

Reconceptualising the Cognition–Achievement Relationship in Secondary Mathematics: Evidence from a Classroom-Based Correlational Study

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Abstract

This study aimed to examine the strength and direction of the relationship between mathematical thinking processes and mathematics learning outcomes among ninth-grade junior high school students. The research employed a quantitative non-experimental correlational design to identify associative patterns between variables without inferring causal relationships. The population consisted of 476 students across twelve classes, and the sample was selected using purposive sampling, resulting in one intact class comprising 36 students. Data on mathematical thinking processes were collected through four constructed-response (essay) items designed to measure reasoning, conceptual linkage, and structured problem-solving abilities. Mathematics learning outcomes were obtained from students' midterm examination scores as indicators of curriculum-based academic achievement. Data analysis was conducted in several stages, including descriptive statistical analysis and normality testing using the Shapiro–Wilk test. Due to non-normal distribution in one variable, the relationship between variables was analysed using Spearman's rank correlation coefficient as a non-parametric alternative. The results indicated that students demonstrated relatively adequate levels of mathematical thinking; however, the correlation between mathematical thinking processes and learning outcomes was positive but weak and statistically non-significant ($\rho = 0.211$, $p > 0.05$). These findings suggest that mathematical thinking, while conceptually important, may not function as a strong standalone predictor of examination-based academic performance. The study implies that mathematics learning outcomes are influenced by multiple interacting cognitive and contextual factors, highlighting the importance of aligning assessment practices with higher-order thinking competencies to enhance the measurable contribution of mathematical reasoning to student achievement.

INTRODUCTION

Mathematical thinking is conceptualised as a higher-order cognitive activity encompassing abstraction, logical structuring, representation, and justified reasoning in mathematical contexts. It reflects the capacity to interpret relationships, construct arguments, and generalise patterns beyond routine procedures. Contemporary scholarship emphasises that mathematical thinking involves critical interpretation and evaluative judgment that enable students to engage with complex and non-routine problems in meaningful ways (Koh et al., 2025). Empirical investigations further demonstrate that students' critical mathematical thinking ability supports relational reasoning and

deep conceptual processing, particularly in tasks requiring structural analysis rather than mechanical computation (Susanti et al., 2025). Case-based research also indicates that distinctive cognitive patterns emerge when learners systematically organise and reflect upon mathematical ideas (Patmawati & Unaenah, 2025). Collectively, these perspectives position mathematical thinking as a multidimensional construct that plays a central role in shaping students' conceptual understanding and academic development at the secondary education level.

The association between mathematical thinking and mathematics performance has been examined from cognitive, affective, and contextual perspectives. Evidence suggests that mathematical thinking significantly predicts problem-solving performance, although its influence may operate through mediating psychological factors such as hope and persistence. Longitudinal analyses further reveal that mathematics achievement develops through interconnected pathways involving cognitive competencies and environmental conditions rather than through isolated skill acquisition (Li & Qi, 2025). Additionally, contextual investigations demonstrate that instructional quality, classroom climate, and learner characteristics contribute to variations in measurable performance outcomes (Bascones et al., 2024). These findings indicate that mathematical thinking constitutes a foundational cognitive resource, yet its observable contribution to achievement may vary depending on contextual moderators. Consequently, empirical examination is required to determine the extent to which mathematical thinking processes are directly associated with mathematics learning outcomes within specific educational settings.

Assessment structures significantly influence how mathematical thinking is translated into observable indicators of academic achievement. Research on higher-level mathematical thinking assessment highlights the necessity of aligning evaluation instruments with reasoning depth, conceptual integration, and analytical flexibility rather than focusing exclusively on procedural accuracy (Koh et al., 2025). Studies on classroom assessment literacy further demonstrate that teachers' capacity to design and interpret assessments affects the validity and consistency of student performance data (Quainoo et al., 2025). Moreover, investigations into curriculum alignment show that discrepancies between instructional objectives and assessment practices may produce divergent achievement patterns, even when students demonstrate comparable cognitive competence (Mahzari et al., 2023). These findings underscore that variations in assessment design can either clarify or obscure the measurable contribution of mathematical thinking to learning outcomes, reinforcing the importance of examining this relationship within coherent curricular and evaluative frameworks.

Although mathematical thinking is theoretically positioned as a determinant of mathematics achievement, empirical findings suggest that the relationship is complex and context-dependent. Studies of critical mathematical reasoning indicate that performance differences often emerge as a function of task characteristics and cognitive demands, even among students with comparable reasoning capacity (Monteleone et al., 2023). Broader investigations of achievement pathways further confirm that mathematics performance is shaped by the interaction of cognitive, instructional, and environmental variables rather than by a single predictive factor (Bascones et al., 2024; Li & Qi, 2025). These patterns imply that mathematical thinking cannot be assumed to exert a uniform or deterministic influence on measurable learning outcomes. Instead, its contribution must be examined empirically within clearly defined curricular and assessment contexts. Accordingly, correlational inquiry remains essential to determine the strength and direction of the association between mathematical thinking processes and mathematics learning outcomes among secondary school students.

METHODS

This study employed a quantitative non-experimental correlational design to examine the association between mathematical thinking processes and students' mathematics learning outcomes without inferring causality. Nonexperimental quantitative research is particularly appropriate when variables cannot be manipulated and when the objective is to identify statistical relationships that may inform instructional considerations rather than establish cause-and-effect mechanisms (Cook & Cook, 2008). Correlational approaches have been widely applied in mathematics education to explore associations between cognitive abilities, such as representational competence and mathematical connections, within authentic classroom contexts (Putra et al., 2023). Consistent with this tradition, the present study seeks to determine the strength and direction of the relationship between the two variables as they naturally occur in the instructional setting, thereby providing an empirically grounded depiction of associative patterns among ninth-grade students.

The population consisted of 476 ninth-grade students distributed across twelve classes. The sample was selected using purposive sampling, a non-probability technique that involves deliberate selection of participants based on predefined criteria aligned with the research objectives (Robinson, 2023). One intact class comprising 36 students was chosen to ensure contextual consistency and the feasibility of data collection. While purposive sampling allows researchers to focus on information-rich cases, it also constrains the generalisability of findings beyond the sampled group. Therefore, the results should be interpreted as context-bound rather than population-representative. The relatively small sample size further implies limited statistical power, particularly in detecting weak associations, and thus necessitates cautious interpretation of correlation estimates derived from the data.

Mathematical thinking processes were measured using four constructed-response (essay) items designed to capture analytical reasoning, conceptual linkage, and structured problem-solving strategies. Constructed-response assessments are recognised for their capacity to elicit deeper cognitive processing and to assess reasoning more comprehensively than selected-response formats (Kim & Cho, 2015). Comparative analyses of mathematics test formats indicate that essay items may differ from multiple-choice items in terms of difficulty level and discriminating power, thereby offering distinct advantages in measuring higher-order thinking (Zulaiha et al., 2021). Mathematics learning outcomes were operationalised through students' midterm examination scores, representing curriculum-based academic performance. Although examination scores provide practical indicators of achievement, they may not fully reflect complex reasoning dimensions, as performance can be influenced by assessment design and evaluative emphasis.

Data analysis proceeded in sequential stages, beginning with descriptive statistics to summarise distributional characteristics. The Shapiro–Wilk test was employed to assess normality assumptions. Because the data did not fully satisfy parametric requirements and the sample size was limited, Spearman's rank correlation coefficient was applied to examine the relationship between variables. Non-parametric statistics are appropriate when distributional assumptions are violated or when measurement scales are ordinal in nature (Miller, 2013). Correlational analysis has been widely used to explore associations among psychological and academic variables in educational contexts (Hu & Qian, 2025). Nevertheless, the restricted sample size may reduce statistical sensitivity, meaning that the findings should be interpreted as indicative of associative tendencies within the studied classroom context rather than definitive population-level estimates.

RESULT

The sample comprised 36 ninth-grade students who completed a mathematical thinking test and whose mathematics learning outcomes were obtained from midterm examination scores. Descriptive statistics for both variables are presented in Table 1.

Table 1. Descriptive Statistical Analysis Results

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Mathematical Thinking Process	36	38	91	73.67	15.024
Student Learning Outcomes	36	23	94	54.44	19.052
Valid N (Listwise)	36				

Based on Table 1, the mathematical thinking process variable obtained a mean score of 73.67, with scores ranging from 38 to 91. The relatively high mean, compared with the maximum possible score of 100, indicates that, on average, students demonstrated adequate competence in reasoning, conceptual linkage, and structured problem-solving. However, the standard deviation of 15.024 suggests noticeable dispersion around the mean. The 53-point range (91–38) further confirms heterogeneity in students’ cognitive performance, indicating that while several students achieved high levels of mathematical thinking, others performed substantially lower. This variability implies unequal mastery of higher-order reasoning skills within the classroom.

In contrast, student learning outcomes showed a mean of 54.44, with a wider score range of 71 points (94–23) and a larger standard deviation of 19.052. The lower mean relative to the mathematical thinking score suggests that overall academic achievement was moderate and less optimal. The higher dispersion indicates greater inequality in achievement levels compared to mathematical thinking performance. This pattern demonstrates that strong reasoning skills do not automatically translate into uniformly high examination results, possibly due to differences in test format, content coverage, or other contextual academic factors.

Before testing the relationship between variables, the assumption of normality was examined using the Shapiro–Wilk test. The results are presented in Table 2.

Table 2. Normality Test Results (Shapiro–Wilk)

Variable	Statistic	df	Sig.
Mathematical Thinking Process	.906	36	.005
Student Learning Outcomes	.971	36	.450

As shown in Table 2, the mathematical thinking process variable yielded a significance value of 0.005, which is below the 0.05 threshold, indicating that the data were not normally distributed. Conversely, the student learning outcomes variable produced a significance value of 0.450, exceeding 0.05, suggesting a normal distribution. Because one variable violated the normality assumption, parametric techniques such as Pearson correlation or linear regression were deemed inappropriate. Consequently, a nonparametric approach was adopted to ensure analytical robustness under non-normal distribution conditions and small sample size constraints.

To examine the relationship between the two variables, Spearman’s rank correlation coefficient was applied. The results are presented in Table 3.

Table 3. Spearman Rank Correlation Results

	Mathematical Thinking Process	Student Learning Outcomes
Spearman's rho		
Mathematical Thinking Process	1.000	.211
Sig. (2-tailed)	.	.218
N	36	36
Student Learning Outcomes	.211	1.000
Sig. (2-tailed)	.218	.
N	36	36

The Spearman correlation coefficient between mathematical thinking processes and student learning outcomes was 0.211, indicating a positive but weak association. The positive direction suggests that higher levels of mathematical thinking tend to be accompanied by higher learning outcomes. However, the magnitude of 0.211 falls within the low correlation range, signifying that the relationship strength is limited. Furthermore, the significance value of 0.218 exceeds the 0.05 criterion, indicating that the correlation is not statistically significant. This means that the observed association could plausibly occur by chance within the sample.

These findings demonstrate that although students generally exhibited relatively good mathematical thinking skills, such competence was not consistently aligned with high academic achievement. The weak and non-significant relationship implies that mathematical thinking processes alone are insufficient to explain variations in learning outcomes. Academic performance likely results from the interaction of multiple factors, including motivation, instructional quality, assessment alignment, and prior knowledge. Therefore, while mathematical thinking remains an important cognitive foundation, its measurable contribution to examination-based achievement appears limited within this specific classroom context. The null hypothesis, stating that there is no significant relationship between the two variables, is thus retained. Nevertheless, the results provide valuable empirical insight into the complexity of cognitive–achievement relationships and highlight the need for broader studies with larger and more diverse samples.

DISCUSSION

Several reports have shown that higher-order mathematical thinking is positively associated with students' academic achievement, particularly when reasoning, abstraction, and modelling competencies are central to instruction and assessment. Advances in the study of mathematical reasoning, including work on structured reasoning processes and modelling skills, emphasise that complex cognitive operations are foundational to successful mathematical performance (Lu et al., 2023; He et al., 2024). A strong relationship between cognitive competence and learning outcomes has frequently been reported in large-scale syntheses of mathematics achievement research, although variability across contexts has also been noted (Wang et al., 2023). In reviewing the literature, comparatively limited attention has been paid to how this relationship manifests when achievement is measured solely through curriculum-based classroom examinations. This study set out with the aim of assessing the extent to which mathematical thinking processes are associated with mathematics learning outcomes in a specific secondary school context. With respect to the

primary research question, it was found that the correlation between the two variables was positive but weak and statistically non-significant.

The most compelling finding is that relatively adequate levels of mathematical thinking were not accompanied by correspondingly high examination performance. Contrary to expectations, this study did not detect a statistically significant relationship between reasoning processes and measured achievement. While prior systematic reviews have identified multiple cognitive predictors of mathematics performance (Wang et al., 2023), the present findings suggest that the predictive strength of such competencies may depend on how outcomes are operationalised. Recent discussions of assessment practices indicate that external examinations often shape instructional priorities and may privilege procedural coverage over analytical depth (Saglam Karakoc & Michou, 2025). Furthermore, contemporary frameworks for 21st-century skills emphasise that higher-order thinking requires assessment models explicitly designed to capture reasoning processes (Kain et al., 2024; Andrijati et al., 2025). These results, therefore, nuance the dominant narrative by indicating that the observable impact of mathematical thinking may be attenuated in evaluative contexts that insufficiently align with higher-order constructs.

Several factors could explain this observation. A possible explanation for this might be that midterm examinations emphasise routine application and content recall, thereby limiting the measurable expression of deeper reasoning competencies. This discrepancy could be attributed to partial misalignment between instructional objectives and assessment design, a concern frequently raised in research on instructional quality and school-level performance (Liu et al., 2022). Moreover, mathematics achievement is increasingly understood as a multidimensional construct shaped by motivational, emotional, and contextual variables (Sydänmaanlakka et al., 2024; Arthur et al., 2022). Systematic investigations have also identified broader institutional and individual determinants influencing academic performance beyond cognitive skills alone (Suleiman et al., 2024). Thus, the observed weak correlation may reflect the complex interplay of cognitive and non-cognitive influences rather than the limited importance of mathematical thinking itself. In this sense, the findings underscore the need to distinguish between cognitive potential and assessment-constrained achievement.

A note of caution is due here since the study was conducted with a relatively small and context-specific sample. Research on statistical modelling and reproducibility has consistently highlighted that small sample sizes may reduce statistical power and attenuate detectable effect sizes (Schweizer & Furley, 2016; Austin et al., 2017). The results, therefore, need to be interpreted carefully, as they may not be generalisable across broader educational settings. Nevertheless, the study contributes theoretically by challenging deterministic interpretations of the cognition–achievement link and empirically by demonstrating that the strength of this relationship is context-sensitive. Future research should incorporate larger samples, multi-level modelling approaches, and diversified achievement indicators. Methodological innovations in mathematics education research further suggest the value of integrating mixed or crossover analytical designs to capture better complex variable interactions (Johnson et al., 2025). Such investigations would enable more precise modelling of how mathematical thinking interacts with instructional, motivational, and evaluative systems to influence measurable academic performance.

CONCLUSIONS

In conclusion, this study set out to examine the relationship between mathematical thinking processes and mathematics learning outcomes among ninth-grade students within a classroom-based assessment context. The findings indicate that although students demonstrated relatively

adequate levels of mathematical thinking, the association between mathematical thinking processes and examination-based learning outcomes was positive but weak and statistically non-significant. This pattern suggests that mathematical thinking, while theoretically central to conceptual understanding and problem solving, may not operate as a strong independent predictor of curriculum-based academic performance when achievement is measured primarily through structured written examinations. Taken together, the findings highlight the context-sensitive and multidimensional nature of the cognition–achievement relationship. The weak correlation observed implies that mathematics learning outcomes are likely shaped by a constellation of interacting factors, including assessment structure, instructional quality, motivational dispositions, emotional engagement, and prior knowledge. Accordingly, the contribution of mathematical thinking to measurable achievement appears contingent upon the degree of alignment between higher-order cognitive competencies and the evaluative frameworks used in schools. When assessment instruments prioritise procedural accuracy over analytical reasoning, the observable impact of deeper thinking processes may be attenuated. This study contributes to mathematics education research by empirically questioning deterministic interpretations of the link between cognitive competence and examination performance. It underscores the importance of considering assessment design and contextual variables when interpreting correlational evidence. Nevertheless, the conclusions should be interpreted cautiously due to the limited sample size and reliance on a single achievement indicator. Future research should employ larger samples, multiple measures of learning outcomes, and assessment models explicitly targeting higher-order reasoning better to capture the complexity of mathematical competence and achievement.

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