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A Qualitative Analysis of Critical Thinking Skills in High School Mathematics: The Case of Arithmetic Sequences

Rani Ramdian[1*], Mohamad Gilar Jatisunda[1]

[1] Department of Mathematics Education, Universitas Majalengka, Indonesia
*Correspondence: ramdianrani@gmail.com

Abstract
This study analyses students' critical thinking skills in solving arithmetic sequence problems using NVivo software. Situated within the context of 21st-century education that emphasizes higher-order thinking, this research addresses the challenge of assessing complex reasoning processes, which traditional methods often fail to capture. The objective is to evaluate critical thinking based on Ennis's five indicators by analyzing qualitative data from student responses. This study employed a qualitative descriptive design with a non-participatory observation method, involving 15 eleventh-grade students from a senior high school in Majalengka Regency, Indonesia, selected through purposive sampling. Data were collected via written tests on arithmetic sequences, semi-structured interviews, and observation, and subsequently analyzed using NVivo to code and identify patterns based on Ennis's critical thinking indicators. The results revealed that while a majority of students (73.33%) could provide straightforward explanations, most struggled with higher-order skills; 66.66% were unable to build fundamental skills, 86.66% could not provide further explanations, and 73.33% failed to organize strategies and tactics. Learning difficulties were attributed to conceptual misunderstandings of formulas, monotonous instruction, and limited time for review. These findings suggest that current pedagogical approaches are insufficient for developing advanced critical thinking skills. The study highlights the need for integrated instructional models that combine conceptual reinforcement with strategic reasoning exercises and suggests that technology-supported qualitative analysis is a valuable tool for a more nuanced assessment of student reasoning.

Keywords: Arithmetic Sequences; Critical Thinking; Learning Difficulties; Mathematics Education; Nvivo; Qualitative Analysis

INTRODUCTION

In the era of the Fourth Industrial Revolution, rapid advancements in science and technology are reshaping multiple sectors, including education (Mattawang & Syarif, 2023; Oke & Fernandes, 2020; Uleanya, 2023). This transformation has driven global education systems to prioritise the mastery of 21st-century competencies, critical thinking, creativity, collaboration, and communication, as essential skills for navigating increasingly complex socio-economic and technological landscapes (OECD, 2018; Rodríguez-Flores et al., 2025; Thornhill-Miller et al., 2023). In Indonesia, these imperatives are reflected in national education policies, where the Ministry of National Education, through the Standar Isi (Permendiknas No. 22 Tahun 2006), mandates the cultivation of logical, critical, analytical, creative, and innovative thinking skills to prepare students for both national and global competition (Putra &

Afrilia, 2020; Sukma & Priatna, 2021).

Critical thinking, defined as purposeful and self-regulatory judgment, entails analysing, evaluating, and synthesising information to guide beliefs and actions (Ennis, 1996; Facione, 2015; Ruminski, 2013). Such skills enable students to approach problems from multiple perspectives, rigorously evaluate arguments, and make informed decisions (Koga, 2022; Nurhikmayati, 2019). In mathematics education, critical thinking is recognised as a vital higher-order thinking skill that supports students' ability to interpret, reason, and solve complex problems (Afriansyah et al., 2021; Setiana et al., 2021). Ennis (1985) identifies five indicators of critical thinking: elementary clarification, basic support, inference, advanced clarification, and strategies and tactics, each reflecting distinct cognitive demands in reasoning processes.

However, assessing these indicators in mathematics classrooms remains challenging. Conventional assessment formats often fail to capture the depth, structure, and contextual dynamics of students' reasoning (Goos, 2014; Martínez et al., 2009). Predominantly, written assessments and observation checklists have been employed, yet these approaches yield only surface-level insights and neglect the nuanced cognitive processes underlying students' responses (Afriansyah et al., 2021; Setiana et al., 2021). Such limitations risk obscuring the manifestation of specific critical thinking indicators in problem-solving contexts (Firdaus et al., 2015; Jablonka, 2014).

A growing body of research highlights the potential of technology-assisted qualitative approaches to address these limitations. NVivo, for instance, enables systematic coding, categorisation, and thematic interpretation of verbal and written explanations, offering more profound insights into students' reasoning (Guo, 2022; Watling et al., 2012). Despite this, applications of NVivo in mathematics education remain scarce, particularly in Indonesian secondary school contexts. Previous studies have established the centrality of critical thinking in mathematics learning (Arisoy & Aybek, 2021; Costa et al., 2020; Hattori et al., 2025) and demonstrated that integrating higher-order thinking skills enhances problem-solving and fosters reasoning dispositions (Aziz & Kharis, 2021; Rahmawati et al., 2020). International research further indicates that technology-assisted learning can enhance critical thinking by providing interactive, adaptive, and context-rich feedback (Abrami et al., 2015; Tashtoush et al., 2025), with emerging evidence supporting the use of artificial intelligence as a promising tool to strengthen mathematical reasoning and metacognitive regulation (Arifin et al., 2025). However, most of these investigations have continued to rely on traditional assessment methods, such as paper-based tests or manual scoring, which may fail to adequately capture the complexity of students' reasoning.

This gap is noteworthy for two reasons. First, NVivo offers robust capabilities

for uncovering subtle patterns in students' responses, enabling educators to move beyond surface-level evaluations (Sidik & Mulya, 2012). Second, there is a paucity of research applying qualitative data analysis software to assess critical thinking in specific mathematics topics, such as arithmetic sequences, which are conceptually significant in bridging algebraic and advanced mathematical understanding. Therefore, this study aims to analyse students' responses to arithmetic sequence problems using NVivo software to evaluate critical thinking abilities based on Ennis's indicators. By employing a technology-supported qualitative approach, this research seeks to reveal reasoning patterns that conventional assessments often overlook. The findings are expected to inform the design of more effective instructional strategies, advance technology-based assessment practices, and provide a novel perspective on leveraging qualitative analysis tools to enhance the evaluation of critical thinking in mathematics education.

METHODS

This study employed a qualitative descriptive design with a non-participatory observation method, which is considered adequate for capturing authentic learning behaviours without researcher interference (Speed, 2019). The design was selected to obtain an in-depth understanding of students' critical thinking processes when solving problems on arithmetic sequences, aligning with approaches in mathematics education research that emphasise contextual and activity-based analysis (Gündoğan & Öztürk, 2023). The research sought to identify indicators of critical thinking, as defined by Ennis (1993), through students' written responses and follow-up interviews, ensuring the assessment captured both cognitive processes and reasoning quality.

The research population comprised senior high school students in Majalengka Regency, Indonesia. The sample consisted of 15 Grade XI students from SMA Negeri 1 Kadipaten, selected using purposive sampling, a method that allows researchers to deliberately choose participants who possess specific characteristics relevant to the study's objectives (Robinson, 2014). This selection was based on the consideration that the class had relatively homogeneous mathematical abilities, enabling more precise identification of differences in critical thinking performance. Four main instruments were used in this study:

1. Test items: A set of arithmetic sequence problems developed according to the mathematics curriculum, validated by content experts, and designed to elicit various critical thinking indicators.
2. Interview guidelines: Semi-structured and unstructured interview prompts were prepared to explore students' problem-solving reasoning and difficulties in greater depth.
3. Expert validation sheets: Instruments provided to two categories of experts,

namely subject matter experts and media experts, to assess the validity of the test and supporting materials.

4. Practicality sheets: Distributed to teachers and selected students to evaluate the practicality and usability of the developed materials in real classroom settings.

The study was conducted in three stages:

1. Preparation stage: Development and validation of test items and interview guidelines. Validation involved two subject matter experts and two media experts, whose feedback was used to refine the instruments.
2. Data collection stage: Administration of the arithmetic sequence test to the selected sample in a controlled classroom setting, followed by semi-structured interviews with participants to clarify and expand on their written responses.
3. Observation and recording: Non-participatory observation was carried out to record students' behaviour and strategies during problem solving without researcher intervention. Field notes were taken to capture contextual and behavioural cues.

Data were collected through written tests, direct observation, and interviews. The written responses were gathered immediately after the test session, while the interviews were audio-recorded with the participant's consent. Observational data were documented through field notes, ensuring the triangulation of data sources.

Qualitative data analysis was conducted using NVivo software. Student responses, interview transcripts, and observation notes were imported into NVivo for coding and analysis. Codes were derived both deductively, based on Ennis's five indicators of critical thinking (elementary clarification, basic support, inference, advanced clarification, and strategies/tactics), and inductively, allowing new themes to emerge from the data. The coding process involved categorising responses, identifying patterns, and mapping relationships among critical thinking indicators. The results were validated through peer debriefing with two independent qualitative researchers. The study received approval from the school administration and adhered to the principles of ethical research. Informed consent was obtained from all participants, and their anonymity was preserved by assigning pseudonyms in all research records. Data were stored securely in password-protected files accessible only to the research team.

RESULTS AND DISCUSSION

The analysis of students' responses to arithmetic sequence problems revealed various levels of critical thinking skills across five leading indicators: (1) Providing Simple Explanations, (2) Building Basic Skills, (3) Drawing Conclusions, (4) Providing Further Explanations, and (5) Organising Strategies and Tactics. Each indicator was represented as a node generated through NVivo coding, with comparison diagrams illustrating the distribution and relationships among nodes. The visual data provided

in Figures 1–6 demonstrate the trends, percentages, and categories identified in the analysis.

Providing Simple Explanations

Based on students' responses, this indicator was classified into two categories: Able to Provide Simple Explanations and Unable to Provide Simple Explanations. Figure 1 presents a comparison diagram showing the relationship between students' responses and the corresponding categories.



Figure 1. Providing Simple Explanations

A total of 11 students, representing 73.33% of the participants, were categorised as able to provide simple explanations. These students demonstrated a clear and systematic understanding of the concepts, delivering concise and relevant explanations that directly addressed the problems presented. Furthermore, they employed appropriate language to convey their ideas effectively. This group included students A, AY, DIS, KF, KNN, MAM, MI, MYRF, NN, SPF, and WAS. A total of four students, accounting for 26.66% of the participants, were identified as unable to provide simple explanations. These students encountered difficulties in formulating clear answers, expressing their ideas or solution steps in a straightforward manner, and linking their conceptual understanding to the required responses. This suggests a need for additional guidance and targeted instructional support to enhance their explanatory skills. The students in this category were IMK, MSS, NIR, and R. The results indicate that most students (73.33%) could provide straightforward explanations, while 26.66% required further guidance.

Building Basic Skills

Student responses were grouped into the "Able to Build Basic Skills and Unable to Build Basic Skills categories. Figure 2 illustrates the distribution.



Figure 2. Building Basic Skills

Analysis of students' ability to build fundamental skills revealed that only five students, representing 33.33% of the sample, demonstrated competence in this area. These students were able to effectively evaluate the given information, conduct in-depth analyses of observations, and draw accurate yet straightforward conclusions based on the available evidence. The students in this proficient group included A, IMK, KF, MAM, and MYRF. Their performance suggests a solid grasp of fundamental analytical processes, indicating that they possess the foundational reasoning skills needed to approach arithmetic sequence problems with confidence. In contrast, the majority of students—ten in total, or 66.66%—struggled to build fundamental skills. These students encountered notable challenges in understanding core arithmetic sequence concepts, linking these concepts to the basic skills required for problem-solving, and assessing the reliability of the information or sources provided. The students in this category included AY, DIS, KNN, MI, MSS, NIR, NN, R, SPF, and WAS. The predominance of this group underscores a critical learning gap that may hinder overall mathematical reasoning. It also highlights the need for targeted interventions, such as concept reinforcement, scaffolded practice activities, and guided analytical exercises, to enhance students' foundational competencies in arithmetic sequences.

Drawing Conclusions

Students' ability to conclude was divided into Able to Conclude and Unable to Conclude. Figure 3 depicts the distribution.

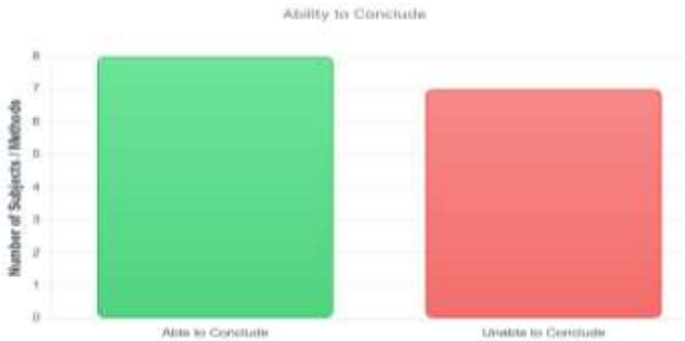

Figure 3. Drawing Conclusions

The analysis of students' ability to conclude showed that eight students, accounting for 53.33% of the total, demonstrated proficiency in this skill. These students were able to identify patterns or relationships within arithmetic sequence problems, apply systematic approaches to problem-solving, and use logical reasoning to arrive at accurate answers. They also effectively based their conclusions on relevant and sufficient information, reflecting a well-developed capacity for analytical thinking. The students in this category included A, DIS, IMK, KF, MAM, MSS, MYRF, and WAS. Their performance suggests a strong correlation between conceptual understanding and the ability to synthesise information into coherent conclusions.

Conversely, seven students, representing 46.66% of the group, were unable to draw accurate conclusions. These students encountered challenges in recognising underlying patterns or relationships within the problems, often committed logical or procedural errors, and struggled to produce conclusions that aligned with the solutions they generated. This group consisted of AY, KNN, MI, NIR, NN, R, and SPF. The near-equal distribution between proficient and struggling students suggests that, while more than half have developed this competency, a substantial proportion still requires targeted support. This support may include explicit instruction in pattern recognition, guided practice in structured problem-solving, and feedback aimed at correcting logical missteps to improve their overall reasoning process.

Providing Further Explanations

This indicator was divided into Able to Provide Further Explanations and Unable to Provide Further Explanations. Figure 4 shows the comparison.



Figure 4. Providing Further Explanations

The assessment of students' ability to provide further explanations revealed that only two students, representing 13.33% of the cohort, demonstrated competence in this area. These students, MAM and SPF, were able to thoroughly evaluate information, conduct an in-depth analysis of observations, and formulate conclusions derived from their analytical processes. Their performance indicates an ability to extend beyond basic comprehension, engaging with information at a higher cognitive level and demonstrating skills aligned with advanced reasoning and synthesis.

In contrast, the vast majority of students—thirteen in total, or 86.66%—struggled

to provide further explanations. These students faced considerable challenges in grasping advanced concepts, connecting those concepts to the advanced skills required for complex problem-solving, and critically assessing the reliability of the sources or information provided. This group included A, AY, DIS, IMK, KF, KNN, MI, MSS, MYRF, NIR, NN, R, and WAS. The prevalence of difficulties in this category highlights a significant gap in higher-order thinking skills across the sample. Addressing this gap will require targeted instructional strategies such as scaffolded tasks that gradually introduce advanced concepts, explicit modelling of analytical reasoning, and structured opportunities for students to justify their conclusions with evidence.

Organising Strategies and Tactics

Responses were categorised as Able to Organise Strategies and Tactics and Unable to Organise Strategies and Tactics. Figure 5 presents the distribution.



Figure 5. Organising Strategies and Tactics

The evaluation of students' ability to organise strategies and tactics showed that four students, representing 26.66% of the total, demonstrated proficiency in this area. These students—DIS, KF, MAM, and MYRF—were able to accurately assess the information provided, conduct practical situational analysis, and formulate logical strategies and tactics suited to the given problems. Their performance reflects a capacity to integrate analytical thinking with structured planning, enabling them to devise coherent and purposeful approaches to problem-solving. In contrast, eleven students, or 73.33% of the group, were unable to organise strategies and tactics effectively. This group, comprising A, AY, IMK, KNN, MI, MSS, NIR, NN, R, SPF, and WAS, faced challenges in understanding key strategic and tactical concepts, applying strategies to the task context, and developing systematic solutions. The predominance of students in this category indicates a notable weakness in planning and execution skills. Addressing this issue will require instructional interventions that emphasise explicit teaching of strategic frameworks, guided practice in applying strategies to diverse scenarios, and opportunities for collaborative problem-solving where students can observe and model practical tactical thinking.

Analysis of Learning Difficulties

In addition to the above indicators, student interviews were analysed to identify learning difficulties in arithmetic sequences using NVivo mapping. Figure 6 provides a visual representation of the relationship between categories of learning difficulties.



Figure 6. Students' Learning Difficulties

The overall analysis revealed several underlying challenges that hindered student performance in mathematical problem-solving, particularly in the context of arithmetic sequences. Several students consistently struggled with understanding core mathematical concepts, particularly formulas and word problems. The inability to fully grasp formulas was often directly connected to their struggles in applying these formulas effectively when solving contextual problems. This interdependence between conceptual comprehension and application skills underscores the importance of strengthening foundational understanding before progressing to more complex problem-solving tasks. Beyond individual cognitive challenges, external factors also played a significant role. Monotonous teaching methods and limited time allocated for completing tasks emerged as critical barriers, both of which reduced student motivation and overall learning effectiveness. The perception among some students that the material itself was inherently problematic further compounded these issues, creating a cycle of low engagement and underperformance.

These challenges can be categorised into two primary aspects. The first involves conceptual understanding issues, which highlight the need for more precise, more engaging, and student-centred explanations that foster deeper comprehension. The second pertains to instructional and time management constraints, which call for the implementation of interactive, adaptive, and time-efficient learning approaches. Addressing both aspects in an integrated manner is essential for improving student outcomes, as it ensures that effective pedagogical strategies and conducive learning conditions support the development of cognitive skills.

Discussion

This study aimed to examine students' critical thinking skills in solving arithmetic

sequence problems across five indicators: Providing Simple Explanations, Building Basic Skills, Drawing Conclusions, Providing Further Explanations, and Organising Strategies and Tactics. Additionally, it explored the underlying learning difficulties contributing to students' performance disparities.

The overall analysis revealed that while most students demonstrated competence in providing simple explanations and drawing conclusions, significant challenges persisted in building basic skills, offering further explanations, and organising strategies and tactics. This uneven development of critical thinking abilities—characterised by strengths in basic explanatory competencies and weaknesses in higher-order reasoning and strategic problem-solving—is consistent with prior research indicating that students often excel in lower-order skills but struggle with tasks requiring deeper conceptual understanding and metacognitive regulation (Dolapcioglu & Doğanay, 2022; Manurung & Pappachan, 2025). Furthermore, studies in both formal and non-formal learning contexts confirm that gaps in foundational skills impede advancement toward sophisticated analytical competencies (Kintoko, Wulandari, & Siswanto, 2025; Setiana, Hakim, & Booribon, 2025). Consequently, targeted instructional designs such as discovery learning and authentic learning approaches are critical to bridging these gaps and fostering balanced development across all critical thinking indicators (Siswanto et al., 2025).

From a theoretical standpoint, the relatively high performance in Providing Simple Explanations may be attributed to the accessibility of this skill, which largely depends on recall and direct application of taught concepts (Duru & Obasi, 2023). However, the low proficiency in Providing Further Explanations and Organising Strategies suggests that many students have not transitioned from procedural fluency to conceptual mastery. This procedural-conceptual distinction is a well-documented factor influencing trajectories of mathematical achievement (Borji, Radmehr, & Font, 2021). The observed pattern aligns with theoretical frameworks proposing that critical thinking in mathematics develops progressively—from foundational comprehension to strategic synthesis—and requires deliberate instructional scaffolding to facilitate this cognitive transition (Evendi et al., 2022; Irshid, Khasawneh, & Al-Barakat, 2023). Moreover, fostering higher-order reasoning skills, such as argumentation and interpretation, is dependent on teacher education practices that balance conceptual mastery with procedural skills (Romero Ariza, Quesada Armenteros, & Estepa Castro, 2024).

When situated within the broader landscape of mathematics education research, these findings show partial alignment with existing literature. In educational contexts prioritising procedural fluency over conceptual reasoning, students frequently perform well on basic explanatory tasks but exhibit difficulty with complex reasoning and developing metacognitive strategies (Pepin, Biehler, & Gueudet, 2021; Suherman & Vidákovich, 2022). The present study's novelty lies in its integrated use of NVivo

software, which not only quantifies critical thinking skill gaps but also visualises the interconnections among indicators, providing a more transparent and diagnostic framework for designing targeted interventions. NVivo's capacity to systematise qualitative coding and visually represent complex relational data has been demonstrated to enhance both the clarity and depth of educational research findings (Limna, 2023; Siregar & Siregar, 2024).

The learning difficulties uncovered offer important explanatory context for the observed performance disparities. Conceptual misunderstandings—particularly related to formula application—were exacerbated by external factors such as monotonous instructional methods and limited time allocated for task completion (Nunes & Moreno, 2022; Radiamoda, 2024). These cognitive and environmental factors appear to reinforce each other, resulting in diminished student engagement and lower persistence in problem-solving activities (de la Fuente et al., 2023; Urhahne, 2021). This dual influence underscores the necessity for comprehensive improvement efforts that encompass not only content delivery but also the learning environment and instructional design, to foster meaningful engagement and sustained motivation for complex problem-solving (Abakah & Brijlall, 2024).

The implications of these findings are both theoretical and practical. Theoretically, the study highlights the interdependence between foundational skills and higher-order thinking within mathematical reasoning. Practically, it suggests the necessity for instructional models that integrate conceptual reinforcement, strategic reasoning exercises, and interactive learning methods. For example, incorporating problem-based learning with deliberate scaffolds can simultaneously build basic skills and cultivate strategic planning abilities. Moreover, optimising lesson time management is essential to facilitate deeper student engagement without compromising curriculum coverage.

Despite its contributions, this study has limitations. The relatively small sample size and focus on a single mathematical topic restrict the generalisability of the results. Additionally, although NVivo coding was systematic, qualitative interpretations inherently carry subjectivity. Future research should involve larger and more diverse samples, explore multiple mathematical domains, and adopt longitudinal designs to track the development of critical thinking over time. Experimental investigations evaluating the efficacy of targeted interventions, such as strategic reasoning workshops or adaptive digital learning tools, would further strengthen causal inferences regarding the improvement of these competencies.

CONCLUSION

Based on the analysis of students' critical thinking skills in solving arithmetic sequence problems, this study concludes that students exhibit varied levels of proficiency across the five critical thinking indicators identified by Ennis. While a majority of students

demonstrated competence in providing simple explanations (73.33%) and drawing conclusions (53.33%), significant weaknesses were observed in higher-order thinking skills. Specifically, most students struggled with building basic skills (66.66%), providing further explanations (86.66%), and organising strategies and tactics (73.33%). These findings address the research question by revealing an uneven development of critical thinking, where foundational skills are more developed than the advanced skills required for complex problem-solving.

The implications of this study are twofold. Theoretically, it highlights the interdependent relationship between basic and advanced critical thinking skills, suggesting that mastery of foundational competencies is a prerequisite for developing higher-order reasoning. Practically, the results underscore the need for instructional interventions that move beyond rote memorisation. Educators should implement strategies that foster analytical and strategic thinking, such as problem-based learning and scaffolded instruction. Furthermore, the identified learning difficulties, including monotonous teaching and time constraints, underscore the need to create a more engaging and supportive learning environment to enhance student motivation and performance.

This study is not without limitations. The findings are based on a small sample of 15 students from a single school, which limits the generalizability of the results to a broader population. The focus on a single mathematical topic, arithmetic sequences, also means that the conclusions may not apply to other areas of mathematics. Future research should aim to address these limitations by employing larger, more diverse samples and exploring critical thinking skills across various mathematical domains. Additionally, longitudinal studies could provide valuable insights into how these skills develop over time, while experimental research could assess the effectiveness of specific interventions designed to improve critical thinking in mathematics.

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