Profiling Statistical Reasoning Development of Junior High School Students in Indonesia: From Procedural to Analytical Thinking

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Received: September 15, 2025 Accepted: June 9, 2026 Online Published: August 7, 2026

doi:10.5430/jct.v15n3p125 URL: https://doi.org/10.5430/jct.v15n3p125

Abstract

In the digital era, statistical reasoning is a key competency required for students to interpret data and make evidence-based decisions. However, many students continue to struggle to progress beyond procedural stages toward deeper conceptual understanding. This study aims to identify the statistical reasoning profiles of eighth-grade students in Indonesia based on four developmental classifications: Idiosyncratic, Transitional, Quantitative, and Analytical. An exploratory case study design was employed with 27 students from a public junior high school in Bandung. Data were collected using the Statistical Reasoning Assessment Tool (SRAT) consisting of open-ended tasks and analyzed with a developmental rubric for statistical reasoning. Coding was conducted independently by two raters with high inter-rater reliability (Cohen's $\kappa = 0.87$). Descriptive statistics, chi-square tests, and qualitative analyses of reasoning patterns and misconceptions were used to address the research questions. The findings revealed that most students were situated at the Quantitative level (63%), followed by Transitional (33%), and Idiosyncratic (4%), with no students reaching the Analytical level. These results indicate that while students were able to recognize and organize statistical information, they had not yet developed higher-order analytical reasoning skills. The implications highlight the need for pedagogical strategies that leverage digital technologies to move students beyond procedural competence toward analytical reasoning, through multi-representational approaches, engagement with authentic datasets, and inquiry-based learning, thereby supporting the development of data literacy as a 21st-century competency.

Keywords: statistical reasoning, developmental levels, junior high school students, exploratory case study

1. Introduction

In today's digital era, statistical reasoning has emerged as a fundamental competency within mathematics education, encompassing the ability to reason about variation, uncertainty, and evidence-based decision-making. Statistical reasoning serves as a critical bridge connecting mathematical understanding to real-world applications, preparing learners to navigate an increasingly data-driven society where interpreting and analyzing data have become daily necessities (Gal & Geiger, 2022). Contemporary challenges in healthcare, technology, and economics are increasingly dependent on data-driven solutions (Burrill & Pfannkuch, 2024; Schreiter et al., 2024). Just as textual literacy drove economic growth and societal well-being, data literacy now emerges as an equally crucial skill for navigating the data-centric landscape of the 21st century (Harvard Data Science Review, 2025; Fagerlund et al., 2025).

Despite the importance of reasoning abilities for students, research reports consistently indicate that many students struggle to understand statistical concepts deeply. Research demonstrates that statistical ideas are frequently misunderstood and misapplied by students, with inappropriate reasoning about statistical concepts being widespread and persistent across all age levels (Garfield, 2002). These difficulties typically manifest when students are required to interpret data, recognize variation, understand uncertainty, and draw conclusions based on available evidence. Studies further reveal that students often become trapped at procedural reasoning levels, where they can perform calculations but fail to integrate statistical concepts into coherent understanding (Chan et al., 2016). At the university level, students consistently find statistics courses challenging, with many struggling to develop deep and flexible conceptual understanding, particularly emphasizing conceptual comprehension over procedural fluency (Silva & Sarnecka, 2025). First-year undergraduate students demonstrate limited understanding of statistical concepts, with most lacking declarative and conditional knowledge that inhibits their procedural knowledge when solving statistical problems (Makwakwa & Wessels, 2024; Putri et al., 2023).

Conversely, comprehensive research on students' statistical reasoning development has been extensively conducted in Western countries using well-established theoretical frameworks. Longitudinal and design-based research by Ben-Zvi (2008) and Garfield & Ben-Zvi (2008) successfully mapped students' statistical thinking stages systematically, ranging from intuitive understanding to advanced reasoning that encompasses informal inference and data-based argumentation. These findings provide robust theoretical foundations regarding how students across various age levels develop understanding of core statistical concepts such as distribution, variability, sampling, and uncertainty. However, similar empirical evidence remains severely limited in Southeast Asian regions, particularly Indonesia. Recent studies indicate that the majority of fifth-grade students in Indonesia remain at the idiosyncratic level in statistical literacy, with limited capacity for data interpretation and no students achieving quantitative or analytical proficiency (Büscher, 2024; Hasanah et al., 2024; North et al., 2014). Research at secondary education levels confirms similar conditions, where Indonesian high school students' statistical reasoning abilities require special attention in developing interpretation and data analysis competencies (Ariwinanda et al., 2022). This is further corroborated by Habibie et al. (2023), who found that the majority of Indonesian students demonstrated low statistical literacy on contextualized test items, with most students failing to master foundational descriptive statistics indicators. Within the broader Southeast Asian region, Chan et al. (2016) developed a validated framework for assessing statistical reasoning among Malaysian high school students, revealing that the majority remained at lower reasoning levels despite structured curriculum exposure. Similarly, Meylasari et al. (2021) documented that Indonesian student with moderate statistical thinking abilities consistently struggled to move beyond data description toward genuine interpretation and analysis. In a related vein, Rauhun et al. (2025) found that Indonesian junior high school students' persistent difficulties in mathematical problem-solving stemmed from a complex interplay of cognitive, linguistic, and affective barriers rather than a single unitary deficit, reinforcing the need for profiling approaches that capture this developmental complexity. At the primary level, Hasanah et al. (2024) found no Indonesian fifth-grade students reaching quantitative or analytical proficiency, underscoring a developmental gap that persists across grade levels. These converging findings from the Indonesian and Southeast Asian contexts indicate that the challenges are not incidental but structural, rooted in curricular emphases on procedural computation and limited instructional support for interpretive reasoning. The present study builds directly on this regional evidence base by profiling statistical reasoning at the eighth-grade level — a critical transitional stage underrepresented in existing Indonesian research — and by situating these profiles within the demands of an increasingly digital educational landscape.

Given these challenges, understanding students' statistical reasoning profiles becomes crucial, not only for mapping existing capabilities but also for identifying barriers to achieving higher-level reasoning. Profile identification enables educators to design learning experiences tailored to each student's specific needs, recognizing that individuals possess different reasoning patterns and learning approaches (Greiner et al., 2024). Furthermore, assessing students' statistical reasoning provides valuable insights for teachers and policymakers in aligning pedagogical approaches with digital society demands, where students must develop abilities beyond calculation to include statistical reasoning for data-driven decision-making (Statistics Teacher, 2024). This necessitates pedagogical strategies that optimize technology use while maintaining focus on developing deep conceptual understanding, making students' statistical reasoning profiles essential foundations for designing statistical education relevant to 21st-century needs.

Therefore, this research aims to identify students' statistical reasoning profiles based on developmental level classifications: Idiosyncratic (Level 1), characterized by intuitive and inconsistent reasoning; Transitional (Level 2), where students begin connecting data with basic interpretation; Quantitative (Level 3), involving systematic use of numerical and graphical information; and Analytical (Level 4), where learners critically evaluate data, integrate contextual knowledge, and draw valid conclusions (Garfield, 2002). In pursuit of these objectives, this research addresses three fundamental questions:

1. What are the statistical reasoning profiles of eighth-grade students in Indonesia?
2. How are students distributed across the four developmental reasoning levels?
3. What implications do these profiles hold for teaching and learning in the digital era?

2. Method

2.1 Research Design

This study employed an exploratory case study design to investigate the statistical reasoning profiles of eighth-grade students in Indonesia. The exploratory case study approach was chosen as it allows for in-depth investigation of a contemporary phenomenon within its real-life context, particularly when the boundaries between phenomenon and context are not clearly evident (Yin, 2018). This design is particularly appropriate for understanding complex cognitive processes such as statistical reasoning, where the goal is to explore and describe patterns rather than to test predetermined hypotheses (Stake, 1995). The exploratory nature of the study acknowledges the limited existing research on statistical reasoning profiles in the Indonesian context, making it essential to first understand what patterns exist before developing more targeted interventions.

The case study approach enables researchers to examine the statistical reasoning phenomenon holistically, considering the multiple factors that may influence students' cognitive processes, including their educational background, cultural context, and individual learning experiences. This research framework draws upon Garfield (2002) hierarchical model of statistical reasoning development, which conceptualizes statistical thinking as progressing through distinct developmental stages. The theoretical foundation guided both the instrument design and analysis approach, ensuring alignment between the research objectives and methodological implementation while allowing for the emergence of unexpected patterns that might be unique to the Indonesian educational context.

2.2 Participants

The target population for this study consisted of eighth-grade students aged 13-14 years enrolled in public junior high schools in Bandung, Indonesia. The study was conducted at one public junior high school selected through purposive sampling based on several criteria including implementation of the national curriculum with standard statistical content coverage, diverse student population representing various socio-economic backgrounds, willingness of school administration and mathematics teachers to participate, and accessibility for research implementation. This school was chosen as a typical case that could provide insights generalizable to similar educational contexts in urban Indonesia.

A total of 27 eighth-grade students participated in this exploratory case study, selected through convenience sampling from two mathematics classes. The sample comprised 15 female students (55.6%) and 12 male students (44.4%), reflecting the typical gender distribution in Indonesian secondary education. All participants had completed the prerequisite mathematics courses covering basic statistical concepts including data representation, measures of central tendency, and simple probability, as mandated by the Indonesian national curriculum. Inclusion criteria required that participants were enrolled in Grade VIII during the 2024 academic year, had no recorded learning disabilities that would impair mathematical reasoning, were present during the data collection session, and provided voluntary consent along with parental permission. Students who had been absent from more than 20% of mathematics classes in the preceding semester were excluded to ensure adequate exposure to statistical content.

Ethical approval was obtained from the university's Institutional Review Board and the regional education authority prior to data collection. Written informed consent was secured from both students and their parents or guardians, clearly explaining the research purpose, procedures, voluntary nature of participation, and data confidentiality measures. Participants were informed of their right to withdraw at any time without penalty, ensuring full compliance with ethical research standards.

2.3 Instrument

The primary data collection instrument was the Statistical Reasoning Assessment Tool (SRAT), specifically developed for this study based on established frameworks from Ben-Zvi and Garfield (2004) and Chan et al. (2016). The SRAT consists of six open-ended tasks designed to elicit students' reasoning processes across key statistical concepts while allowing for differentiation across four developmental levels. Each task was carefully constructed to target specific aspects of statistical reasoning, including data interpretation where students analyze datasets and draw conclusions about central tendencies and variability, graphical reasoning requiring interpretation and comparison of multiple representations, sampling and inference evaluation of conclusion validity, variability recognition in real-world contexts, probability and uncertainty reasoning, and comparative analysis of datasets to justify evidence-based claims.

Content validity was established through expert review by three statistics education researchers and two experienced mathematics teachers, followed by pilot testing with 12 students from a comparable school, leading to refinements in task wording and clarity. The instrument demonstrated acceptable internal consistency with Cronbach's alpha $\alpha = 0.78$, while test-retest reliability was established through a two-week interval administration with a subset of participants ($n = 15$), resulting in a correlation coefficient of $r = 0.82$.

Student responses were evaluated using a comprehensive rubric adapted from established frameworks by Garfield (2002) and Watson and Callingham (2003). The rubric delineates four hierarchical levels of statistical reasoning as presented in Table 1. The classification system progresses from basic intuitive responses to sophisticated analytical reasoning, providing a framework for understanding the developmental trajectory of students' statistical thinking capabilities.

Table 1. Levels of Statistical Reasoning

Level	Category	Description
1	Idiosyncratic	Responses are intuitive, fragmented, and lack conceptual basis. Students rely on personal experiences rather than data analysis, demonstrate inconsistent reasoning across similar tasks, and show limited use of statistical vocabulary.
2	Transitional	Demonstrates partial understanding with inconsistent application across tasks. Students show some recognition of data patterns but with basic statistical vocabulary and limited comprehension of underlying concepts.
3	Quantitative	Provides coherent explanations supported by data and evidence. Students demonstrate systematic use of statistical procedures, appropriate recognition of variability, and consistent application of statistical reasoning.
4	Analytical	Exhibits advanced reasoning by integrating multiple representations and higher-order inference. Students can critically evaluate statistical arguments, demonstrate sophisticated understanding of uncertainty, and synthesize evidence from various sources.

Each level represents a qualitatively different approach to statistical reasoning, with higher levels indicating more sophisticated cognitive processes and deeper understanding of statistical concepts. The rubric serves as both an assessment tool and a developmental framework, enabling researchers to identify not only where students currently perform but also the trajectory for their continued growth in statistical reasoning capabilities.

2.4 Data Collection Procedure

Data collection occurred during regular mathematics class periods over two consecutive days, with the lead researcher accompanied by the regular mathematics teacher to maintain a familiar environment for students. The 90-minute assessment session was divided into two 45-minute periods with a 10-minute break to prevent fatigue effects. Prior to task administration, students received standardized instructions emphasizing the importance of showing their thinking processes and reasoning rather than merely providing final answers, with clarifying questions about task requirements addressed without providing mathematical guidance.

All student responses were collected in written form using specially designed answer booklets that provided adequate space for extended explanations and diagram construction. Students were encouraged to use diagrams, tables, or other visual representations to support their reasoning, while audio recordings were made with consent to capture any verbal explanations during individual task completion. To ensure consistency across administration sessions, a detailed protocol was followed including standardized verbal instructions read verbatim, identical physical setup and materials, consistent timing procedures, and prohibition of calculators or digital tools to focus assessment on reasoning rather than computational ability.

2.5 Data Analysis

Student responses underwent systematic content analysis using the established rubric through a multi-stage coding process. Initial familiarization involved reading all responses completely to gain overall understanding of student reasoning patterns, followed by response segmentation where each student's work was divided into analyzable units corresponding to specific tasks and reasoning components. Two independent raters, the lead researcher and a trained graduate student in mathematics education, conducted primary coding of all responses according to the four-level rubric, achieving strong inter-rater reliability with Cohen's kappa $\kappa = 0.87$. Discrepancies between raters were resolved through discussion and consultation with a third expert when necessary.

Descriptive statistics were employed to characterize the distribution of students across reasoning levels, including frequency distributions, percentages, and cross-tabulations to address the research questions. Chi-square tests were conducted to examine potential associations between student characteristics such as gender and prior achievement with reasoning levels. Representative response excerpts were selected to illustrate the characteristics of each reasoning level based on three explicit criteria: (1) the response clearly exemplified the defining features of its assigned level as described in the rubric, with no ambiguous or borderline characteristics; (2) both raters independently assigned the response to the same level without initial discrepancy, ensuring inter-rater consensus on its typicality; and (3) the written response was sufficiently detailed and legible to allow meaningful qualitative illustration of level-specific reasoning. Where multiple responses met all three criteria within a given level, the excerpt demonstrating the broadest range of level-characteristic features was selected. This systematic selection procedure was designed to minimize researcher subjectivity and ensure that the illustrated responses are genuinely representative of the reasoning patterns observed at each developmental level. Thematic analysis was additionally conducted across all responses within each level to identify recurring reasoning strategies and common misconceptions. To enhance trustworthiness of findings, several validation strategies were implemented including member checking where selected students were invited to review interpretations of their responses, peer debriefing with colleagues in mathematics education research, maintaining an audit trail with detailed documentation of all analytical decisions and reasoning processes, and providing rich description through comprehensive documentation of the research context and participant characteristics. All data were stored securely with participant identities protected through numerical coding systems, with digital files password-protected and stored on encrypted servers, while paper-based materials were kept in locked filing cabinets accessible only to authorized research personnel.

3. Results

3.1 Profiles of Statistical Reasoning with Representative Student Responses

To investigate students' statistical reasoning, participants were presented with a bar chart (Figure 1) showing the number of villages in Lampung Province affected by four types of disease outbreaks in 2024: diarrhea, dengue fever, measles, and malaria. Based on this figure, students were asked to identify the type of diagram and the data it represented, as well as to describe the province, year, and the diseases included. This task was designed to capture how students interpret, describe, and justify their understanding of statistical representations in context.

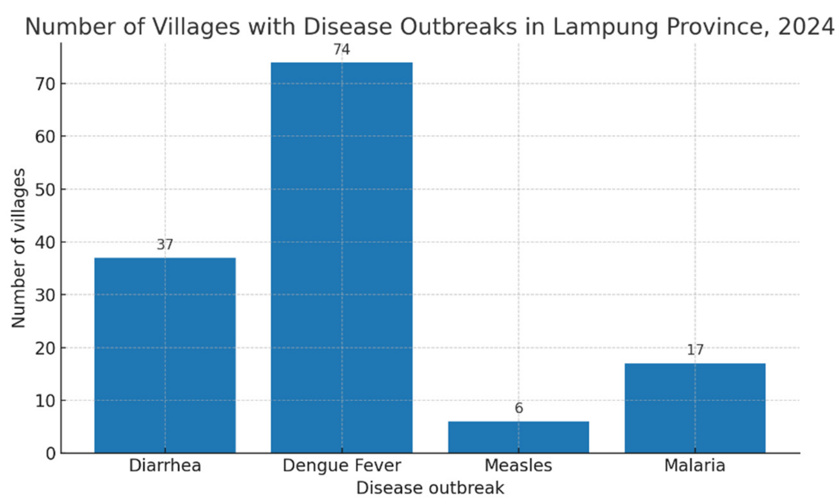

Figure 1. Number of Villages with Disease Outbreaks in Lampung Province, 2024

The responses were then analyzed and categorized according to the four levels of statistical reasoning defined in the rubric: Idiosyncratic, Transitional, Quantitative, and Analytical. Each level is illustrated below with representative excerpts from students' written work, highlighting the distinctive features of their reasoning processes.

Level 1: Idiosyncratic (4%)

A small proportion of students (4%) demonstrated reasoning at the Idiosyncratic level, where responses were intuitive, fragmented, and disconnected from the statistical content of the task. These students tended to rely on superficial features of the diagram rather than engaging with the data presented.

No.	Jawaban (Answer)	Alasan/Penjelasan (Reason/Explanation)
1.a	Diagam Balok (Bar Chart/Block Diagram)	Karna berbentuk balok (Because it is shaped like a block)

Figure 2. Student response Classified as Idiosyncratic Reasoning

One student's written response is shown in Figure 2. The student identified the diagram as a Diagram Balok (beam chart) but justified the choice by stating karna berbentuk balok (because it is shaped like a beam). While the term beam chart was not incorrect, the justification indicates reasoning based purely on the visual shape of the diagram rather than its statistical meaning. Furthermore, the student did not address the other aspects of the question, such as the location (Lampung Province), the year (2024), or the types of diseases represented (diarrhea, dengue fever, measles, and malaria).

This type of reasoning exemplifies Level 1(Idiosyncratic), as defined in the scoring rubric, where students either provide irrelevant answers or fail to respond to the statistical aspects of the question. The response lacked evidence of understanding that a diagram represents structured data rather than merely a picture. Students at this level remain dependent on intuitive impressions and have yet to develop the ability to interpret data systematically. The presence of Idiosyncratic responses suggests that some students require explicit instructional support to move beyond intuition and to recognize that diagrams are tools for organizing and interpreting data. Without such scaffolding, their engagement with statistical tasks may remain limited to surface features. This response pattern aligns with findings by Zora and Saban (2023), who observed that students at early reasoning stages tend to conflate the visual appearance of diagrams with their statistical function, treating graphical representations as pictures rather than as structured data displays. The absence of engagement with the data's content in this study may therefore reflect insufficient prior exposure to tasks that explicitly require interpretation rather than merely identification of diagram types. Such a finding carries an important pedagogical implication: when instruction emphasizes diagram naming and construction over data reasoning, students internalize form over function, and this internalization persists as a barrier to progression toward higher reasoning levels. Targeted instructional intervention that explicitly connects visual features of diagrams to their underlying statistical meaning is therefore essential for students at this level.

Level 2: Transitional (33%)

No.	Jawaban (*Answer*)	Alasan/Penjelasan (*Reason/Explanation)*
1.a	mendeskripsikan data (Kejadian luar Biasa wabah penyakit), di Provinsi Lampung, Pada tahun 2024, Ada penyakit muntaber, demam berdarah *(Describes the data [extraordinary occurrence of disease outbreaks] in Lampung Province, in 2024, there are diarrheal disease and dengue fever outbreaks.)*	Karna sudah sesuai yang ada di soal *(Because it is already in accordance with the question)*

Figure 3. Student Response Classified as Transitional Reasoning

A considerable proportion of students (33%) demonstrated reasoning at the Transitional level. At this stage, students began to reference aspects of the data but did so inconsistently or incompletely. Their answers often reflected only a partial understanding of the statistical information, sometimes by repeating elements directly from the diagram or the task prompt, without elaborating on the deeper statistical meaning. This indicates that while students at this level were no longer relying solely on intuition, their reasoning remained limited and lacked coherence.

An example of a Transitional-level response is presented in Figure 3. In this case, the student wrote: "*Mendeskripsikan data (kejadian luar biasa wabah penyakit) di Provinsi Lampung, pada tahun 2024, ada penyakit muntaber, demam berdarah*." (Describes the data [extraordinary occurrence of disease outbreaks] in Lampung Province, in 2024, there are diarrheal disease and dengue fever outbreaks). For the explanation, the student added: "*Kar(e)na sudah sesuai yang ada di soal*" (Because it is already in accordance with the question.). This response shows that the student was able to identify certain details correctly, namely the province, the year, and some of the diseases. In doing so, the student recognized key elements of the data presented in the bar chart.

However, the answer remains incomplete. The student failed to mention all of the categories represented in the diagram, omitting measles and malaria. The explanation provided was also superficial, as it did not offer a statistical justification or interpretation but instead relied on the idea that the answer simply matched the information presented in the question. Such reasoning illustrates the core characteristic of the Transitional level: partial correctness without comprehensive understanding. The omission of measles and malaria from the student's response may indicate selective attention, a well-documented cognitive pattern wherein students prioritize the most familiar or visually salient elements of a display while overlooking less prominent data points. This aligns with Lavigne and Lajoie's (2007) observation that students at the Transitional stage tend to anchor their reasoning on familiar contextual cues — in this case, the more commonly known diseases — rather than systematically scanning all available categories in the diagram. Furthermore, the justification strategy of citing task alignment ("because it is already in accordance with the question") reveals an externally-directed form of validation: the student evaluates correctness by matching the answer to the question rather than by independently interrogating the data. This distinction is critical because it reveals that Transitional-level students have not yet developed the internal statistical judgment necessary for autonomous data interpretation, which is the defining feature of higher-level reasoning.

According to the scoring rubric, this type of response fits within Level 2: Transitional because it addressed some aspects of the question correctly while neglecting others, and because the justification offered was limited and lacked depth. The student's work demonstrates an emerging awareness of the statistical content, yet it falls short of the ability to synthesize information from the diagram in a meaningful way.

The presence of students at the Transitional level underscores the importance of instructional scaffolding. Learners at this stage require teaching approaches that encourage them to move beyond simply recalling or restating visible details. They benefit from guided prompts that emphasize completeness in describing and interpreting data. Moreover, they need structured opportunities to practice explicit reasoning about patterns, variability, and comparisons, which can gradually help them progress toward more advanced forms of statistical reasoning.

Level 3: Quantitative (63%)

No.	Jawaban	Alasan/Penjelasan
1.a	Nama diagram: Batang Dalam diagram tersebut menjelaskan bahwa ada 4 wabah penyakit yaitu muntaber, demam berdarah, campak, malaria di Provinsi Lampung tahun 2024 *(Name of the diagram: Bar Chart. The chart shows that there are four disease outbreaks, namely gastroenteritis (diarrhea and vomiting), dengue fever, measles, and malaria, in Lampung Province in 2024.)*	karena sudah sesuai dengan yang ada di soal *(Because it is already in accordance with the information provided in the question.)*

Figure 4. Student Response Classified as Quantitative reasoning.

The majority of students (63%) demonstrated reasoning at the Quantitative level, where responses showed a coherent understanding of the task supported by data drawn from the diagram. At this stage, students were able to identify the type of diagram, list all categories, and include contextual details such as the province and year. Their answers reflected an ability to systematically organize and restate information, indicating a shift from partial recognition to more structured statistical reasoning.

A representative student response is shown in Figure 4. The student wrote: "*Nama diagram: Batang. Dalam diagram tersebut menjelaskan bahwa ada 4 wabah penyakit yaitu muntaber, demam berdarah, campak, malaria di Provinsi Lampung tahun 2024*." (Name of the diagram: Bar chart. The diagram explains that there are four disease outbreaks, diarrhea, dengue fever, measles, and malaria, in Lampung Province in 2024.). For the explanation, the student added: "*Karena sudah sesuai dengan yang ada di soal*." (Because it is already in accordance with the question.).

This response illustrates the characteristics of quantitative reasoning. The student correctly identified the diagram as a bar chart, included all four diseases displayed in the figure, and mentioned both the location and year. In doing so, the response demonstrated the ability to extract and represent the essential information accurately. However, the justification remained limited, as the explanation was restricted to aligning the answer with the task rather than offering any independent interpretation of the data. This reliance on task alignment as justification — "because it is already in accordance with the question" — reveals a characteristic limitation of Quantitative reasoning that Garfield (2002) describes as a procedural ceiling: students can accurately reproduce and organize data but validate their answers by referencing the task rather than by exercising independent statistical judgment. The student's response is complete in content yet hollow in reasoning, demonstrating procedural accuracy without conceptual agency. Critically, this pattern also exposes a limitation of single-diagram identification tasks as assessment instruments: they can confirm that students recognize statistical representations, but they cannot elicit the comparative, inferential, or evaluative thinking that characterizes Analytical reasoning. To facilitate progression from Level 3 to Level 4, instruction must move beyond asking students to describe what a diagram shows and instead require them to explain what the data means, why certain patterns exist, and what conclusions can legitimately be drawn — questions that demand the kind of independent statistical judgment currently absent from these responses.

According to the scoring rubric, this type of response is placed at Level 3: Quantitative because it addressed nearly all aspects of the task comprehensively, even though the reasoning did not extend to broader analysis. The student exhibited procedural competence in recognizing and reporting the data, but had not yet reached the reflective reasoning required for the Analytical level. The prevalence of students at this level suggests that many learners are capable of interpreting statistical diagrams correctly, but their reasoning is largely descriptive. To help them progress, instructional support should move beyond procedural recall and instead emphasize deeper engagement with the data. Prompts that encourage students to compare differences across categories, reason about variability, or consider implications in real-world contexts could guide them toward developing analytical reasoning skills.

3.2 Distribution of Students Across the Four Developmental Reasoning Levels

The analysis of students' statistical reasoning profiles reveals a distinctive distribution pattern across the hierarchical levels, with significant implications for understanding the current state of statistical education in Indonesian junior high schools. The distribution demonstrates a pronounced concentration in the middle levels of statistical reasoning development, suggesting both achievements and limitations in current pedagogical approaches.

Table 2. Distribution of Students' Statistical Reasoning Levels

Level	Category	Frequency	Percentage
1	Idiosyncratic	1	4%
2	Transitional	9	33%
3	Quantitative	17	63%
4	Analytical	0	0%
Total		27	100%

As presented in Table 2, the data shows that the vast majority of students (96%) have progressed beyond purely intuitive reasoning, with only one student (4%) classified at the Idiosyncratic level. This finding indicates that most eighth-grade students have developed some capacity to engage with statistical information beyond mere personal impressions or surface-level observations. The minimal presence at Level 1 suggests that basic exposure to statistical concepts through the national curriculum has been successful in moving students away from entirely fragmented or irrelevant responses to statistical tasks.

The largest concentration of students appears at the Transitional level, with nine students (33%) demonstrating partial but inconsistent understanding of statistical concepts. This substantial proportion indicates that approximately one-third of students are in a critical developmental phase where they recognize statistical elements but struggle with comprehensive interpretation and application. Their responses typically show awareness of data components but lack the systematic organization and complete analysis required for higher-level reasoning. Most significantly, the majority of students (63%) achieved Quantitative reasoning, representing 17 participants who demonstrated coherent explanations supported by data evidence. This concentration at Level 3 suggests that current instructional approaches have been effective in developing students' ability to systematically organize and interpret statistical information. Students at this level can accurately identify diagram types, extract relevant information, and provide comprehensive descriptions of statistical representations. However, their reasoning remains largely descriptive and procedural, focusing on data extraction rather than deeper analytical interpretation.

The complete absence of students at the Analytical level (0%) represents a critical finding that reveals a developmental ceiling in current statistical reasoning instruction. None of the 27 participants demonstrated the advanced reasoning capabilities characterized by integration of multiple representations, critical evaluation of statistical arguments, or sophisticated inferential thinking. This gap indicates that while students can process and describe statistical information effectively, they have not developed the higher-order cognitive skills necessary for complex statistical reasoning required in contemporary data-driven contexts. The distribution pattern suggests a developmental trajectory where students progress successfully through initial stages of statistical reasoning but encounter barriers in transitioning to analytical thinking. The concentration at Quantitative level, while positive, may indicate instructional approaches that emphasize procedural competence over conceptual depth and critical analysis. Several factors may account for the observed distribution pattern. First, the Indonesian national curriculum at the junior high school level has historically prioritized procedural competence — such as reading and constructing graphs — over interpretive and inferential reasoning tasks. This curricular emphasis likely creates a ceiling effect at the Quantitative level, where students can accurately organize and report data but are rarely required to go further. Second, the absence of students at the Analytical level may reflect limited classroom exposure to open-ended, multi-representational tasks that demand higher-order thinking. When statistical instruction focuses predominantly on single correct answers, students have few opportunities to develop the evaluative and inferential skills characteristic of Level 4. Third, chi-square analysis conducted in this study found no statistically significant association between gender and reasoning level ($p > .05$), suggesting that the distributional pattern is relatively uniform across male and female students and is more likely attributable to shared instructional experiences than to individual demographic differences. These converging factors point to a systemic rather than individual explanation for the developmental ceiling observed in this sample.

3.3 Implications for Teaching and Learning in the Digital Era

The statistical reasoning profiles identified in this study hold profound implications for redesigning mathematics education to meet the demands of an increasingly digital and data-driven society. The distribution patterns reveal both opportunities and urgent needs for instructional transformation, particularly as digital technologies create new possibilities for statistical learning while simultaneously raising expectations for sophisticated data analysis skills.

The absence of students at the Analytical level presents the most significant concern for digital era education. In contemporary society, students encounter vast amounts of data through digital platforms, social media, and online information sources that require critical evaluation and sophisticated interpretation skills (Burrill & Pfannkuch, 2024). The inability of students to demonstrate analytical reasoning suggests they may be ill-equipped to navigate the complex statistical information that characterizes digital communication and decision-making. This gap becomes particularly problematic when considering that digital citizenship requires individuals to critically assess data-driven claims, understand statistical manipulation in media, and make informed decisions based on complex statistical evidence.

The concentration of students at the Quantitative level, while representing an achievement in basic statistical competence, reveals an instructional ceiling that must be addressed for digital era readiness. Students who can accurately describe and organize statistical information but cannot critically analyze or synthesize data from multiple sources will struggle with the complex, multi-modal statistical presentations common in digital environments. Digital platforms often present statistical information through interactive visualizations, dynamic data displays, and integrated multimedia representations that require analytical reasoning skills for meaningful interpretation.

The substantial proportion of students at the Transitional level (33%) indicates a critical intervention point where targeted digital tools and pedagogical approaches could facilitate advancement to higher reasoning levels. Digital technologies offer unique opportunities to support these students through interactive simulations, real-time data manipulation, and scaffolded analysis tools that can bridge the gap between partial understanding and systematic reasoning. Technology-enhanced instruction could provide the consistent practice and immediate feedback necessary to help transitional students develop more coherent and complete statistical reasoning patterns.

For students already at the Quantitative level, the digital era presents both opportunities and requirements for advancement to analytical reasoning. Digital tools can provide access to authentic, large-scale datasets that require sophisticated analysis techniques, moving beyond the descriptive approaches that characterize Level 3 reasoning. Recent evidence further suggests that AI-based tools such as ChatGPT, when integrated into structured learning models, can function as adaptive scaffolding that bridges procedural competence and deeper conceptual understanding (Monike et al., 2025; Sudirman et al., 2026). Online statistical software, interactive visualizations, and collaborative data analysis platforms can create learning environments where students must integrate multiple representations, evaluate conflicting evidence, and develop complex inferential reasoning skills essential for Level 4 performance.

The findings suggest that current instructional approaches, while successful in developing basic statistical competence, are insufficient for preparing students for the analytical demands of digital society. Traditional pedagogical methods that emphasize procedural skills and descriptive analysis must be supplemented with approaches that foster critical thinking, multi-representational reasoning, and sophisticated inference capabilities. This transformation requires not only technological integration but also fundamental shifts in pedagogical philosophy from knowledge transmission to inquiry-based exploration and critical analysis.

The digital era also presents unique opportunities for personalized learning pathways that can address the diverse reasoning levels identified in this study. Adaptive digital platforms can provide differentiated instruction that meets students at their current reasoning level while providing appropriate challenges and supports for advancement. For Transitional level students, digital tools can offer structured scaffolding and guided practice, while Quantitative level students can engage with more complex, open-ended data analysis projects that require analytical reasoning.

Furthermore, the digital context necessitates explicit instruction in statistical literacy that extends beyond traditional mathematical content to include understanding of algorithmic decision-making, data privacy implications, and the social consequences of statistical analysis. Students must develop not only technical statistical reasoning skills but also ethical awareness and critical consciousness about the role of data and statistics in digital society. The implications extend to teacher preparation and professional development, as educators must be equipped to facilitate learning experiences that promote analytical reasoning while integrating digital technologies effectively. This requires ongoing professional learning opportunities that help teachers understand both the technical aspects of statistical reasoning development and the pedagogical approaches necessary for fostering higher-order thinking in digital environments.

4. Discussion

4.1 Profiling Students' Statistical Reasoning in the Indonesian Context

The present study provides an empirical portrait of Indonesian junior high school students' statistical reasoning. The analysis revealed that students' responses clustered within three developmental levels—Idiosyncratic, Transitional, and Quantitative, while none demonstrated reasoning at the Analytical level. This pattern underscores that student are able to recognize and describe information from statistical representations but face considerable challenges in extending their reasoning to more advanced forms of analysis. According to the framework laid out by Chan et al., the levels of statistical reasoning resonate with the structure of the SOLO (Structure of Observed Learning Outcomes) model, aligning the Idiosyncratic level with pre-structural reasoning and the Transitional level with multi-structural understanding, indicating a gradual transition from instinctive thinking to more organized approaches to statistical concepts (Chan et al., 2016). Additionally, the classification of students in this study was found to be consistent with the findings of Ben-Zvi and Garfield, in which the necessity for developing a critical understanding of data interpretations across various educational contexts was emphasized (Ben-Zvi & Garfield, 2004).

The small proportion of students at the Idiosyncratic level indicates that only a minority rely on intuitive impressions disconnected from the data. This aligns with findings in the literature where researchers have identified similar trends in statistical reasoning, emphasizing that many students struggle to engage meaningfully with statistical data due to an emphasis on calculative skills rather than interpretative reasoning (Zora & Saban, 2023). Furthermore, the larger presence of students situated at the Transitional level suggests that they have begun to grasp key aspects of the data, albeit without full comprehension or the ability to engage in more complex analyses, reflecting a crucial developmental stage in their learning process (Meylasari et al., 2021). The findings mirror trends noted in international studies, as detailed by Garfield and Ben-Zvi, who argue that students commonly exhibit difficulties in advancing their reasoning capabilities to higher levels of cognitive engagement (Garfield & Ben-Zvi, 2009).

The largest group was found at the Quantitative level, where students provided coherent and accurate descriptions of the diagram but stopped short of making generalizations or contextual interpretations. This phenomenon reflects a crucial insight presented in research by Hasim et al., which points out that while students can categorize and represent data proficiently, they often lack the skills necessary for effective analysis and interpretation (Hasim et al., 2024). The absence of students at the Analytical level highlights a persistent gap in students' abilities to engage with data at a higher cognitive plane. This trend is consistent with studies conducted by Garfield and Chance, which have systematically noted this deficit in the context of statistical reasoning across various educational environments, indicating that both an understanding of statistical concepts and their application in real-life contexts remain underdeveloped (Garfield & Chance, 2000).

Thus, the profiles identified in this study not only reflect the developmental trajectory described in the literature but also provide a localized account of how Indonesian students navigate statistical tasks within their curriculum. Compared to findings from neighbouring Malaysia, where Chan et al. (2016) similarly documented a concentration of students at lower reasoning levels despite structured curriculum exposure, the present study reveals a comparable pattern in the Indonesian context — yet with a notably higher proportion of students reaching the Quantitative level. This suggests that Indonesian eighth-grade students may have developed stronger procedural competencies than their Malaysian counterparts at equivalent grade levels, while still sharing the same critical barrier: the inability to transition into Analytical reasoning. Within Indonesia itself, this study extends the work of Hasanah et al. (2024) at the primary level and Ariwinanda et al. (2022) at the senior high school level, providing an empirical anchor at the junior high school stage that was previously absent from the Indonesian research landscape. Together, these studies begin to form a developmental trajectory of statistical reasoning across Indonesian schooling, revealing a persistent gap at the analytical level that transcends grade boundaries and calls for coordinated curricular intervention. Given the noted challenges, it is imperative to enhance instructional practices aimed at fostering higher-level statistical reasoning, encouraging an environment that promotes students to move beyond mere descriptions to more complex data interpretations, as suggested by the frameworks developed by prominent researchers in statistics education (Ben-Zvi & Makar, 2015; Everson et al., 2008).

4.2 Distribution Patterns Across Developmental Levels of Reasoning

The distribution of students across the four developmental levels of statistical reasoning revealed a concentration at the Quantitative level (63%), followed by the Transitional level (33%), and a very small proportion at the Idiosyncratic level (4%). Notably, no students demonstrated reasoning at the Analytical level. This pattern suggests that while the majority of students have advanced beyond purely intuitive or fragmented reasoning, their engagement with statistical tasks remains largely descriptive and procedural. The significant predominance of the Quantitative level indicates that most students were able to identify relevant features of the bar chart, such as categories, location, and time, and to represent these accurately in their responses—echoing findings by Chan et al. which categorize statistical reasoning levels to highlight similar trends in the identification and structuring of statistical data among students (Chan et al., 2016). However, their reasoning rarely extended beyond mere description. This is supported by a continuum of research illustrating that junior high school learners often plateau at procedural or quantitative stages of reasoning, struggling to reach higher-order levels of inference (Ben-Zvi & Garfield, 2008).

The relatively large proportion of students in the Transitional level further reflects the tendency to reference the data more systematically; these responses often remain incomplete or inconsistent, underscoring the challenge of moving from partial understanding to coherent reasoning. Research by Lavigne and Lajoie emphasizes that while students engage with statistical inquiry, their reasoning processes may not always support deeper analysis (Lavigne & Lajoie, 2007). The near absence of students at the Idiosyncratic level is encouraging, suggesting that only a minority relied on intuitive or irrelevant responses, as corroborated by Saidi and Siew, who demonstrated that only a few students exhibit such a rudimentary understanding of statistical reasoning (Saidi & Siew, 2022). Nevertheless, the complete lack of students at the Analytical level is a critical finding that denotes a significant gap: none of the participants displayed the capability to synthesize multiple representations, reason about variability, or make generalized conclusions from the data. Such analytical skills are emphasized in the literature as essential for advanced statistical reasoning, particularly by Garfield, who argues that moving beyond basic understanding to analytical capabilities is pivotal for educational advancement in statistics (Garfield, 2003).

Taken together, the distribution patterns observed in this study highlight both progress and limitations in the development of statistical reasoning among Indonesian junior high school students. While foundational reasoning skills are being acquired, research by Conway et al. indicates the necessity of creating more explicit instructional opportunities aimed at scaffolding the transition from quantitative to analytical reasoning (Conway et al., 2019). Enhancements in teaching methodologies that address these gaps in reasoning ability can consequently lead to improved statistical literacy, as suggested by the collective findings from various studies on educational practices (Jones et al., 2000; Maghfiroh & Prayitno, 2023; Schapiro & Turk-Browne, 2015).

4.3 Pedagogical Implications for Teaching and Learning in the Digital Era

The identification of students' statistical reasoning profiles provides valuable implications for teaching practice. The concentration of students at the Quantitative and Transitional levels suggests that many learners can engage with statistical representations but are not yet equipped to reason about data in a reflective or analytical manner. Accordingly, teachers need to design learning environments that intentionally scaffold the progression from partial and procedural reasoning toward deeper forms of analysis. Research indicates that scaffolding is essential in aiding students' understanding and reasoning abilities, with guided questioning promoting articulation and reflection that can lead to improved statistical reasoning skills (Dyer & Sherin, 2015).

One implication concerns the use of guided questioning and scaffolding strategies. Students at the Transitional level require prompts that encourage them to articulate their reasoning more fully, address overlooked aspects of data, and justify their interpretations. This assertion is supported by findings from Dyer and Sherin, which underscore the importance of responsive teaching that adapts to students' needs and promotes active learning (Dyer & Sherin, 2015). Similarly, students at the Quantitative level benefit from tasks that go beyond the simple identification of categories or descriptions of patterns. Instruction should emphasize reasoning about variability, comparisons between groups, and evidence-based conclusions, as these higher-order thinking skills are crucial for advancing students' statistical reasoning.

The findings also underscore the potential of interactive digital technologies to support this progression. Digital tools, such as dynamic graphing software and statistical simulation programs, can provide opportunities for students to manipulate data sets, explore patterns, and test hypotheses in real time (Qureshi et al., 2021). Similarly, the integration of technologies such as augmented reality into project-based learning frameworks has demonstrated promise in fostering higher-order reasoning and self-regulation among junior high school students in Indonesia (Isharyadi et al., 2026; Kadir et al., 2026; Sudirman et al., 2026). These experiences foster active engagement and encourage learners to move beyond procedural description toward analytical interpretation, which aligns with discussions regarding the efficacy of technology-enhanced learning resources (Clunie et al., 2017). Previous research has highlighted that technology-mediated environments can strengthen students' conceptual understanding and reasoning by providing authentic, interactive contexts for learning statistics.

Moreover, the integration of digital tools aligns with the broader agenda of 21st-century education, where competencies such as data literacy, critical thinking, and problem-solving are prioritized. Empirical findings further confirm that technology integration and learner engagement are significant predictors of mathematical problem-solving ability, underscoring the need for blended instructional frameworks that combine pedagogical guidance with digital tools (Gyenyn et al., 2026). By linking statistical reasoning tasks with digital technologies, educators can both strengthen students' conceptual development and prepare them for participation in a society increasingly driven by data. As education shifts toward a more technology-integrated approach, understanding the factors influencing students' engagement with digital technologies is vital for enhancing learning outcomes (Oyetade et al., 2024). This highlights the necessity for professional development for educators to adequately support the integration of these tools in instructional settings (Cao et al., 2023).

4.4 Broader Contributions to Data Literacy and 21st-Century Competencies

Although the present study was conducted with a limited sample of Indonesian junior high school students, the results provide broader insights into how statistical reasoning develops in relation to global educational goals. The identification of distinct reasoning profiles contributes to an empirical model that highlights not only where students currently stand but also the conceptual gaps that prevent them from reaching advanced levels of reasoning. Such profiling enriches the international literature on statistics education by offering evidence from a Southeast Asian context that has been underrepresented in prior research. According to Park and Kyei, understanding regional educational dynamics is crucial for developing effective teaching strategies, particularly in the context of educational attainment across cultures (Park & Kyei, 2011).

These findings also reinforce the centrality of data literacy as a foundational competency for 21st-century learners. In an era where decisions in science, health, economics, and everyday life increasingly rely on the interpretation of data, students must be able to reason beyond surface-level descriptions of graphs or tables. Previous research underscores the importance of educational reforms that promote higher-order reasoning, given the documented correlation between mathematical literacy and critical engagement with information (Carmichael et al., 2010). By demonstrating that most learners remain at the transitional and quantitative levels, this study highlights the urgent need for pedagogical reforms that foster critical engagement with data and encourage deeper cognitive processing.

Bridging this gap is essential for preparing students not only to succeed academically but also to participate responsibly in a data-driven society. The integration of digital tools in teaching statistical reasoning is not merely an instructional choice but a necessity for equipping learners with skills relevant to modern contexts. Studies have shown that digital technologies serve as vital adjuncts in educational settings, enabling students to practice reasoning skills in authentic and interactive environments (Doğan, 2023). By providing students with authentic opportunities to interact with data through technology, educators can help cultivate reasoning abilities that extend beyond the classroom to real-world decision-making.

In this way, the study contributes both theoretically and practically: theoretically, by offering an empirical model of reasoning profiles that can inform future research; and practically, by pointing to actionable strategies for teachers and curriculum designers. The intersection of statistical reasoning, data literacy, and digital pedagogy positions this work within the broader conversation about how mathematics education can support the development of globally relevant competencies for the 21st century. This further strengthens the imperative for educational reform.

5. Conclusion

This study sought to identify the statistical reasoning profiles of eighth-grade students in Indonesia and to examine how these profiles are distributed across developmental levels. The findings revealed that the majority of students were situated at the Quantitative level, followed by the Transitional level, with very few at the Idiosyncratic level and none at the Analytical level. These results indicate that while students were generally capable of extracting and restating information from statistical diagrams, their reasoning remained largely procedural and descriptive. The absence of students at the Analytical level highlights a significant gap in their ability to synthesize multiple representations, evaluate variability, and generalize conclusions, which are fundamental aspects of higher-level statistical reasoning.

The identification of these profiles provides valuable insight into the challenges and opportunities for mathematics education in Indonesia. Students who remained at the Transitional level demonstrated only partial engagement with the data, while those at the Quantitative level showed procedural mastery without deeper inference. These findings suggest that instruction must go beyond surface-level engagement with data and provide scaffolding that supports the transition to analytical reasoning. Teachers can design activities that explicitly prompt students to justify their answers, reason about variability, and make connections between data and real-world contexts.

The use of the Statistical Reasoning Assessment Tool (SRAT), comprising six open-ended tasks targeting key statistical concepts including data interpretation, graphical reasoning, variability recognition, and comparative analysis, proved effective in capturing meaningful qualitative differences across the four developmental levels. Unlike closed-format assessments that yield only correctness scores, the open-ended nature of the SRAT allowed students to express their reasoning processes in full, making it possible to distinguish between surface-level pattern recognition and deeper data interpretation. The instrument's ability to differentiate between Idiosyncratic, Transitional, and Quantitative reasoning — while also revealing the complete absence of Analytical responses — demonstrates its diagnostic utility for identifying where students currently stand and what instructional support they require. Future studies may consider adapting the SRAT for use in digital environments, across different grade levels, or within intervention designs that track reasoning development over time, thereby building on its potential as both an assessment and a research tool in statistics education. A key implication of this study lies in the integration of digital technologies into the teaching of statistics. Interactive graphing tools, statistical simulations, and online platforms can provide authentic opportunities for students to manipulate data, explore patterns, and test hypotheses. Such tools may also help students coordinate between graphical, numerical, and contextual representations, thereby supporting the development of analytical reasoning. In line with global trends in 21st-century education, the use of digital technologies has the potential to bridge the gap between procedural competence and critical data literacy.

Despite its contributions, the study has several limitations. The research was conducted in a single school with a relatively small sample, which restricts the generalizability of the findings. Moreover, the assessment of students' reasoning was limited to written responses on one set of tasks. Future research could include larger and more diverse samples, as well as longitudinal designs that trace the development of statistical reasoning over time. Individual interviews or classroom observations may also provide richer insights into how students articulate and refine their reasoning processes. In conclusion, this study contributes to the literature by presenting an empirical model of statistical reasoning profiles in a Southeast Asian context. It underscores the importance of pedagogical strategies that deliberately scaffold students' reasoning across levels, while also emphasizing the potential of digital tools to foster more advanced engagement with data. Ultimately, strengthening statistical reasoning is not only a matter of improving mathematics achievement but also a step toward cultivating the critical data literacy required for informed participation in contemporary society.

6. Limitations

This study has several limitations that should be acknowledged. First, the research involved only 27 students from a single urban public junior high school in Bandung, which limits the generalizability of findings to other educational contexts. The homogeneity of the sample — drawn from one school with a specific socioeconomic profile and instructional environment — means that the reasoning profiles identified here may not fully represent students in rural schools, private institutions, or schools with significantly different resource levels and pedagogical approaches. While this limitation is inherent to the exploratory case study design, which prioritizes depth of understanding over breadth of generalization (Yin, 2018), it nonetheless constrains the external validity of the findings. Future research should employ purposive or stratified sampling across multiple school types, geographic regions, and socioeconomic contexts within Indonesia to examine whether the developmental ceiling observed at the Quantitative level is a localized phenomenon or a systemic pattern across the national educational landscape. Second, the cross-sectional design provides only a snapshot of students' reasoning at one point in time rather than tracking development over time. Third, the assessment relied solely on written responses to statistical tasks, which may not capture the full range of students' reasoning abilities. Finally, the study did not control for factors such as prior achievement, socioeconomic background, or specific instructional experiences that might influence statistical reasoning development. Future research should include larger and more diverse samples, longitudinal designs to track reasoning development, and multiple assessment methods including interviews and observations to provide richer insights into students' statistical thinking processes.

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Acknowledgments

The authors gratefully acknowledge Universitas Pendidikan Indonesia for providing the research funding that supported this study. We thank the school administration, mathematics teachers, and students who participated in this research for their cooperation and enthusiasm. Special appreciation is extended to the graduate students who assisted with data coding and analysis, and to colleagues who provided valuable feedback during various stages of this research. Finally, we thank the anonymous reviewers for their constructive comments that helped improve this manuscript.

Authors contributions

Bambang Avip Priatna Martadiputra and Yaya Sukjaya Kusumah were responsible for study conceptualization, research design, and manuscript revision. Lussy Midani Rizki was responsible for data collection and formal analysis. Sudirman Sudirman contributed to methodology development and data interpretation. Siti Faizah contributed to data coding and validation. Camilo Andrés Rodríguez-Nieto contributed to theoretical framing and critical revision of the manuscript. Bambang Avip Priatna Martadiputra drafted the manuscript, and all co-authors reviewed and revised it critically for important intellectual content. All authors read and approved the final manuscript.

Funding

This work was supported by the 2025 Collaborative Research Grant among State Universities with Legal Entity Status (Hibah Penelitian Kolaborasi antar Perguruan Tinggi Negeri Berbadan Hukum), awarded by Universitas Pendidikan Indonesia [Approval Number: 1156/UN40.F7/PT.01.01/2025].

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Disclosure of AI Use

AI-based tools (ChatGPT) were used solely to check grammar and improve the clarity of the English language in the manuscript. AI was not used for data analysis, interpretation, or generation of scientific content. All intellectual contributions, analyses, and conclusions are the authors' own.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Sciedu Press.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.