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Analysis of students' relational critical thinking abilities using an in-depth learning approach

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Abstract. Achieving the Golden Age Indonesia 2045 vision requires advancing human resources, particularly among educators. This is due to low PISA scores, a test of academic ability and critical thinking skills. This research is urgent because it aims to improve educator quality through a deep learning approach. This study aims to analyze students' Relational Critical Thinking (RCT) abilities in mathematics using a deep learning approach. This study employs a quantitative methodology using the Rasch model for data analysis. The research population includes Senior High Schools and Islamic Senior High Schools in Banten Province, with participants selected through random sampling. Data were collected using Google Forms with 15 essay questions on relational critical thinking. The results: 103 students (27.54%) fall into the developing RCT category, 152 students (40.64%) fall into the basic RCT category, and 119 students (31.82%) fall into the incompetent RCT category. These findings demonstrate that students' RCT abilities in mathematics are largely at the basic and incompetent levels. Deep learning can enhance students' RCT. This study recommends that educators consistently implement deep learning project-based learning approaches and use a valid critical thinking instrument.

Introduction

Education plays a pivotal role in enhancing the quality of human resources. Educational institutions must adapt to rapid advances in science and technology (Bhismantara et al., 2024). Sustained attention is continuously directed toward educational progress to improve the quality of national education. High-quality education will cultivate superior and qualified human resources (Made et al., 2024). One of the primary factors in improving educational quality is teachers' competence. Furthermore, character education has become a crucial aspect in addressing the impacts of increasingly rapid technological development (Anisa Amalia Maisaroh & Sri Untari, 2024). Indonesia aims to achieve "Golden Age Indonesia 2045," with the millennial generation as a primary target. Therefore, fostering a young generation with resilient character who can compete in the global era is essential (Permatasari & Murdiono, 2022).

Another factor contributing to improved educational quality is students' cognitive ability. Students' cognitive ability to solve problems using Higher Order Thinking Skills (HOTS) is categorized as low in Indonesia compared with other nations (Solihin et al., 2024). This condition is evidenced by the results of the 2022 Programme for International Student Assessment (PISA). The PISA results indicate a reading proficiency score of 359, categorized as Lower Order Thinking Skills; mathematics proficiency of 366, falling into the same category; and science proficiency of 383, which also remains in the Lower Order Thinking Skills category. Although these results show improvement compared to 2018, they still do not reflect an optimal outcome.

Current issues concern the low scores of the 2025 High School Academic Competency Test (Choir, 2025). Although it is not used as a determinant for graduation, its scores still serve as a national representation of students' academic abilities and merit significant attention. Academic Competency Test items are designed not only to measure rote memorization but also to assess students' ability to apply concepts and evaluate their reasoning skills. The 2025 average Academic Competency Test scores for high school students were 36.1 for mathematics, 25.93 for English, and 55.38 for Indonesian. These issues regarding students' cognitive abilities have broad implications if not addressed promptly.

The low achievement in PISA and the Academic Competency Test indicates that the primary challenge in Indonesian education relates to HOTS (Widana et al., 2020). Several studies show that students' ability to solve HOTS-based test items remains a challenge across various education levels (Loyens et al., 2023). Performance-based assessment can comprehensively enhance critical thinking skills, specifically: analyzing information, evaluating evidence, constructing arguments, and solving contextual problems (Hyytinen et al., 2025). However, most of these research instruments have not yet been validated. Problem-based learning, inquiry-based learning, project-based learning, and collaborative learning have been shown to enhance critical thinking skills by involving analyzing problems, evaluating information, constructing arguments, and making decisions (Q. Wang & Abdullah, 2024). Nevertheless, critical thinking remains suboptimal because the implementation of learning approaches and tools is not yet effective. Problem-based learning positively impacts critical thinking by helping students identify problems, analyze information, evaluate alternative solutions, construct arguments, and make decisions (Darwis et al., 2024). Implementing problem-based learning using Wordwall can positively contribute to mathematical critical thinking skills, specifically: identifying information, constructing mathematical models, developing solution strategies, and drawing conclusions (Mudrika et al., 2024). Digital learning media based on scaffolding has been shown to enhance critical thinking skills by providing tiered assistance, immediate feedback, and encouragement of active student engagement in problem-solving (Pastoriko et al., 2024).

Based on the findings from several studies regarding the development of students' critical thinking skills, a viable solution for educators is to adopt a deep learning approach. The deep learning approach is student-centered, allowing students to construct knowledge by solving complex problems. This approach is increasingly vital for preparing students to face global challenges (Rahayu et al., 2022). Deep learning is a process for acquiring six global competencies. Fullan et al. (2018) character, citizenship, collaboration, communication, creativity, and critical thinking. Deep learning encompasses three dimensions Marton & Saljo (1976); 1) mindful learning, which is learning focused on full awareness, meaning that students are truly present, both mentally and emotionally, in the learning process. Mindful learning embraces the diversity of students' learning styles Jeet & Pant (2023) and can enhance understanding and cognitive flexibility in learning; 2) meaningful learning, which refers to significant learning. Meaningful learning encourages students to develop critical and creative thinking skills related to the real world. Masayu Andayanie et al.

(2025), and 3) joyful learning, which refers to an enjoyable and motivating learning experience (Feriyanto & Anjariyah, 2024).

The objective of deep learning is to realize the Graduate Profile Puskurjar (2025), which includes: 1) possessing faith and devotion to God Almighty, 2) exhibiting good citizenship, 3) being capable of critical thinking, 4) possessing creativity, 5) being capable of collaboration, 6) demonstrating independence, 7) maintaining health, and 8) possessing strong communication skills. The levels of deep learning comprise: 1) excellence, 2) secure, 3) developing, 4) foundation, and 5) incompetence. The excellence category of deep learning uses operational verbs reflecting (Puskurjar, 2025). According to the SOLO (Structure of Observed Learning Outcomes) Taxonomy, the excellence level of deep learning employs operational verbs associated with deep abstract thinking. According to the revised Bloom's Taxonomy, the excellence level of deep learning employs operational verbs such as creating and evaluating. The secure category of deep learning utilizes the operational verb applying. According to the SOLO Taxonomy, the secure level of deep learning uses operational verbs associated with relational thinking, whereas the revised Bloom's Taxonomy uses operational verbs such as analyzing and applying.

The SOLO Taxonomy encompasses five dimensions Huang et al. (2024); 1) pre-structural, 2) uni-structural, 3) multi-structural, 4) relational, and 5) extended abstract. The first three dimensions constitute Lower Order Thinking Skills (LOTS), while the fourth and fifth dimensions represent HOTS. The dimensions and operational verbs in the HOTS-Munali SOLO Taxonomy Munali (2023) the relational dimension, with the operational verbs: distinguishing, classifying, investigating, predicting, assessing, decision-making, planning, and proving; and 2) the extended abstract dimension, with the operational verbs: formulating hypotheses based on criteria, creating something new, and problem-solving.

Several relevant studies on deep learning include integrating it into innovative education, including problem-based and project-based learning (Zhang, 2020; Zhu & Zhang, 2022). The dimensions of deep learning measurement (C. Wang et al. (2022) the cognitive dimension: knowledge and critical thinking, 2) the capability dimension: metacognition, collaboration, and innovation, and 3) the emotional dimension: learning motivation, engagement, and self-efficacy. Design-Based Learning (DBL) can enhance student satisfaction with deep learning (Weng et al., 2023). The dimensions of Design-Based Learning (DBL) are: problem-solving, critical thinking, and motivation. Pre-service teachers in blended learning environments perceive deep learning as high, and demographic factors do not influence this perception (Koca & Tatli, 2022). The dimensions of deep learning perception include meaningful learning, integrating new knowledge with prior knowledge, reflection and deep understanding, and high cognitive engagement. Demographic factors include gender, field of study, grade level, and previous educational background. A limitation of this research is that high perceptions do not necessarily reflect actual deep learning.

Meaningful learning helps students develop critical thinking and problem-solving skills through project-based learning (Feriyanto & Anjariyah, 2024). By connecting project-based learning to real-world situations, students become more motivated to learn, participate actively throughout the learning process, and construct a deeper understanding (Putri, 2024). The implementation of deep learning in schools produces impacts demonstrated through three indicators: 1) increased student engagement, 2) reasoning ability, and 3) self-confidence (Prihantoro et al., 2025). The student engagement indicator increased from 52% to 75% before and after implementing deep learning. The reasoning ability indicator increased from an average of 64 to 88, and the self-confidence indicator increased from 45% to 76%.

The project-based learning model within a deep learning approach (Munali et al. (2025) mindful learning, meaningful learning, and joyful learning. Mindful learning is characterized by outdoor learning activities, in which students create educational videos through collaborative group work. Meaningful learning takes place within the classroom, where students present their educational videos and engage in discussions. Joyful learning focuses on enjoyable learning, characterized by interactions between students and between students and educators. The project-based learning model immerses students in learning experiences related to daily life, motivating them to think critically and creatively and to collaborate (Agustika & Diputra, 2025). Research findings indicate that the project-based deep learning approach can enhance the creativity of both teachers and students (Wahyuni et al., 2024).

Applying the project-based learning model within a deep learning approach not only enhances in-depth understanding but also helps develop 21st-century skills, such as collaboration, communication, critical thinking, creative thinking, and problem-solving abilities (Taufik et al., 2025; Zulyusri et al., 2023). Teachers are advised to design challenging project-based learning models, create space for reflection, and use digital technology effectively so students can internalize concepts and apply them in the real world (Taufik et al., 2025).

Based on several theoretical studies and relevant research concerning deep learning, it can be concluded that deep learning is a pedagogical approach aimed at developing cognitive, affective, and psychomotor aspects in depth. In the cognitive aspect, HOTS-based capabilities include: critical thinking, creative thinking, and problem-solving. Enhancements in critical thinking involve: 1) performance-based assessment with the operational verbs: analyzing information, evaluating evidence, constructing arguments, and problem-solving Hyytinen et al. (2025), 2) problem-based learning, inquiry-based learning, project-based learning, and collaborative learning with the operational verbs: analyzing problems, evaluating, constructing arguments, and decision-making (Q. Wang & Abdullah (2024), 3) problem-based learning with the operational verbs: encouraging exploration, collaboration, and in-depth reasoning Darwis et al. (2024), 4) problem-based learning with Wordwall with the operational verbs: identifying information, constructing mathematical models, developing solution strategies, and drawing conclusions (Mudrika et al. (2024), and 5) the use of digital learning media based on scaffolding with the operational verbs: providing immediate feedback and encouraging active student engagement in problem-solving (Pastoriko et al., 2024).

Based on the aforementioned research on learning approaches to enhance critical thinking skills, the identified research gap is a deep learning approach focused on the meaningful learning dimension. In this study, the meaningful learning dimension represents critical thinking ability. Furthermore, the synthesis of the previously mentioned operational verbs is identical to the operational verbs of the SOLO HOTS-Munali Taxonomy within the relational dimension. This research is novel in integrating the meaningful learning dimension, specifically critical thinking, with the relational dimension of the SOLO HOTS-Munali Taxonomy, resulting in Relational Critical Thinking (RCT). Relational Critical Thinking (RCT) is defined as the ability to think critically using operational verbs derived from the relational dimension of the SOLO HOTS-Munali Taxonomy. The operational verbs used to measure RCT are: distinguishing, classifying, investigating, predicting, assessing, decision-making, planning, and proving. Consequently, this study aims to analyze students' Relational Critical Thinking (RCT) abilities using the relational dimension in the context of mathematics. Measuring RCT serves as a pilot study for implementing the deep learning approach currently being developed by the Government of Indonesia. RCT ability is classified into five categories: 1) excellence, 2) secure, 3) developing, 4) foundation, and 5) incompetence. RCT contributes to the need for educators to implement deep learning approaches to enhance critical thinking skills. The variable in this study is Relational Critical Thinking (RCT). Based on this variable and the research objective, the research problem is formulated as follows: (1) How is the students' RCT ability in mathematics in Banten Province? (2) How can students'

RCT ability in mathematics be improved in Banten Province? Research hypotheses: (1) The students' RCT ability in mathematics in Banten Province is in the low category; (2) The students' RCT ability can be improved through the deep learning approach.

Method

Research Methodology

This study uses a quantitative research methodology and applies data analysis techniques based on the Rasch model, implemented in Winsteps 4.0.1. The Rasch model is a psychometric technique that improves instrument accuracy by identifying respondent ability and determining item difficulty and question level (Bond & Fox, 2013; Sofyan et al., 2026). The Rasch model identifies respondent ability and item difficulty for both dichotomous and polytomous data, ensuring adherence to interval scale measurement (Tennant & Conaghan, 2007). The Rasch model considers two parameters: respondent ability and item difficulty. It describes the relationship between respondents and test items on a common logit scale by converting ordinal scales into interval scales (Davidowitz & Potgieter, 2016; Sumintoro et al., 2015). This study uses the Rasch model because it only measures the respondents' abilities, which include: 1) student fit order, 2) student reliability alpha Cronbach, 3) student reliability, 4) mean student measure, and 5) student measure. To ensure that respondents and test items align with the characteristics of the Rasch model, several assumptions must be met Tabatabaee-Yazdi et al. (2018) unidimensionality, group invariance (monotonicity), and local independence. Unidimensionality implies that the items measure a single underlying construct (Baghaei, 2009). Group invariance dictates that respondents of varying ability levels, from low to high, exhibit a monotonic increase in their responses to the items. Local independence signifies that each test item and respondent is independent; there is no association between individual items or between individual respondents. If these three assumptions are met, proceed with data analysis. Data analysis is conducted to determine which respondents and items fit the Rasch model characteristics, which is referred to as "Rasch model fit." If respondents and items do not fit the Rasch model, they are removed. Once the respondents and items fit the Rasch model, further analysis is conducted. These results serve as research findings for discussion.

Sampling Techniques and Samples

The sampling technique used was random sampling. The research subjects consisted of Senior High Schools (SMA) and Islamic Senior High Schools (Madrasah Aliyah) in Banten Province. The specific research samples included SMA An-Nurmaniyah (Tangerang City), Madrasah Aliyah Negeri 2 (Tangerang Regency), Madrasah Aliyah Negeri 2 (Serang City), and Madrasah Aliyah Jamiyyah Islamiyyah (South Tangerang City). The total research sample comprised 440 students enrolled in the odd semester of the 2024/2025 academic year in mathematics.

Time and Place

The researcher resides in South Tangerang City. Leveraging local professional networks, the researcher received recommendations for potential study sites near Tangerang City. Following these recommendations, the researcher formally requested research permits from the principals and heads of the selected Islamic senior high schools (Madrasah Aliyah) in Banten Province in early September 2024. Upon receiving approval, the researcher coordinated with the respective mathematics teachers. The study was conducted from September 2024 to October 2024.

Research Procedure

The researcher submitted a formal request for research authorization to the Institute for Research and Community Service at Indraprasta PGRI University. The researcher then distributed research permit applications to several principals and heads of Islamic senior high schools (Madrasah Aliyah) in Banten Province. Upon receiving institutional approval from the respective principals and heads, the researcher coordinated with the mathematics teachers and disseminated the Relational Critical Thinking (RCT) instruments. The research stages are as shown in Image 1 below.

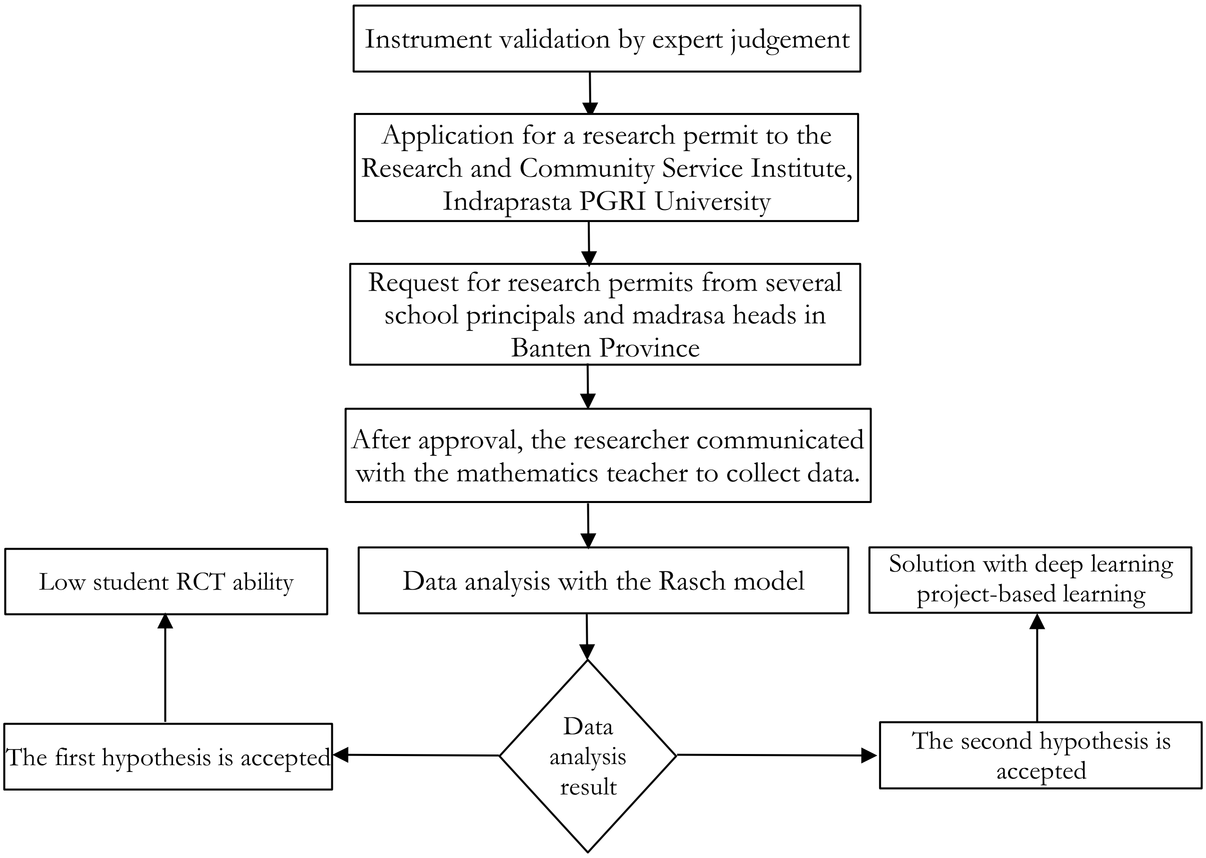

Image 1. Research Procedures

Data Collection Technique

Data collection was conducted using Google Forms. The researcher disseminated the Relational Critical Thinking (RCT) instrument, consisting of 15 polytomous essay items covering Three-Dimensional Geometry and Statistics, to the mathematics teachers. Before administering the RCT instrument, the researcher conducted a content validity test. Five experts with doctoral degrees conducted this validation: two specializing in mathematics and three in educational evaluation. The content validity analysis utilized Aiken's V coefficient (Ilyana Ismarau Tajuddin et al., 2025; L.R., 1985). Aiken's V validity scores for items 1 through 15 were 0.87, which is greater than the 0.70 threshold; therefore, it was concluded that the RCT instrument possessed high content validity and was suitable for measurement. The essay items were scored using an analytical rubric. The maximum scores for the items were as follows: items 1, 3, 5, 6, 10, 11, and 14 each had a maximum score of 13; items 2, 4, 9, 12, 13, and 15 each had a maximum score of 10; and items 7 and 8 each had a maximum score of 9.

Data Analysis Technique

In this paper, the researcher analyzes students' Relational Critical Thinking (RCT) capabilities based on: 1) student fit order, 2) student reliability Cronbach's Alpha, 3) student reliability, 4) mean student measure, and 5) student measure or RCT proficiency levels. The various aspects and criteria used in the data analysis technique employing the Rasch model Munali & Alifah (2024a) are presented in Table 1 below.

Table 1. Rasch Model Data Analysis Technique

Aspect	Criteria
Undimension	The unidimensionality criterion is met if the score in the Raw Variance Explained by Measures row and the Empirical column is at least 20% (James et al., 1979; Muhammad et al., 2023).
Local independent	The local independence criterion is met if the score in the Residual Correlation column is < 0.20 (Burcu Tunç, 2023; Christensen et al., 2017).
Invariance group	The group invariance criterion is met if the Average Measure score for each test item shows an increasing trend (Burcu Tunç, 2023; Kang et al., 2018).
Item of fit and student fit	The criterion for one of the assumptions is met if the scores fall within the following ranges: 0.50 < Outfit MNSQ < 1.50; -2.00 < Outfit ZSTD < +2.00; or 0.40 < Point Measure Correlation < 0.85 (Chan et al., 2014; Medriati et al., 2022).
Instrument and item reliability	The reliability coefficient of an instrument is considered acceptable if the Cronbach's Alpha (KR-20) ≥0.70 (Santun Naga, 2012). The interpretation of the item reliability coefficient is as follows: less than 0.67 is considered the "weak" category; the range of 0.67 – 0.79 is "fair"; the range of 0.80 – 0.90 is "good"; the range of 0.91 – 0.94 is "very good"; and more than 0.94 is "excellent" (Medriati et al., 2022; Mohamad et al., 2015).

Results and Discussion

Student Fit

The criteria used to identify students who fit the Rasch model are that one of the Outfit MNSQ, Outfit ZSTD, or Point Measure Correlation scores must be met. If none of these three criteria are met, the student is considered a misfit and is excluded from the analysis. The criteria for fit students used are: 1) 0.50 < MNSQ < 1.50; 2) -2.00 < ZSTD < +2.00; and 3) 0.40 < Point Measure Correlation < 0.85. In this paper, the researcher uses the Outfit ZSTD criterion: -2.00 < ZSTD < +2.00. Before analyzing student abilities, the first step is to determine students who fit the Rasch model using Winsteps 4.0.1 software. Based on the results, 374 of 440 students fit the model. Meanwhile, the Rasch model identified 66 misfit students. In Table 2, the 66 misfit students do not meet the Outfit ZSTD criteria (-2.00 < ZSTD < +2.00). Some points related to misfit students: 1) the response pattern of students in answering test items is unusual or an outlier, meaning that high-ability students cannot correctly respond to easy test items, possibly due to lack of focus or carelessness, and 2) low-ability students can correctly respond to high test items, possibly because they guessed the answers. The results of the misfit student analysis are presented in the following Table 2.

Table 2. Student Misfit

Misfit	Total	Student Number
Student	66	395, 421, 386, 412, 387, 413, 439, 185, 436, 403, 429, 174, 112, 130, 271, 203, 219, 31, 234, 16, 132, 156, 54, 93, 288, 327, 377, 308, 12, 167, 126, 127, 41, 40, 229, 228, 354, 249, 313, 60, 209, 274, 162, 206, 106, 105, 369, 346, 347, 243, 25, 141, 291, 330, 363, 76, 159, 57, 96, 188, 258, 88, 177, 286, 201, 322.

After removing 66 student misfits from the data, we re-analyzed the remaining data. The re-analysis showed that 374 students fit the Rasch model. Table 3 presents some of the student-fit data.

Table 3. Student Fit

Student Number	Measure	Outfit ZSTD
1	2.42	-0.09
411	0.11	1.5
Mean	1.47	-0.01

(Source: Output Winstep Version 4.0.1, processed in October 2024)

In Table 3, 374 students fit the Rasch model with Outfit ZSTD scores: -2.00 < ZSTD < +2.00. Table 3 informs: 1) student number 1 has the highest ability of 2.42 logits, 2) student number 411 has an ability of 0.11 logits, and 3) the average ability of students responding to the items holistically is 1.47 logits. After analyzing the fit, the next step is to test the assumptions of the Rasch model. The assumptions of the Rasch model include unidimensionality, local independence, and group invariance. Tables 4, 5, and 6 present the assumption tests below.

Table 4. Unidimensional

Raw Variance Explained By Measures	Observed Minimum	Asumtion
78.5%	20%	Unidimensional fulfilled

(Source: Output Winstep Version 4.0.1, processed in October 2024)

In Table 4, the row for raw variance explained by measures shows 78.5%, which is more than 20%, meaning the unidimensionality assumption is met.

Table 5. Local Independent

Loading	Items
-0.01	4
-0.02	11
-0.02	5
-0.08	6

(Source: Output Winstep Versiom 4.0.1, processed in October 2024)

In Table 5, the scores in the loading column are less than 0.20, meaning the local independence assumption is met.

Table 6. Invariation Group

Ability Mean	Items
0.37 - 1.68	4
0.42 - 1.59	6
0.57 - 2.18	11
0.23 - 3.33	4

(Source: Output Winstep Versiom 4.0.1, processed in October 2024)

In Table 6, in the Ability Mean column for each item, there is an increase, meaning the assumption of group invariance is met.

Student Reliability Cronbach's Alpha (KR-20), Student Reliability, and Mean Student Measure

Student reliability Cronbach's Alpha, student reliability, and mean student measure, as in Table 7 below.

Table 7. Student Reliability Cronbach's Alpha

Student Reliability Cronbach's Alpha (KR-20)	Student Reliability	Mean Student Measure
0.62	0.69	1.46

(Source: Output Winstep Version 4.0.1, processed in October 2024)

In Table 7, the student reliability coefficient score Cronbach's Alpha (KR-20) is 0.62 < 0.70. The student's reliability score is holistically categorised as weak. The result is caused by: 1) a teacher-centred learning approach. This is in line with the opinion Munali & Alifah (2025); Rahayu et al. (2022) and 2) Indonesian students respond to HOTS-based questions in the low category (Widana & Ratnaya, 2021). This is consistent with the 2022 PISA results (Solihin et al., 2024).

Student Reliability

In Table 7, the student reliability score is 0.69, which is < 0.70. The student reliability score falls into the sufficient category. This indicates that 103 out of 374 students responded to the items.

Mean Student Measure

The mean student measure score shows the average of all students' responses to the test items. Table 7 shows that the mean student measure score is 1.46 logits > 0.00 logits, meaning students' average ability to respond to the test items is higher than the test items' difficulty level. The average RCT ability score of students is 1.46 logits, which, when converted to a scale of 100, is 43.84. This average score indicates that students' RCT ability is in the basic category. Student measures are presented in the following Table 8

Table 8. Student Measure

Student Measure (logit)	Student Measure (Scale:1-100)	Total Students	Category	Persentation
3.33	100	2	Extreme	-
2.42	73	103	Developing	103 or 27.54%
1.93	58	3	Foundation	
1.79	54	33	Foundation	
1.67	50	13	Foundation	
1.55	47	49	Foundation	
1.44	43	9	Foundation	152 or 40.64%
1.33	40	8	Foundation	
1.11	33	34	Foundation	
1.01	30	3	Foundation	
0.91	27	25	Incompetence	
0.82	25	5	Incompetence	
0.73	22	5	Incompetence	
0.65	20	17	Incompetence	
0.57	17	14	Incompetence	119 or 31.82%
0.49	15	5	Incompetence	
0.42	13	24	Incompetence	
0.27	8	17	Incompetence	
0.19	6	2	Incompetence	
0.11	3	3	Incompetence	
Total Students		374		

In Table 8, the information provided is: 1) student ability (student measure) of 3.33 logits or a scale (1-100) of 100, with 2 students categorised as extreme items (either all correct or all incorrect), thus these students are misfits, 2) student ability of 2.42 logits or a scale (1-100) of 73, with 103 students categorised as developing, 3) student ability within the interval 1.01≤logit≤1.93 or a scale (1-100) of 152 persons categorised as foundation, and 4) student ability within the interval 0.11≤logit≤0.91 or a scale (1-100) of 119 students categorised incompetence.

First Hypothesis

Research results: RCT ability in the developing category with 103 students or 27.54%, RCT ability in the foundation category with 152 students or 40.64%, and RCT ability in the incompetence category with 119 students or 31.82%. These research results indicate that RCT ability in mathematics is in the foundation and incompetence or low categories. These research results are in line with PISA results, which state that students' ability to respond to HOTS-based questions, in this case, critical thinking ability, is in the low category Solihin et al. (2024), and in line with the 2025 Academic Competency Test results, with a low category (Choir, 2025). The results indicate that the hypothesis that students' Relational Critical Thinking (RCT) ability in mathematics subjects in Banten Province falls in the low category is supported.

Second Hypothesis

The results of this study were then confirmed with educators as research samples, who affirmed that the learning used is still teacher-centered. The findings recommend shifting learning from teacher-centered to student-centered through a deep learning approach. Educators are currently using the deep learning approach at the stage of creativity for both educators and students Wahyuni et al. (2024) and have not yet reached the stage of enhancing critical thinking skills. The deep learning approach currently used by educators is at the mindful and joyful learning dimensions. Therefore, the deep learning approach needs continuous development, as it has been shown to enhance student engagement, reasoning ability, and self-confidence. This aligns with the research findings (Prihantoro et al., 2025). However, several challenges remain in implementing deep learning in the field.

The application of the deep learning approach has several advantages and challenges. Some advantages and challenges in the application of deep learning Feri et al. (2025); 1) Advantage: increasing student engagement and motivation. Challenges: lack of teacher readiness and training; 2) Benefits: strengthening critical thinking, creative thinking, and problem-solving skills. Challenges: a rigid curriculum that causes teachers to focus on the curriculum and learning materials not linked to the real world; 3) Benefits: encouraging empathy, collaboration, and skills. Challenge: limited school facilities and infrastructure; and 4) Benefit: building independence and lifelong learning habits. Challenge: resistance to pedagogical innovation. Teachers should create learning innovations that can increase students' interest and motivation, making learning more challenging.

The results of this study further emphasize that students' low ability in Relational Critical Thinking (RCT) is closely related to the suboptimal implementation of HOTS-based learning. This finding is in line with research Sepriyanti et al. (2022), which states that 21st-century learning has a significant impact on improving HOTS. Additionally, students' critical thinking skills are categorized as low, especially in the dimensions of analysis, evaluation, and inference (Nur Kartika et al., 2026). Empirical studies on mathematics learning also show that students still struggle to solve HOTS-based questions because they are unfamiliar with contextual questions and HOTS activities, especially in critical and creative thinking skills (Nizar Zulfikar et al., 2025). This suggests that conventional learning has not yet been able to develop RCT skills optimally. Therefore, applying deep learning through problem-solving learning models, project-based learning, discovery-based learning, and STEAM learning is important to enhance engagement, conceptual understanding, and sustainable confidence.

Some deep learning approaches that can be used: problem-based learning, project-based learning Munali et al. (2025), STEAM-based learning Munali & Alifah (2024b), inquiry-based learning and reflective teaching (Prihantoro et al., 2025). Some of these deep learning approaches have proven effective in creating deep learning because they are student-centred, encourage active student engagement, emphasise contextual learning, and improve student learning outcomes (Bell, 2010). The results of the study indicate that the hypothesis stating that improving students' Relational Critical Thinking (RCT) abilities can be achieved through a deep learning approach has been proven. This research highlights the need to enhance students' relational critical thinking (RCT) abilities through a deep learning approach, especially in the dimension of meaningful learning. The meaningful learning dimension emphasizes the importance of developing valid critical-thinking instruments. Based on the research results, the recommendation for further research is for educators to implement a deep learning project-based learning approach sustainably and use valid critical thinking instruments.

Conclusion

The conclusion of the research results can be written as follows: 1) the Relational Critical Thinking (RCT) ability of students in mathematics subjects in Banten Province is in the foundation and incompetence category, and 2) the improvement of students' relational critical thinking (RCT) ability can be achieved through a deep learning approach. This research provides information that improving students' relational critical thinking (RCT) ability in mathematics subjects in Banten Province can be achieved through a deep learning approach, especially in the dimension of meaningful learning. The dimension of meaningful learning emphasizes the development of valid instruments for critical thinking. This research recommends that educators continuously apply the deep learning project-based learning approach and use valid critical-thinking instruments. Several deep learning approaches that can enhance critical thinking skills include: problem-based learning, project-based learning, STEAM, inquiry-based learning, and reflective teaching.

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