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Systematic literature review: students' adaptive reasoning in mathematics learning

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Abstract

This study aims to examine trends in research methods used in articles related to students' adaptive reasoning abilities in mathematics learning from 2015 to 2024 and to describe the improvement of students' adaptive reasoning abilities. The method employed was a Systematic Literature Review (SLR) involving the identification, selection, evaluation, and data analysis of relevant articles. The reviewed articles were selected based on their relevance to students' adaptive reasoning, were published between 2015 and 2024, were sourced from Google Scholar, focused on junior high to senior/vocational high school levels, and were indexed in Sinta 1 to 3. Irrelevant articles published before 2015, not obtained from Google Scholar, outside the specified education levels, or published in proceedings and journals below Sinta 3 were excluded. Students' abilities increase by up to 82.7% with the use of Collaborative problem-solving-based tools and are very effective in improving students' adaptive reasoning abilities. This study emphasizes the importance of implementing innovative and adaptive teaching methods while considering individual student factors to enhance adaptive reasoning abilities in mathematics learning. These findings are expected to serve as a reference for educators in designing more effective teaching strategies.

Keywords: adaptive reasoning; mathematics learning; systematic literature review

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I. Introduction

Reasoning is central to mathematics learning because it fosters deep understanding, strategic thinking, and problem-solving abilities. The Indonesian curriculum, including the Merdeka Curriculum, emphasizes the importance of higher-order thinking skills, where reasoning plays a key role (Kemdikbudristek, 2022). Globally, reasoning is also recognized as a critical competency to be developed in early mathematics education (OECD, 2021; NCTM, 2014). Reasoning is also not only procedural; it requires students to evaluate, choose strategies, and make decisions based on the situation at hand (Verschaffel, Van Dooren & Star, 2020). Therefore, mathematics learning should focus not only on final results but also on students' thinking processes and ability to adapt strategies throughout the learning process (Tzur, 2018); (Star & Rittle-Johnson, 2017).

In a broader context, mathematics education is vital in shaping individuals who can

think logically, systematically, and adaptively in today's dynamic world. Mathematical literacy, especially reasoning, is closely linked to the ability to deal with real-world problems, make complex decisions, and actively participate in a data-driven society (OECD, 2021; Boaler, 2016). Adaptive reasoning becomes a critical competency to equip students to face uncertainty and rapid change across various sectors, including technology, the economy, and the environment (Turner, Dominguez, Maldonado & Empson, 2020; Kazemi, 2017; Leikin, 2021). Therefore, strengthening adaptive reasoning in mathematics learning contributes to academic achievement, character development, and readiness to face 21st-century challenges (Bartell, 2020; Watson, A., & Mason, 2017).

Student mathematical competencies have been defined by various national and international standards. The National Council of Teachers of Mathematics (NCTM) recognizes five essential process standards for fostering mathematics education: reasoning and proof, problem-solving, communication, connections, and representation (NCTM, 2014; Schoenfeld, 2015). One key aspect of these standards is reasoning, which includes logical capability and flexibility in thinking. At the national level, Indonesia's Ministry of Education Regulation (Permendikbud) No. 21 Year 2016 emphasizes that mathematics core competencies must involve advanced cognitive abilities, such as critical thinking and finding solutions. These standards affirm that mastering content alone is insufficient; students must also be guided to think reflectively and adaptively when facing varied mathematical challenges (Kemdikbud, 2016; Lesh & Zawojewski, 2017).

Adaptive reasoning is the ability to reason logically, reflectively, and flexibly when applying mathematical knowledge to new or unstructured situations (Kilpatrick, Swafford & Findell, 2002). In modern educational contexts, adaptive reasoning is regarded as a foundation for higher-order thinking because it requires students to grasp the meaning of a concept, reflect on their approach, and consciously revise or replace strategies when encountering obstacles (Verschaffel et al., 2020). This type of reasoning differs from routine reasoning as it relies not on memorized procedures but on metacognitive ability and strategic flexibility. Therefore, strengthening adaptive reasoning is crucial for helping students become independent thinkers ready to solve complex problems in real life and STEM fields (Star & Rittle-Johnson, 2017; Hatano, G., & Inagaki, 2017).

This systematic literature review aims to identify and analyze recent findings related to students' adaptive reasoning in mathematics learning. The primary focus includes (1) how adaptive reasoning is defined and assessed across different learning contexts, (2) effective instructional strategies for developing adaptive reasoning, and (3) challenges and practical recommendations for educators and policymakers. This article seeks to contribute conceptually and practically to developing more responsive mathematics pedagogy aligned with 21st-century student needs by compiling and synthesizing empirical evidence from studies published in the past seven years.

II. Research Method

The method used in this research is *a Systematic Literature Review*, which aims to find, analyze, assess, and interpret all existing studies. Through this method, researchers conduct reviews and systematically select journals based on predetermined steps (Triandini et al., 2019), which include (1) Research Questions, (2) Search Process, (3) Inclusion and Exclusion Criteria, (4) Quality Assessment; (5) Data Collection; (6) Data Analysis; (7) Deviations from the Protocol.

The first step is to develop a research question (RQ) that addresses the demands of the subject being studied. The research questions addressed in this study are: (1) What research methods are used in articles about students' adaptive reasoning in mathematics learning? Moreover, (2) How can students' adaptive reasoning skills in mathematics learning be improved?

The second step, the Search process required to find the literature involved in the Systematic Literature Review is literature that meets the research criteria. The Systematic Literature Review in this study was conducted to evaluate and analyze several studies published in journals that discuss similar topics, namely, students' adaptive reasoning in mathematics learning. Literature on the theme of adaptive reasoning was searched through Google Scholar published from 2015 to 2024 or within the last 10 years, to ensure that the data obtained is relevant to current issues. At this stage, the number of articles obtained reached 207 on November 15, 2024, which became the research population. The criteria were determined only for journal articles that provided full text.

The third step is the Inclusion and Exclusion Criteria to determine whether the articles obtained are suitable for use in this study. In this study, articles can be selected and used if they meet the criteria listed in Table 1.

Table 1Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Relevant international or national articles related to students' adaptive reasoning abilities in mathematics learning.	Irrelevant international or national articles on students' adaptive reasoning abilities in mathematics learning.
The time range used is articles published in 2015 – 2024.	The time range used is articles published before 2015.
Articles obtained from *Google Scholar*.	Articles obtained other than from *Google Scholar*.
The level of education utilized is junior high school, vocational school, or senior high school.	The educational methods not used are the Elementary School (SD) and college students.
The journal index used is Sinta 1 - Sinta 3	The journal index used is Sinta 3 and below, proceedings, and conferences.

The fourth step is Quality Assessment (QA) to assess the data or articles collected based on the evaluation criteria set, such as the research questions asked in this study: (1) Was the article published between 2015 and 2024?; (2) Does the article explain the improvement of students' adaptive reasoning abilities in mathematics learning? Furthermore, each article will receive a "Yes" or "No" response. The fifth stage is Data Collection, which aims to collect data or articles in the form of secondary data (e.g., research methods, findings on adaptive reasoning, etc.). The secondary data comes from a literature review of articles that discuss students' adaptive reasoning abilities in mathematics learning, which are obtained through Google Scholar. In the sixth stage, data analysis is carried out by reviewing the data or articles collected by referring to the predetermined research questions (RQ). The final stage, Deviation From Protocol, is done by correcting the search keywords to match the search keywords in the database (Sucianti et al., 2022).

I. Results and Discussion

Search Process Results and Selection of Inclusion Criteria

The initial search results using publications or Perish with the Google Scholar database with the keywords "Adaptive Reasoning," "Adaptive Reasoning," and "Mathematics" in each database produced 207 articles. Furthermore, a selection of articles that met the inclusion criteria was carried out, so that 18 articles were selected, and 189 articles included the exclusion criteria. The data from the literature study collected and presented can be found in Table 2.

Table 2 Classification literature selected and types of research methods used

Writer	Year	Journal	Level	Types of Methods	Index
IR Pratiwi, N Novitasari, EM Sari	2024	JOHME: Journal of Holistic Mathematics Education	SENIOR HIGH SCHOOL	Qualitative	Synta 3
WH Irawan	2024	JP2M (Journal of Mathematics Education and Learning)	JUNIOR HIGH SCHOOL	Qualitative	Synta 3
N Nurhayati, YS Kusumah, D Juandi	2024	AKSIOMA: Journal of Mathematics Education Study Program	JUNIOR HIGH SCHOOL	Plomp development model	Synta 2
DSN Afifah, M Syauqy, M Ilman Nafián	2023	Al-Ishlah: Journal of Education	Vocational School	Qualitative	Synta 2
K Khotimah, Y Supriani, R Oktaviyanthi.	2022	AKSIOMA: Journal of Mathematics Education Study Program	SENIOR HIGH SCHOOL	Data mining apriori algorithm technique.	Synta 2
R Darmayanti, R Sugianto…	2022	Numerical: Journal of Mathematics and Mathematics Education	SENIOR HIGH SCHOOL	Qualitative	Synta 3
EBA Putra	2021	MATHEdunesa	SENIOR HIGH SCHOOL	Quantitative	Synta 3
N Salwanda, TYE Siswono	2020	MATHEdunesa	SENIOR HIGH SCHOOL	Qualitative	Synta 3
NN Permana, A Setiani, NA Nurcahyono	2020	Journal of Mathematics Learning Development (JPPM SUKA)	JUNIOR HIGH SCHOOL	Qualitative	Synta 3
HTN Rizki, A Wijaya, D Frentika	2020	AXIOM: Journal of Education and Mathematics	JUNIOR HIGH SCHOOL	ADDIE Developmen t	Synta 3
A Fikriya, SB Waluya, S Sunarmi	2018	Unnes Journal of Mathematics Education	SENIOR HIGH SCHOOL	*Mixed method*	Synta 3
Y Ardiawan, N Nurmaningsih	2018	Axiom Journal of Mathematics Education	JUNIOR HIGH SCHOOL	Quantitative	Synta 2
FR Maharani, AH Rosyidi	2018	MATHEdunesa: Scientific Journal of Mathematics Education,	JUNIOR HIGH SCHOOL	Qualitative	Synta 3
IF SADIYAH, TYE Siswono	2018	MATHEdunesa: Scientific Journal of Mathematics Education,	JUNIOR HIGH SCHOOL	Qualitative	Synta 3
I Nuraida	2018	Mosharafa: Journal of Mathematics Education	JUNIOR HIGH SCHOOL	*Quasy Experimenta l design*	Synta 2
FZ Ikram, D Djadir, A Ahmad	2017	Journal of Educational Reasoning	SENIOR HIGH SCHOOL	*Quasy Experimenta l design*	Synta 3
RWY Putra	2016	Al-Jabar: Journal of Mathematics Education	JUNIOR HIGH SCHOOL	*Quasy Experimenta l Design*	Synta 2

D Nopitasari	2016	MATHLINE: Journal of Mathematics and Mathematics Education	JUNIOR HIGH SCHOOL	*Quasy Experimental design*	Synta 3

From Table 2 above, the details consist of the author's name along with the year the article was published, journal publication, level of education, research method, and the number for how many places where the author publishes.

Data Analysis Results

Next, the information obtained from each research article is presented in Table 3, which relates to the findings related to improving students' adaptive reasoning abilities in mathematics learning, such as the research results obtained by the researchers (e.g., the type of method that is most effective in adaptive reasoning, the percentage of students with adaptive reasoning abilities, and the shortcomings of each method used).

Table 3Findings Literature related Improvement Ability Reasoning Adaptive Students in Learning Mathematics.

Writer	Year	Findings
IR Pratiwi, N Novitasari, EM Sari	2024	The data analysis of this study reduced the data and found that one student used adaptive reasoning thoroughly in answering the questions. This shows the student has good numeracy skills and can solve problems using adaptive reasoning.
WH Irawan	2024	Data analysis revealed differences in adaptive thinking. When tackling issues of mathematical literacy, pupils with field-dependent and field-independent cognitive styles were integrated with Islam. Students classified as field dependent could only meet 3 to 4 indicators of adaptive reasoning, while students classified as field independent could meet all of these indicators.
N Nurhayati, YS Kusumah, D Juandi	2024	Data analysis shows that the *Collaborative problem-solving-based learning device* is quite legitimate, useful, and successful for junior high school pupils in grade VIII. The learning instrument has been validated, and its practicality is demonstrated by its adherence to the indicators of mathematical adaptive reasoning ability. From the ease of use, its effectiveness is proven by an increase in student abilities by 82.70%.
DSN Afifah, M Syauqy, M Ilman Nafián	2023	Data analysis includes the tasks of minimizing data, presenting it visually, and making inferences. It demonstrates that the adaptive reasoning skills of TSM (Motorcycle Engineering) students, when tackling mathematical issues, incorporate various strategies, illustrated through both written content and images and linking previous knowledge. TSM students' conclusions are more straightforward to the core of the problem.
K Khotimah, Y Supriani, R Oktaviyanthi.	2022	Student characteristics such as left-brain dominance, *self-efficacy*, personality tendencies, and *self-directed learning* can affect the level of students' adaptive reasoning abilities. However, differences in individual characteristics cannot be explained solely from the calculations' results. Educators can use these results as a guide to optimize student development.
R Darmayanti, R Sugianto, Y	2022	Students who can satisfy all criteria for adaptive thinking and have a convergent learning style in Kolb's learning style are those

Muhammad, PVdS Santiago.		who can use Polya's steps to solve HOTS issues using adaptive reasoning abilities and all indicators in Polya's steps.
EBA Putra	2021	The Wilcoxon test shows that improving students' conceptual understanding, critical thinking, and adaptive reasoning after learning using GeoGebra. N-gain is low because the data is not normally distributed; Kruskal-Wallis shows no significant difference after treatment. Observation of student activities shows active participation and positive student responses.
N Salwanda, TYE Siswono	2020	Students who can solve math problems accurately demonstrate adaptive reasoning abilities in all aspects; students who solve math problems with less accurate results demonstrate adaptive reasoning abilities that almost meet all aspect indicators; while students who complete math tasks with inaccurate results do not demonstrate adaptive reasoning abilities in any aspect.
NN Permana, A Setiani, NA Nurcahyono	2020	Subjects with high and moderate mathematical reasoning abilities can make assumptions about HOTS questions with the criteria for making assumptions. Subjects with limited abilities cannot make assumptions. Similar situations also occur in other indicators, such as explaining the reasons behind a truth, drawing conclusions, checking the truth of an argument, and identifying patterns in mathematical phenomena.
HTN Rizki, A Wijaya, D Frentika	2020	Learning tools that use the Knisley approach, which is oriented towards Van Hiele's level of thinking and adaptive thinking skills, are very suitable for implementation because of their high validity according to experts, practicality according to teachers and students, and effectiveness in achieving the desired level of thinking and reasoning skills.
A Fikriya, SB Waluya, S Sunarmi	2018	The Treffinger learning approach, which integrates ethnomathematics, is successful in enhancing students' ability to reason adaptively. Teachers' actions in applying this model are viewed positively. Test outcomes indicated a notable improvement following the students' lesson participation. Learners who possess strong self-confidence generally perform better in adaptive reasoning abilities. Treffinger's implementation can improve students' abilities.
Y Ardiawan, N Nurmaningsih	2018	According to the study's findings, students' average adaptive reasoning skill was 42. 96%, placing them in the adequate range. In institutions classified as high-performing, the average adaptive reasoning skill was recorded at 48. 82%, which is also deemed fairly adequate. The variation in adaptive reasoning skills between schools of high, medium, and low-performance levels suggests a need for additional research to enhance these skills.
FR Maharani, AH Rosyidi	2018	Based on the analysis, visualizer students represent information in various forms and find patterns in mathematical problems, while verbalizer students tend not to use patterns and can make calculation errors. Both check the correctness of the solution by ensuring the formula used is appropriate. Understanding students' adaptive reasoning preferences is important to improving their problem-solving abilities.
IF SADIYAH, TYE Siswono	2018	The study's results showed differences in adaptive thinking between reflective and impulsive students when asking

		questions. Reflective students completed tasks carefully, explained procedures in detail, and double-checked answers. Impulsive students tended to be fast but less thorough, often making mistakes. They did not explain procedures in detail or double-check answers. Reflective students also modified questions more often than impulsive students.
I Nuraida	2018	The study's findings indicated a notable disparity in the enhancement of adaptive reasoning skills among learners who were taught using the RME method and those who used conventional methods. Students in the PS and PAM groups showed better improvement through RME learning than conventional methods. This study demonstrates how well the RME method enhances students' adaptive reasoning skills.
FZ Ikram, D Djadir, A Ahmad	2017	The typical performance of students' adaptive reasoning skills, instructed through the Problem-Based Learning (PBL) method and the cooperative approach with a scientific perspective, was elevated. The enhancement of students' adaptive thinking skills in both educational methodologies was in the moderate range. There was no noteworthy distinction in adaptive reasoning skills when comparing the two teaching methods. The advancement in students' adaptive thinking abilities did not reveal a significant variation between the Problem-Based Learning (PBL) method and the cooperative model.
RWY Putra	2016	Students who apply the accelerated learning method show a significantly better increase in adaptive thinking skills when assessed overall than learners who utilize traditional educational approaches.
D Nopitasari	2016	Research indicates that the Creative Problem-Solving approach enhances students' adaptive math reasoning abilities. This framework exhibits superior results on intuitive inductive and deductive reasoning indicators when assessed against traditional learning methods. Students taught with the Creative Problem-Solving method show better adaptive mathematical reasoning skills than those who receive lessons with conventional methods.

RQ1: What research methods are used in articles related to students' adaptive reasoning abilities in mathematics learning between 2015 and 2024?

Based on the results of Table 2, a bar chart is obtained showing the types of research methods used in articles regarding students' adaptive reasoning abilities in mathematics learning between 2015 and 2024 as follows.

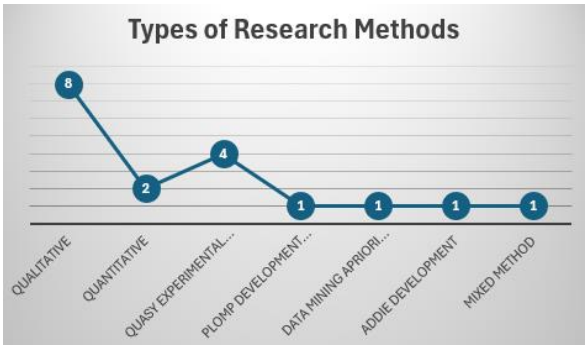

Figure 1 Research methods related ability reasoning adaptive students in learning mathematics from 2015-2024

The results of the study examining students' skills in adaptive reasoning within math education in the period 2015 - 2024, which refers to 18 articles from national journals, show that various types of research methods are applied. Figure 1, relating to the use of types of research methods in articles that have met the inclusion criteria, shows that qualitative research methods are used more in 8 articles. Furthermore, this study uses a quantitative method consisting of 2 articles and research using the *quasi-experimental design method of* as many as 4 articles, as well as the Plomp Development Model research method, Data mining apriori algorithm techniques, ADDIE Development, and *mixed method research,* each with only 1 article.

RQ2: What are the ways to improve students' adaptive thinking skills in mathematics learning?

Based on Table 3, it can be concluded that 18 national articles referenced show that improving students' adaptive reasoning abilities in mathematics learning is influenced by various learning methods, tools, and student characteristics. Research shows that *Collaborative problem-solving*-based learning devices are very effective, with an increase in student abilities reaching 82.70% (Nurhayati, Kusumah & Dadang, 2024)(Ardiawan, 2018). *Treffinger's* model based on ethnomathematics has also proven effective, especially for students with high self-confidence (Fikriya, Waluya & Sunami, 2018). In addition, the *Realistic Mathematics Education* (RME) approach produces significant improvements compared to conventional methods (Nuraida, 2018)(Nopitasari, 2016). The use of accelerated learning methods shows superior performance compared to conventional learning methods (Putra, 2016), while problem-based learning models (PBM) and cooperative learning with a scientific approach both provide significant improvement results (Ikram, Ahmad & Djadir, 2017).

Personal factors also have an important impact. Reflective students have better adaptive thinking skills than impulsive students (Farihatus Sadiyah and Yuli Eko Siswono, 2018). In addition, students with convergent learning styles tend to meet all indicators of adaptive reasoning through Polya's steps (Darmayanti, Sugianto & Muhammad, 2022). Visualizer students represent information in various forms and find patterns in math problems, while verbalizer students tend not to use patterns and can make calculation errors (Maharani & Rosyidi, 2018). Students with high numeracy show full use of adaptive reasoning (Pratiwi, Novitasari & Elisa, 2024). *Field-independent* cognitive styles are superior in meeting indicators compared to *field-dependent students*. (Irawan, 2024).

Student characteristics such as *self-efficacy*, left-brain dominance, and self-directed learning abilities also affect their adaptive abilities (Khotimah, Supriani & Oktavianthi, 2022). In addition, learning strategies that integrate Islamic-based mathematical literacy help students meet adaptive reasoning indicators (Irawan, 2024). TSM students use alternative strategies and relate previous knowledge in solving mathematical problems (Afifah, Syauqy & Nafian, 2023).

Other research findings show that students who propose hypotheses, provide rational reasons, and identify mathematical patterns show better adaptive abilities than students who only meet a few criteria (Permana et al., 2020) (Salwanda & Siswono, 2020). In addition, devices that use the Knisley approach and focus on the Van Hiele level of thinking effectively improve students' adaptive reasoning abilities (Rizki et al., 2020). The Wilcoxon test shows that GeoGebra can help improve students' conceptual understanding and adaptive reasoning abilities, although there is no significant difference (E. B. A. Putra, 2021).

In general, various learning methods that focus on innovation and are tailored to student needs have been shown to significantly improve students' adaptive reasoning abilities in mathematics.

III. Conclusion

The improvement of students' adaptive thinking skills in mathematics learning is greatly influenced by various teaching methods, tools, and individual student characteristics. Approaches such as *Collaborative problem-solving*-based learning devices have proven to be very effective, with an increase in student abilities of up to 82.70%. In addition, other approaches, such as the *Treffinger method based on ethnomathematics*, *Realistic Mathematics Education (RME)*, and *accelerated learning methods*, also provide significant results in improving students' adaptive reasoning skills.

Individual student characteristic factors, including learning style, left brain dominance, self-confidence, and *self-directed learning*, significantly influenced the achievement of Adaptive Thinking Indicators. Students who have reflective and convergent learning styles showed better abilities in achieving adaptive reasoning indicators than students who are impulsive or context dependent. In addition, contextual learning strategies, such as the integration of Islamic-based mathematical literacy, provided positive results on students' abilities in meeting adaptive reasoning indicators.

These studies emphasize the importance of implementing innovative, adaptive, and student-based learning approaches to improve their adaptive thinking skills. By maximizing learning styles and considering individual factors, these skills can be significantly improved in mathematics learning.

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