–0081

De Jong, T., Lazonder, A. W., Chinn, C. A., Fischer, F., Gobert, J., Hmelo-Silver, C. E., ... & Zacharia, Z. C. (2023). Let's Talk Evidence–The Case for Combining Inquiry-Based and Direct Instruction. *Educational Research Review*, *39*, 100536. https://doi.org/10.1016/j.edurev.2023.100536

Fah, L. Y., Hoon, K. C., & Lee, J. C. O. (2009). The Relationships Among Integrated Science Process Skills, Logical Thinking Abilities, and Science Achievement Among Rural Students of Sabah, Malaysia. In *Third International Conference on Science and Mathematics Education, 1-12*

Fehér, Z., Jaruska, L., Szarka, K., & Tóthová Tarová, E. (2023). Students' Propositional Logic Thinking in Higher Education From the Perspective of Disciplines. In *Frontiers in Education*, *8*, 1247653. Frontiers Media SA. https://doi:10.3389/feduc.2023.1247653

Feronika, T. (2023). Hubungan Efikasi Diri dengan Kemampuan Berpikir Logis Mahasiswa Calon Guru Kimia pada Materi Asam Basa (*Skripsi*). UIN Syarif Hidayatullah Jakarta

Firdausi, E. A., Suyudi, A., & Yuliati, L. (2020). Identifikasi Kemampuan Penalaran Ilmiah Materi Elastisitas dan Hukum Hooke pada Siswa SMA. *Jurnal Riset Pendidikan Fisika*, *5*(2), 69-75.

García-Carmona, A. (2025). Scientific Thinking and Critical Thinking in Science Education: Two Distinct but Symbiotically Related Intellectual Processes. *Science & Education*, *34*(1), 227-245. https://doi.org/10.1007/s11191-023-00460-5

Giang, N. T. C., Anh, N. T. Q., Dao, T. T., Tuan, P. A., Linh, C. T. H., & Chau, P. T. H. (2024). A Systematic Review of Problem-Solving Skill Development for Students in STEM Education. *International Journal of Learning Teaching and Educational Research*, *23*(5), 1-20. https://doi.org/10.26803/ijlter.23.5.1

Hoskinson, A. M., Caballero, M. D., & Knight, J. K. (2013). How Can We Improve Problem Solving in Undergraduate Biology? Applying Lessons from 30 Years of Physics Education Research. *CBE Life Sciences Education*, *12*(2), 153–161. https://doi.org/10.1187/cbe.12-09-0149

Ioannidou, O., & Erduran, S. (2022). Policymakers' Views of Future-Oriented Skills in Science Education. In *Frontiers in Education*, *7*, 910128. Frontiers Media SA. https://doi.org/10.3389/feduc.2022.910128

Kaldaras, L., & Wieman, C. (2023). Introducing an Instructional Model for Teaching Blended Math-Science Sensemaking in Undergraduate STEM Courses Using Computer Simulations. *arXiv preprint arXiv:2305.13451*. https://doi.org/10.48550/arXiv.2305.13451

Kemendikbudristek. (2022). *Capaian Pembelajaran pada Pendidikan Anak Usia Dini, Jenjang Pendidikan Dasar, dan Jenjang Pendidikan Menengah pada Kurikulum Merdeka*.

Liana, Y. R., Linuwih, S., & Sulhadi, S. (2020). Internet of Things Based Learning Media with Problem Solving Approach: Its Effect on Higher Order Thinking Skills. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *9*(2), 225–239. https://doi.org/10.24042/jipfalbiruni.v9i2.6313

Lu, D., & Xie, Y. N. (2024). The Application of Educational Technology to Develop Problem-Solving Skills: A Systematic Review. *Thinking Skills and Creativity*, *51*, 101454. https://doi.org/10.1016/j.tsc.2023.101454

Luthfia, S. (2023). Enhancement of Problem-Solving Skill Using IDEAL Problem-Solving Learning Model. *SUJANA: Education and Learning Review*, 1-15. https://doi.org/10.56943/sujana.v2i4.461

Maulida, R. (2016). Pengaruh Model Pembelajaran Problem Solving Berbasis Just in Time Teaching Terhadap Keterampilan Proses Sains Siswa pada Materi Struktur dan Fungsi Jaringan Tumbuhan (*Skripsi*). UIN Syarif Hidayatullah Jakarta

Mazfufah, N. F. (2017). Pengaruh Metode Diskusi Isu-Isu Sosiosaintifik Terhadap Kemampuan Penalaran Ilmiah Peserta Didik (*Skripsi*). UIN Syarif Hidayatullah Jakarta

Modestou, M., & Gagatsis, A. (2010). Cognitive and Metacognitive Aspects of Proportional Reasoning. *Mathematical Thinking and Learning*, *12*(1), 36–53. https://doi.org/10.1080/10986060903465822

Mujib, A., & Sulistiana, E. (2023). Kemampuan Penalaran Proporsional menurut Langrall dan Swafford pada Siswa Sekolah Menengah Pertama. *Plusminus: Jurnal Pendidikan Matematika*, *3*(1), 117-126. https://doi.org/10.31980/plusminus.v3i1.1228

Muyasaroh, A., Pujiastuti, E., & Kharisudin, I. (2023). Analisis Level Probabilistic Thinking Ability Peserta Didik Dalam Menyelesaikan Soal Cerita Peluang di Sekolah Menengah Atas. *JPMI (Jurnal Pembelajaran Matematika Inovatif)*, *6*(2), 551-560. https://doi.org/10.22460/jpmi.v6i2.16989

Mukimzhonovich, E. M. (2022). Features of Geometric Problems for the Development of Self-Awareness and Logical Thinking. *JournalNX*, *8*(12), 185-190.

Ongcoy, P. J. (2016). Logical Reasoning Abilities of Junior High School Students in The Province of Cotabato, Philippines. *Asia Pacific Journal of Multidisciplinary Research*, *4*(4), 18-21.

Poernomo, E., Kurniawati, L., & Atiqoh, K. S. N. (2021). Studi Literasi Matematis. *Algoritma: Journal of Mathematics Education*, *3*(1), 83-100. https://doi.org/10.15408/ajme.v3i1.20479

Prasetyono, R. N., & Hariyono, R. C. S. (2020). Development of Flipbook Using Web Learning to Improve Logical Thinking Ability in Logic Gate. *International Journal of Advanced Computer Science and Applications*, *11*(1), 342–348. https://doi.org/10.14569/ijacsa.2020.0110143

Price, A. M., Kim, C. J., Burkholder, E. W., Fritz, A. V., & Wieman, C. E. (2021). A Detailed Characterization of the Expert Problem-Solving Process in Science and Engineering: Guidance for Teaching and Assessment. *CBE Life Sciences Education*, *20*(3), 1–15. https://doi.org/10.1187/cbe.20-12-0276

Punia, P., Malik, R., Bala, M., Phor, M., & Chander, Y. (2022). Relationship Between Logical Thinking, Metacognitive Skills, and Problem Solving Abilities: Mediating and Moderating Effect Analysis. *Polish Psychological Bulletin*, *53*(4), 243–253. https://doi.org/10.24425/ppb.2022.143370

Rahaded, S., & Tuasikal, A. (2025). Karakterisasi Penalaran Proporsional Siswa dalam Memecahkan Masalah Rasio dan Proporsi Berdasarkan Kemampuan Dasar Matematika. *Cognitivism: Journal of Educational Research and Development*, *1*(1), 40-52.

Rahman, M. M. (2019). 21st Century Skill "Problem Solving": Defining the Concept. *Asian Journal of Interdisciplinary Research*, *2*(1), 64–74. https://doi.org/10.34256/ajir1917

Rahman, M. T. A., Subarinah, S., & Triutami, T. W. (2023). Kemampuan Penalaran Proporsional ditinjau dari Gaya Belajar pada Siswa. *Journal of Classroom Action Research*, *5*(4), 433-440. https://doi.org/10.29303/jcar.v5i4.5951

Ramirez, H. J. M., & Monterola, S. L. C. (2022). Co-creating Scripts in Computer-Supported Collaborative Learning and its Effects on Students' Logical Thinking in Earth Science. *Interactive Learning Environments*, *30*(5), 908–921. https://doi.org/10.1080/10494820.2019.1702063

Rimadani, E., Parno, P., & Diantoro, M. (2017). Identifikasi Kemampuan Penalaran Ilmiah Siswa SMA pada Materi Suhu dan Kalor. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan, 2*(6), 833-839. https://doi.org/10.17977/jptpp.v2i6.9440

Ross, J. A., & Cousins, J. B. (1993). Patterns of Student Growth in Reasoning about Correlational Problems. *Journal of Educational Psychology*, *85*, 49–65. https://psycnet.apa.org/doi/10.1037/0022-0663.85.1.49

Rott, B., Specht, B., & Knipping, C. (2021). A Descriptive Phase Model of Problem-Solving Processes. *ZDM-Mathematics Education*, *53*(4), 737–752. https://doi.org/10.1007/s11858-021-01244-3

Schwichow, M., Christoph, S., Boone, W. J., & Härtig, H. (2016). The Impact of Sub-Skills and

Item Content on Students' Skills with Regard to the Control-of-Variables Strategy. *International Journal of Science Education*, *38*(2), 216–237. https://doi.org/10.1080/09500693.2015.1137651

Setiawati, A., Pertiwi, C. M., & Hidayat, W. (2024). Kemampuan Pemecahan Masalah Matematis, Model Problem Based Learning, Platform Book Creator: Muatan Pembelajaran Inovatif Abad 21 Bagi Siswa SMP. *JPMI (Jurnal Pembelajaran Matematika Inovatif)*, *7*(3), 555-566. https://doi.org/10.22460/jpmi.v7i3.23002

Sevinc, S., & Lizano, C. (2024). Bar Model Method as a Problem-Solving Heuristic: an Investigation of Two Preservice Teachers' Solution Paths in Problems Involving Ratio and Percentage. *Mathematics Education Research Journal*, *36*(1), 71-95. https://doi.org/10.1007/s13394-022-00427-9

Sezen, N., & Bülbül, A. (2011). A Scale on Logical Thinking Abilities. *Procedia-Social and Behavioral Sciences*, *15*, 2476–2480. https://doi.org/10.1016/j.sbspro.2011.04.131

Shek, D. T., Chau, G. C., & Lee, B. M. (2025). Development of 21st-Century Skills: A Comprehensive Analysis Based on the OECD Learning Compass 2030. *Promoting Holistic Development in University Students*, *17*, 89. https://link.springer.com/book/10.1007/978-981-96-0251-3#page=107

Subramaniam, R. C., Borse, N., Allen, W., Sirnoorkar, A., Morphew, J. W., Rebello, C. M., & Rebello, N. S. (2025). Applying a STEM Ways of Thinking Framework for Student-generated Engineering Design-based Physics Problems. *arXiv preprint arXiv:2503.05957*. https://doi.org/10.48550/arXiv.2503.05957

Szabó, Z. A., Soós, S., & Schiller, E. (2025). Deductive Content Analysis as a Research Method in The Field of Education Sciences–A Systematic Literature Review of Journal Articles in Web of Science (2019–2023). *Journal of Adult Learning, Knowledge and Innovation*, *7*(2), 49-57. https://doi.org/10.1556/2059.2023.00094

Siti, W. B. (2024). Pengaruh Model Pembelajaran Problem Based Learning (PBL) terhadap Kemampuan Berpikir Kritis Ditinjau dari Minat Belajar Siswa di SMP Negeri 7 Bandar Lampung (*Skripsi*). UIN Raden Intan Lampung

Tan, A. L., Ong, Y. S., Ng, Y. S., & Tan, J. H. J. (2023). STEM Problem Solving: Inquiry, Concepts, and Reasoning. *Science & Education*, *32*(2), 381-397. https://doi.org/10.1007/s11191-021-00310-2

Tobin, K. G., & Capie, W. (1981). The Development and Validation of A Group Test of Logical Thinking. *Educational and Psychological Measurement*, *41*, 413–423.

Yimer, A., & Ellerton, N. F. (2010). A Five-Phase Model for Mathematical Problem Solving: Identifying Synergies in Pre-Service-Teachers' Metacognitive and Cognitive Actions. *ZDM-International Journal on Mathematics Education*, *42*(2), 245–261. https://doi.org/10.1007/s11858-009-0223-3

Yu, L., & Zin, Z. M. (2023). The Critical Thinking-Oriented Adaptations of Problem-Based Learning Models: a Systematic Review. In *Frontiers in Education*, *8*, 1139987. Frontiers Media SA. https://doi:10.3389/feduc.2023.1139987

Zakiah, N. E., Sunaryo, Y., & Amam, A. (2019). Implementasi Pendekatan Kontekstual pada Model Pembelajaran Berbasis Masalah Berdasarkan Langkah-Langkah Polya. *Teorema: Teori dan Riset Matematika*, *4*(2), 111-120. https://dx.doi.org/10.25157/teorema.v4i2.2706