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Analysis of students' mathematical literacy in curved-surface solids based on learning motivation

Abstract

Purpose: This study aims to describe students' mathematical literacy in solving problems involving curved-surface solids according to low, moderate, and high levels of learning motivation.

Method: A descriptive qualitative design was employed. The participants were 10 ninth-grade students at MTs Miftahul Huda. Data were collected using three contextual mathematical literacy tasks, a 10-item learning motivation questionnaire, and follow-up interviews. Three focal participants representing low, moderate, and high learning motivation were selected for in-depth analysis.

Findings: Students with low learning motivation met few mathematical literacy indicators and had trouble identifying relevant information, constructing mathematical models, applying appropriate procedures, and interpreting results. Students with moderate motivation met several indicators but did not consistently present systematic solution processes or relate their results to the problem context.

Practical implications: Mathematics teachers should combine contextual problem-solving activities with strategies that strengthen persistence, confidence, and independent learning. Students with low learning motivation require structured scaffolding, feedback, and sustained encouragement, while students with higher motivation should receive opportunities for independent exploration and reflective problem solving.

Originality/value: This study provides a qualitative account of how mathematical literacy varies across three levels of learning motivation in the specific context of curved-surface solids. It integrates written solution analysis and interview evidence to explain students' performance in the PISA processes of formulating, employing, and interpreting mathematics.

Keyword

curved-surface solids; learning motivation; mathematical literacy; PISA processes; secondary mathematics.

INTRODUCTION

In the contemporary global educational paradigm, mathematical literacy has emerged as a fundamental competency required for individuals to analyze, reason, and communicate quantitative ideas effectively across diverse real-world contexts (OECD, 2019). Mathematical literacy extends far beyond rudimentary arithmetic calculation, encompassing logical reasoning, problem-solving, and critical thinking necessary to interpret complex societal challenges (Gal & Tout, 2014; Hartono et al., 2019). Global assessments consistently emphasize that mastering these cognitive skills equips students to navigate modern technological and economic demands (OECD, 2023). Consequently, educational institutions worldwide prioritize fostering mathematical literacy to ensure learners develop the intellectual autonomy needed for lifelong learning (Genc & Erbas, 2019). Providing adequate opportunities to cultivate these analytical capabilities remains a pivotal agenda within secondary mathematics education (Tran, 2026).

Developing proficiency in specific mathematical domains, particularly geometry and spatial reasoning, plays a critical role in enhancing students' overall rational thinking and analytical capabilities (Juliani et al., 2016). Within secondary geometry curricula, curved-surface solids—such as cylinders, cones, and spheres—represent key conceptual topics that directly bridge abstract mathematical principles with tangible physical applications (Muzaki & Masjudin, 2019). However, successful engagement with these demanding mathematical tasks is deeply interconnected with affective factors, most notably learning motivation (Kompri, 2016). High learning motivation serves as a vital internal catalyst that drives students' persistence, active engagement, and academic performance when confronting complex problem-solving scenarios (Andres, 2019; Chan et al., 2023). Understanding how affective drivers influence cognitive processing in spatial contexts is therefore essential for optimizing educational outcomes and preparing students for STEM-oriented career pathways (Machaba & Du Plooy, 2019).

Existing literature extensively documents either students' cognitive difficulties and geometric misconceptions in curved-surface solids (Istiqomah & Rahaju, 2014; Ozerem, 2012) or general relationships between motivation and overall academic achievement (Nguyen, 2025; Rehman et al., 2020). Similarly, research on mathematical literacy frequently focuses on general contextual problem-solving without isolating specific geometric subdomains (Sari, 2015). Crucially, there is a distinct lack of empirical investigation examining how varying categories of student learning motivation explicitly influence mathematical literacy performance in curved-surface solids. Furthermore, few studies have explored the nuanced ways in which high, moderate, and low motivational levels shape students' truth-seeking behaviors and logical reasoning during geometric task resolution (Kurniawati et al., 2026). This separation of affective factors from specific spatial literacy competencies leaves a significant void in current mathematics education research.

To address this gap, this study offers a novel perspective by integrating psychological motivational frameworks with domain-specific mathematical literacy analysis in 3D curved geometry. Unlike prior research that treats mathematical literacy as a purely cognitive construct (Graven & Venkat, 2007), this investigation examines mathematical literacy through the lens of student motivational profiles (Kamsyach & Kompri, 2016). By categorizing learners according to their motivational levels, the study uniquely dissects how intrinsic and extrinsic drivers affect spatial visualization and problem-formulation skills in curved-surface solids (Yang & Quadir, 2018). Additionally, this research provides an innovative qualitative mapping of mathematical reasoning processes across different motivational tiers in secondary education settings. Consequently, this integrative framework departs from traditional single-variable assessments to offer a holistic evaluation of geometry learning.

The primary objective of this study is to analyze and describe secondary students' mathematical literacy in solving curved-surface solid problems based on their levels of

learning motivation. Specifically, the investigation aims to evaluate how students categorized into high, medium, and low motivation groups formulate, employ, and evaluate mathematical concepts in spatial contexts. Furthermore, the study seeks to identify specific error patterns and mathematical reasoning strategies exhibited by each motivational group during geometric problem-solving. By fulfilling these aims, the research directly resolves the previously identified literature gap regarding the interaction between affective drives and spatial literacy. Ultimate emphasis is placed on establishing an empirical baseline for motivational influence on geometric literacy performance.

The urgency of this study is underlined by persistent international report findings indicating low mathematical literacy achievement and widespread geometric misconceptions among secondary school students (OECD, 2023; Ozerem, 2012). In classroom environments, educators frequently encounter challenges in engaging dismotivated learners with complex 3D geometry topics like curved-surface solids (Mulaudzi & Ngcobo, 2026). Addressing these challenges is urgent, as spatial reasoning and mathematical literacy are critical foundational skills required in the modern workforce and digital age applications (Machaba & Du Plooy, 2019; Tariq et al., 2013). Without understanding how learning motivation intersects with geometric reasoning, instructional interventions risk remaining ineffective for lower-performing student cohorts. Therefore, establishing timely, evidence-based insights into this relationship is vital for contemporary curriculum reform and instructional enhancement.

Ultimately, this study contributes valuable theoretical and practical insights to the fields of mathematics education and educational psychology. On a theoretical level, it enriches the existing literature by establishing a synthesized framework that connects motivational orientation directly with geometric literacy competencies (Thompson & Erdil-Moody, 2016). On a practical level, the findings offer educators actionable guidance for designing differentiated instructional strategies tailored to students' varying motivational tiers. By helping teachers anticipate specific mathematical literacy

obstacles associated with motivation levels, the research aids in mitigating geometric misconceptions and improving learner engagement (Chan et al., 2023; Mulaudzi & Ngcobo, 2026). Consequently, this work serves as a valuable resource for curriculum developers seeking to build inclusive, motivation-sensitive mathematics learning environments..

METHODS

This study employed an in-depth qualitative embedded single-case study design (Yin, 2018) to investigate ninth-grade students' mathematical literacy in curved-surface solids across varying levels of learning motivation. An embedded case study approach was selected because it allows for the examination of multiple sub-units—specifically, individual students with distinct motivational profiles—within a single real-world educational setting at MTs Miftahul Huda, West Java. Field data collection was systematically conducted on 26 November 2025 during the 2024/2025 academic year.

Participant Selection & Purposive Sampling Criteria

To capture rich, context-bound qualitative data, a two-tier purposive sampling strategy was implemented. In the first tier, an initial cohort of 10 ninth-grade students was systematically chosen based on three explicit inclusion criteria: completion of formal instruction on curved-surface solids (cylinders, cones, and spheres), a heterogeneous academic profile across achievement categories determined by prior formative assessments, and demonstrated communicative ability to express mathematical thinking verbally and in writing.

In the second tier, a focal sample of 3 students was selected from the initial cohort for intensive qualitative analysis and post-test interviews. This subset was stratified based on score distributions from the Learning Motivation Questionnaire to represent High, Moderate, and Low motivation categories, ensuring maximum variation, cross-case contrast, and qualitative depth.

Research Instruments and Expert Validation

The primary research instrument was the researcher, who facilitated data collection, classroom observation, and thematic interpretation. Supporting instruments included a 3-item Mathematical Literacy Test on curved-surface solids and a 10-item Learning Motivation Questionnaire adapted from Sardiman's motivational framework. To guarantee psychometric and pedagogical rigor, all instruments were evaluated by a panel of three expert validators: a senior lecturer in mathematics education specializing in PISA literacy, an assistant professor in educational measurement, and a senior IX-grade master teacher with over 12 years of experience. Content validity was quantified using Aiken's V Index:

$$V = \frac{\sum s}{n(c-1)}$$

where $s = r - l_o$, n is the number of raters, and c is the maximum rating category. Validation yielded high item validity across all five PISA indicators (V scores ranging from 0.83 to 0.92) and strong construct alignment for the motivation questionnaire (V scores ranging from 0.80 to 0.88).

Instrument reliability and item quality were further evaluated to ensure data integrity. The internal consistency of the 10-item motivation questionnaire was confirmed via Cronbach's Alpha, yielding a coefficient of $\alpha = 0.865$, which exceeds the standard reliability threshold ($\alpha > 0.70$). Additionally, Classical Test Theory (CTT) item analysis for the mathematical literacy test demonstrated moderate difficulty indices (P values between 0.45 and 0.68) and strong discrimination indices ($D > 0.35$) across all contextual items.

Frameworks for Data Categorization

Students' written test solutions were evaluated across five PISA-adapted mathematical processes tailored to curved-surface solids: problem formulation, conceptual application, mathematical modelling, problem solving, and result interpretation. The structural alignment of these processes to geometric concepts is summarized in Table 1.

To establish comparative student profiles, learning motivation and mathematical literacy performance were categorized using standardized norm-referenced evaluation criteria. Following Fatchurrohman, Mulyono, and Rosyida (2022), student learning motivation scores (x) were categorized into three distinct levels based on the sample mean (μ) and standard deviation (σ): Low ($x < \mu - \sigma$), Moderate ($\mu - \sigma \leq x < \mu + \sigma$), and High ($\mu + \sigma \leq x$). Concurrently, adapted from Mahiuddin et al. (2019), mathematical literacy performance was benchmarked on a standard 100-point scale, categorized as Low (Score < 60), Moderate ($60 \leq$ Score < 80), or High (Score ≥ 80).

Table 1. Adapted PISA Mathematical Literacy Framework

PISA Literacy Indicator	Description	Application to Curved-Surface Solids
Formulating the problem	Identifying information and expressing questions mathematically.	Identifying geometric elements (r, h, s) from contextual prompts.
Applying concepts & reasoning	Using mathematical formulas and principles appropriately.	Applying formulas for surface area and volume of cylinders, cones, and spheres.
Mathematical modelling	Constructing a mathematical model from a real-world context.	Presenting a sketch, net, or spatial equation representing the solid.
Solving the problem	Performing accurate calculations based on the constructed model.	Calculating surface area or volume from contextual problem data.
Interpreting results	Relating mathematical solutions back to the original context.	Explaining the real-world meaning of the calculated geometric output.

Data Triangulation and Analysis Procedure

To establish data trustworthiness—specifically credibility, transferability, dependability, and confirmability—this study applied a rigorous methodological and source triangulation protocol. Written test scripts, motivation questionnaire responses, and verbatim transcripts from audio-recorded semi-structured interviews were systematically cross-validated against one another to confirm consistency between student reasoning and motivational self-reports.

Qualitative data were analyzed following the interactive model of Miles, Huberman, and Saldana (2014) across three systematic stages: data reduction (coding written responses and interview transcripts against PISA indicators and Van Hiele cognitive levels), data display (constructing comparative cross-case matrices across motivation tiers), and conclusion drawing with audit trails (generating thematic assertions on spatial-cognitive blockages, verified through peer debriefing and continuous documentation).

RESULT AND DISCUSSION

RESULTS AND DISCUSSION

Baseline Profile of Mathematical Literacy and Learning Motivation

An initial screening of the $N = 10$ ninth-grade cohort revealed a pronounced skew toward lower performance tiers in both mathematical literacy and learning motivation. As summarized in Table 4, 80% of participants ($n = 8$) demonstrated low mathematical literacy, while 10% ($n = 1$) achieved moderate literacy and 10% ($n = 1$) reached the high literacy threshold (Mahiuddin et al., 2019). Concurrently, Table 5 illustrates that 60% of students ($n = 6$) exhibited low learning motivation, 20% ($n = 2$) displayed moderate motivation, and 20% ($n = 2$) demonstrated high motivation (Fatchurrohman et al., 2022).

This baseline distribution underscores a systemic alignment between affective orientation and spatial-cognitive execution in curved-surface solids. The high concentration of students in the low literacy tier highlights severe foundational blockages when translating real-world spatial contexts into formal geometric models,

mirroring the international baseline trends documented by the OECD (2023) and local empirical findings by Istiqomah and Rahaju (2014).

Table 4. Results of the Mathematical Literacy Test ($N = 10$)

Mathematical Literacy Category	Score Range	Number of Students (n)	Percentage (%)
Low	Score < 60	8	80%
Moderate	$60 \leq$ Score < 80	1	10%
High	Score ≥ 80	1	10%

Table 5. Results of the Learning Motivation Questionnaire ($N = 10$)

Learning Motivation Category	Score Range Criteria	Number of Students (n)	Percentage (%)
Low	$x < \mu - \sigma$	6	60%
Moderate	$\mu - \sigma \leq x < \mu + \sigma$	2	20%
High	$\mu + \sigma \leq x$	2	20%

Cross-Case Embedded Analysis of Focal Participants

To unpack the qualitative mechanics underlying these distributions, three focal participants ($n = 3$) representing contrasting motivational profiles were analyzed across PISA process indicators and Van Hiele levels of geometric thought.

1. Low Learning Motivation: Subject 1 (S1)

Subject 1 (S1) exhibited severe cognitive blockages and minimal task engagement, corresponding to Van Hiele Level 0 (Visualisation). In Question 1, S1 bypassed problem formulation entirely, omitting given values (radius r, height h, or slant height s) and target quantities. Rather than constructing a spatial model, S1 engaged in arbitrary arithmetic manipulation. In Question 2, S1 wrote isolated operations such as $850{,}000 + 75{,}000$ without contextual justification or dimensional units, reflecting a complete breakdown in the PISA *formulating* and *modelling* processes.

The post-test interview confirmed that low task persistence and anxiety prevented S1 from engaging in reflective problem-solving (Sardiman, 2018). S1 reported feeling overwhelmed by contextual text, choosing to perform superficial operations to complete the task quickly without verifying logical consistency or interpreting final outputs.

Interview Transcript Excerpt: Subject 1 (Low Motivation)

		Query / Response
R	:	When working on Question 1, what did you do first?
S1	:	I immediately tried to calculate. I did not write down what was known or what had to be found.
R	:	Why did you not write down the known and required information first?
S1	:	I was confused about where to start, so I immediately tried to calculate.
R	:	Did you construct a mathematical model or select a formula before calculating?
S1	:	No. I only used calculations that I thought might be suitable.
R	:	In Question 2, where did the numbers $850{,}000$ and $75{,}000$ come from?
S1	:	I saw them in the question, but I did not know how to explain them, so I wrote them down directly.
R	:	After obtaining an answer, did you check it or write a conclusion?
S1	:	No. I felt tired and stopped immediately after writing the result.

2. Moderate Learning Motivation: Subject 2 (S2)

Subject 2 (S2) demonstrated functional procedural execution but lacked deeper contextual abstraction, corresponding to Van Hiele Level 1 (Analysis). On written tasks, S2 successfully identified key geometric dimensions (r, h) and selected appropriate surface area and volume formulas taught in class, fulfilling the PISA *applying concepts* indicator. However, S2's formulation remained semi-structured; intermediate steps were occasionally omitted, and algebraic transformations were presented in a non-linear sequence.

During triangulation interviews, S2 expressed moderate confidence in executing routine algorithms but acknowledged a reluctance to perform contextual verification. Once a numerical output was calculated, S2 terminated the problem-solving sequence without evaluating whether the result satisfied the real-world constraints of the problem, leaving the PISA *interpreting results* indicator unfulfilled.

Interview Transcript Excerpt: Subject 2 (Moderate Motivation)

		Query / Response
R	:	When you read the problems, did you understand what they were asking?
S2	:	Yes, I understood most of them, but I had to reread some parts to identify the key numbers.
R	:	Did you write down all the known information and required steps?
S2	:	Not all of it. I only wrote the information that I thought was important to save time.
R	:	Did you use a particular formula during the solution process?
S2	:	Yes. I used the formulas for curved surfaces that had been taught in class.
R	:	After obtaining the result, did you relate it back to the context or write a conclusion?
S2	:	Not really. I focused only on getting the final numerical result and stopped there.

3. High Learning Motivation: Subject 3 (S3)

Subject 3 (S3) exhibited advanced spatial reasoning, systematic self-regulation, and holistic process execution, operating at Van Hiele Level 2 (Informal Deduction). In written responses, S3 systematically structured problem parameters, constructed accurate geometric representations (nets and cross-sectional sketches), and executed multi-step algebraic calculations without procedural errors. S3 fulfilled all five PISA mathematical literacy indicators.

This high-level performance demonstrates how intrinsic motivational drivers interact directly with advanced cognitive processes in 3D geometry. This study aligns

with the research of Hartono et al. (2019) and Juliani et al. (2016), who argued that systematic mathematical execution is deeply rooted in a student's capacity for rational, logical, and critical thinking. On a global scale, S3's complete fulfillment of the PISA processes resonates with the empirical observations of Kurniawati et al. (2026), who highlighted that truth-seeking characteristics and persistent logical reasoning are essential prerequisites for solving complex mathematical literacy tasks. Furthermore, S3's structural mastery contrasts sharply with the widespread geometric misconceptions and measurement errors identified in domestic secondary settings by Istiqomah and Rahaju (2014) and Muzaki and Masjudin (2019), as well as international contexts such as South Africa (Mulaudzi & Ngcobo, 2026) and Cyprus (Ozerem, 2012). While those studies documented frequent breakdowns when students attempted to transition from 2D representations to 3D spatial solids, S3 successfully bypassed these cognitive blockages through structured problem modeling and spatial net construction (Gal & Tout, 2014; OECD, 2019).

The interview dialogue revealed high intrinsic goal orientation and metacognitive monitoring (Sardiman, 2018). S3 routinely cross-checked calculations at each operational stage, contextualized the mathematical output against the original real-world scenario, and formulated explicit concluding statements validating the solution's physical plausibility.

This metacognitive reflection and task persistence confirm that learning motivation acts as a critical psychological catalyst during complex problem-solving routines. This study aligns with the research of Andres (2019), Chan et al. (2023), and Yang and Quadir (2018), confirming that high intrinsic motivation significantly elevates academic engagement, task persistence, and self-regulated learning behaviors. S3's willingness to re-evaluate mathematical models against real-world constraints directly supports the theoretical frameworks of Kamsyach and Kompri (2016), and Kompri (2016), which emphasize that sustained learning achievement relies heavily on internal drive and self-directed monitoring. Internationally, these findings mirror the results of Tran (2026)

and Ozkale and Ozdemir Erdogan (2022), who reported that opportunities to develop mathematical literacy are heavily mediated by students' confidence, emotional self-efficacy, and intrinsic value of mathematics (Tariq et al., 2013). Moreover, S3's seamless integration of contextual interpretation with formal calculations reinforces the mathematical modeling practices advocated by Machaba and Du Plooy (2019) and Genc and Erbas (2019), demonstrating that authentic literacy requires bridging theoretical formulas with real-world applicability (OECD, 2023; Sari, 2015).

These empirical insights deliver significant theoretical and practical contributions to the field of mathematics education. Methodologically and theoretically, these findings enrich the literature by providing an integrated diagnostic perspective on how affective motivational factors (Nguyen, 2025; Rehman et al., 2020) interlock with Van Hiele geometric abstraction levels and PISA process competencies. Practically, for classroom instruction, S3's performance underscores the need for teachers to adopt active, motivation-sensitive pedagogical strategies (Andres, 2019; Graven & Venkat, 2007). Rather than relying on passive formula memorization, educators should implement structured contextual modeling, metacognitive prompting, and scaffolding that encourages students across all motivational tiers to cultivate truth-seeking and self-checking habits when learning 3D geometry.

Interview Transcript Excerpt: Subject 3 (High Motivation)

		Query / Response
R	:	What did you do first after reading the problem?
S3	:	I read the problem several times and wrote down the known information and what had to be found to avoid choosing an incorrect step.
R	:	Did you construct a mathematical model or plan before calculating?
S3	:	Yes. I selected the formula and planned the solution steps sequentially according to the problem geometry.
R	:	Were you confident about each step?

S3	:	Yes, because I rechecked the calculations at every stage to ensure there were no errors.
R	:	What did you do after obtaining the calculation result?
S3	:	I related the result back to the real-world context, evaluated whether it was reasonable, and wrote a clear final conclusion.

Comparative Cross-Case Synthesis

Cross-case synthesis reveals a structural correspondence between affective motivation, geometric abstraction levels, and PISA mathematical literacy processes. As detailed in Table 6, low motivation restricts cognitive engagement to superficial arithmetic operations (Van Hiele Level 0), resulting in low literacy. Moderate motivation supports algorithmic formula application (Van Hiele Level 1), yielding partial literacy mastery. High motivation fosters complete metacognitive oversight and contextual synthesis (Van Hiele Level 2), facilitating full PISA literacy attainment. This study aligns with the research of Istiqomah and Rahaju (2014) and Muzaki and Masjudin (2019), who documented similar geometric difficulties and procedural errors among domestic secondary students when solving 3D curved-surface solid problems. Internationally, this study aligns with the research of Machaba and Du Plooy (2019) and Mulaudzi and Ngcobo (2026) in South Africa, as well as Genc and Erbas (2019) in Turkey, which highlighted that secondary learners frequently encounter severe cognitive blockages when attempting to translate real-world contextual scenarios into formal geometric models. Furthermore, this study aligns with the research of Andres (2019), Chan et al. (2023), and Nguyen (2025), confirming that higher learning motivation serves as a crucial psychological engine that fosters active academic engagement, self-regulation, and sustained task persistence during multi-step problem solving. In line with the logical reasoning and truth-seeking frameworks of Hartono et al. (2019), Juliani et al. (2016), and Kurniawati et al. (2026), these findings reinforce the global assessment standards outlined by Gal and Tout (2014) and OECD (2019), proving that authentic

mathematical literacy extends beyond mechanical computation to require deep structural abstraction.

Table 6. Cross-Case Synthesis of Focal Participants

Focal Participant	Motivation Category	Van Hiele Geometric Level	Fulfilled PISA Literacy Processes	Spatial-Cognitive Characteristics
Subject 1 (S1)	Low ($x < \mu - \sigma$)	Level 0 (Visualisation)	None (Fragmented execution)	Impulsive calculation, inability to extract r, h, s, absence of model and interpretation.
Subject 2 (S2)	Moderate ($\mu - \sigma \leq x < \mu + \sigma$)	Level 1 (Analysis)	Formulating (Partial), Applying Concepts, Solving	Rote formula application, linear procedural execution, lack of contextual verification.
Subject 3 (S3)	High ($\mu + \sigma \leq x$)	Level 2 (Informal Deduction)	Formulating, Applying Concepts, Modelling, Solving, Interpreting	Systematic variable extraction, accurate net/model construction, robust metacognitive evaluation.

The empirical findings demonstrate that mathematical literacy in curved-surface solids is mediated by affective motivational structures. The high prevalence of low literacy (80%) and low motivation (60%) in this sample corroborates global assessments by the OECD (2023) and local investigations by Ozerem (2012) and Istiqomah and Rahaju (2014), which document pervasive spatial misconceptions among secondary learners. When confronted with three-dimensional contextual problems, students lacking internal motivational drivers frequently experience cognitive overload, reverting to disconnected numerical operations rather than constructing geometric

models (Sari, 2015; Muzaki & Masjudin, 2019). Internationally, this structural defect aligns with observations by Mulaudzi and Ngcobo (2026) in South Africa, where unaddressed spatial-conceptual gaps hindered contextual problem solving in secondary geometry. This study aligns with the research of Hartono et al. (2019), Juliani et al. (2016), and Kurniawati et al. (2026), which demonstrates that systematic mathematical problem solving is heavily dependent on students' rational thinking, truth-seeking traits, and logical reasoning capacity. Furthermore, these empirical data reinforce international findings by Ozkale and Ozdemir Erdogan (2022) in Turkey and Tariq et al. (2013) in the United Kingdom, confirming that student engagement in complex mathematical literacy tasks is strongly mediated by non-cognitive factors, including emotional self-efficacy, anxiety regulation, and intrinsic value.

From a theoretical perspective, these results validate the integrated affective-cognitive frameworks proposed by Andres (2019) and Chan et al. (2023). High learning motivation serves as an essential psychological engine that sustains perseverance during multi-step mathematical modelling. While cognitive skills dictate how spatial transformation occurs, motivational drivers govern whether a student allocates sufficient executive processing resources to analyze spatial relations, cross-check algebraic steps, and interpret real-world outcomes (Kurniawati et al., 2026; Tran, 2026). By demonstrating how motivational tiers correlate directly with Van Hiele geometric abstraction levels (ranging from Level 0 Visualisation in low-motivated cohorts to Level 2 Informal Deduction in high-motivated learners), this work directly resolves a critical literature gap highlighted in the State of the Art—specifically, the traditional separation of psychological motivational constructs from domain-specific 3D spatial literacy competencies (Graven & Venkat, 2007; Machaba & Du Plooy, 2019).

In terms of contributions to mathematics education, this research provides an integrative diagnostic baseline that empowers curriculum developers and teachers to transition away from passive formula memorization toward motivation-sensitive, inquiry-driven pedagogy (Andres, 2019; Genc & Erbas, 2019). By demonstrating that

low motivation active blocks the formulation and modeling phases of PISA problem solving, this study underscores the necessity of embedding metacognitive prompting, dynamic visual manipulatives, and structured scaffolding into core geometry instruction (Graven & Venkat, 2007; Machaba & Du Plooy, 2019).

However, several methodological limitations must be acknowledged to contextualize these findings. First, the empirical investigation was conducted within a single institutional setting (MTs Miftahul Huda) utilizing a small sample size ($N = 10$ for initial screening and $n = 3$ for focal qualitative analysis), which restricts the statistical generalizability of the findings across broader populations. Second, the domain scope was strictly limited to 3D curved-surface solids (cylinders, cones, and spheres), leaving other essential geometric subdomains—such as polyhedra, coordinate geometry, or transformational geometry—unexamined. Finally, the categorization of student motivation relied on self-reported questionnaire scales, which may introduce subjective response bias.

Instructional Implications, Limitations, and Future Directions

From a practical stance, these diagnostic insights necessitate a shift away from uniform algorithmic instruction toward differentiated pedagogical frameworks. Mathematics educators must integrate structured contextual scaffolding—such as dynamic 3D visual manipulatives and guided spatial modeling protocols—to support students operating at lower Van Hiele levels (Graven & Venkat, 2007). Fostering intrinsic motivation through authentic, project-based geometry tasks can encourage low-motivated learners to transition from passive formula memorization to active mathematical inquiry (Andres, 2019).

This study acknowledges specific methodological limitations, including an embedded sample restricted to a single institutional site (MTs Miftahul Huda) and a focus limited to curved-surface solids. Additionally, relying on self-reported motivational scales can introduce response bias. Future research should implement

longitudinal, multi-site mixed-methods designs across broader geographic demographics and geometric topics to further validate and expand these findings.

CONCLUSION

This study establishes that secondary students' mathematical literacy in curved-surface solids is intrinsically bound to their level of learning motivation. High learning motivation enables students to operate at Van Hiele Level 2 (Informal Deduction) and systematically fulfill all five PISA mathematical literacy processes—formulating, applying, modelling, solving, and interpreting—when addressing complex 3D geometric tasks. Conversely, low learning motivation restricts students to Van Hiele Level 0 (Visualisation), resulting in fragmented mathematical execution, cognitive overload, and an inability to translate spatial contexts into formal geometric models. Moderate motivation supports routine algorithmic application (Van Hiele Level 1) but fails to foster contextual interpretation or reflective evaluation.

This behavioral and cognitive divergence occurs because learning motivation serves as an active psychological engine and metacognitive catalyst during spatial problem-solving. High intrinsic motivation drives academic engagement, sustained task persistence, and rigorous self-regulation. This enables learners to allocate necessary cognitive executive resources toward spatial net construction, multi-step algebraic manipulation, and validation of mathematical outputs against real-world physical constraints. In contrast, low motivation induces anxiety and task avoidance, causing learners to bypass qualitative problem formulation in favor of superficial, uncontextualized arithmetic operations.

To address the methodological limitations of this study—specifically its single-site embedded case design at MTs Miftahul Huda, small sample size, focus limited to curved-surface solids, and reliance on self-reported motivational scales—future research should expand to multi-site, longitudinal mixed-methods designs involving

broader, geographically diverse student demographics. Additionally, scholars should investigate the interaction between learning motivation and spatial literacy across other geometric subdomains, such as polyhedra, coordinate geometry, and transformational geometry. Finally, future studies ought to evaluate the empirical efficacy of differentiated, technology-enhanced pedagogical interventions—such as dynamic 3D visual manipulatives, structured spatial modeling scaffolds, and metacognitive prompting—tailored specifically to support learners in lower motivational tiers.

The overarching vision of this research direction is to bridge the long-standing divide between affective drivers and cognitive processing in mathematics education. By embedding motivation-sensitive frameworks into core geometry curricula, educational systems can move away from passive formula memorization toward inclusive, inquiry-driven learning environments. Ultimately, cultivating both affective resilience and spatial-conceptual mastery will empower all learners—regardless of initial performance or motivational tier—to acquire the critical analytical reasoning and mathematical literacy necessary for STEM-oriented career pathways and complex real-world problem-solving.