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Dynamics and Independence of Junior High School Students' Mathematical Communication Skills and Self-Regulated Learning in SQ5R-Based Learning

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Abstract

This study is motivated by the low levels of mathematical communication skills and self-regulated learning among junior high school students facing abstract geometric concepts. The objective of this research is to examine the temporal dynamics and structural independence of students' written mathematical communication skills and self-regulated learning through the implementation of an SQ5R-based learning model on the Pythagorean Theorem. The research method applied a descriptive quantitative approach with a Pre-Experimental One-Group Time-Series Design tracking 25 eighth-grade students selected via purposive sampling over five consecutive sessions. Data were collected through daily written essay tests, periodic self-assessment questionnaires, observation logs, and confirmation interviews. The scientific findings revealed that the progression of students' mathematical communication skills is explicitly non-linear, transitioning from a slow initial adaptation phase (N-gain = 0,07) to an accelerated development phase at the third session (N-gain = 0,42), before stabilizing efficiently at subsequent sessions (N-gain = 0,41). Concurrently, the trajectory of self-regulated learning documented an acute cognitive-load-driven self-regulation crisis during the third session where the High category frequency dropped sharply to 8% followed by a robust affective resilience that successfully reached a peak dominance of 72% at the final cycle. Crucially, the global Pearson correlation coefficient uncovered an extremely weak relationship (r_{XY}= 0,068), empirically proving that cognitive communication and affective self-regulation develop independently within the classroom setting.

Keywords: *Mathematical Communication, Self-Regulated Learning, SQ5R Model, Time-Series Design, Pythagorean Theorem*

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INTRODUCTION

Mathematics is a fundamental discipline in modern education that plays an important role in developing logical, analytical, and creative thinking through systematic modeling and problem solving. At the junior high school level, mathematics learning is directed not only toward mastery of concepts and procedures but also toward the development of higher-order thinking competencies, including students' mathematical communication skills and self-regulated learning (OECD, 2023). Mathematical communication enables students to express ideas, construct arguments, interpret representations, and communicate solution procedures, whereas self-regulated learning supports students in managing their learning processes independently.

However, the actual condition of mathematics learning in Indonesia indicates that students' mathematical communication skills have not yet developed optimally. The Ministry of Education study (2023) reported that many junior high school students experience difficulty in presenting mathematical ideas systematically, while a substantial proportion remain highly dependent on teacher instruction (Nasution et al., 2022). The 2022 PISA results also indicate that Indonesian students continue to face challenges in mathematical reasoning, representation, and problem solving. These conditions highlight the need for learning approaches that simultaneously develop cognitive communication skills and students' learning autonomy.

To address these problems, a deep learning approach can contribute to the development of students' mathematical communication skills and self-regulated learning by emphasizing connections among concepts and reflective repetition (Fullan et al., 2022). One relevant approach is SQ5R-based learning (Survey, Question, Read, Recite, Record, Review, Reflect), a structured learning strategy that emphasizes active information processing, questioning, comprehension, recording, review, and reflection. In mathematics learning, these stages can guide students to process abstract information systematically and actively construct conceptual understanding.

The development of mathematical communication skills can be facilitated sequentially through the reasoning stages of the SQ5R model. At the Read stage, students are directed to study the material deeply and purposefully so that they can construct stronger conceptual understanding and represent mathematical ideas symbolically and verbally (Delfia Rahma, 2021). The Recite stage encourages verbal expression and confidence in explaining mathematical reasoning, while the Record and Review stages support students in organizing written solution procedures and checking the accuracy of their work. Thus, the SQ5R sequence provides opportunities for students to communicate mathematical ideas through multiple forms of representation.

The dimension of self-regulated learning is strengthened through the higher-order metacognitive stages of the SQ5R model. Based on self-regulation theory, learning independence is not merely an academic ability but a dynamic process in which students actively manage their cognition, motivation, and behavior to achieve learning goals (Hargis, 2020). This regulatory cycle is stimulated through Review activities that reinforce long-term retention and through Reflect activities that encourage students to evaluate their learning strategies, strengths, and weaknesses. Consequently, SQ5R provides a structured space for the development of students' initiative, discipline, responsibility, confidence, time management, goal setting, independent resource seeking, and self-evaluation.

There is a close and mutually supportive relationship between the SQ5R syntax and indicators of students' mathematical communication skills and self-regulated learning. Survey activities stimulate the interpretation of visual representations and encourage learning initiative and goal setting (Robinson et al., 2018). Read activities support visual interpretation while training students to seek learning resources independently. The Recite stage promotes fluency in explaining solution procedures and communicating discussion results, whereas Record, Review, and Reflect reinforce discipline, responsibility, self-evaluation, and metacognitive awareness.

Previous studies have shown a positive relationship between students' mathematical communication skills and self-regulated learning (Sari, Putra, & Rahmawati, 2024). The flexibility of the Question and Reflect stages has been reported to support intrinsic motivation and deductive reasoning in learning the Pythagorean Theorem, while the combination of Read, Recite, and Review is effective for learning abstract mathematical concepts (Kurniawan & Santoso, 2021). Nevertheless, a research gap remains because most previous studies have examined mathematical communication and self-regulated learning separately and through stationary, one-shot measurements. In mathematics instruction, "dynamics" refers to movement, fluctuation, and adaptive transformation in students' thinking schemes and behavioral changes from one phase to another (Sanjaya et al., 2021).

In descriptive quantitative research using a time-series design, dynamics are understood as patterns of fluctuation, trend direction, and stability in the rate of change in student performance measured repeatedly at each learning session (Creswell & Creswell, 2018). Periodic evaluation using essay-test scores and sequential response questionnaires is intended to carefully trace error patterns and the operational relationships underlying students' written communication performance and self-regulation. Based on this rationale, this study aimed to comprehensively examine the dynamics of students' mathematical communication skills after learning through SQ5R-based instruction, the dynamics of students' self-regulated learning after SQ5R-based instruction, and the relationship between written mathematical communication skills and self-regulated learning among junior high school students learning the Pythagorean Theorem.

METHOD

This study employed a descriptive quantitative approach with a pre-experimental One-Group Time-Series Design. The research was conducted in one sample class without a control or comparison group. Student performance was measured repeatedly across five learning sessions to observe actual patterns of change, developmental trends, score fluctuations, and a comprehensive picture of the dynamics of students' cognitive and affective development over time.

This study was conducted at UPT SMP Negeri 1 Kurra during the second semester of the 2025/2026 academic year and included instrument preparation, SQ5R-based instructional intervention on the Pythagorean Theorem, data collection, and data analysis. The population consisted of all eighth-grade students, while the sample was selected using purposive sampling. Class VIII A, consisting of 25 students, was selected as the single sample because it

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represented heterogeneous academic abilities and had not previously learned the topic through the SQ5R model.

The cognitive variable was limited to students' written mathematical communication skills, measured periodically through pretests and posttests at each session based on six indicators: explaining mathematical ideas in writing; translating problems into mathematical form; using symbols and notation correctly; explaining solution procedures systematically; interpreting visual representations such as figures and graphs; and communicating the results of discussions or problem solving. The self-regulated learning variable measured daily psychological aspects through a self-assessment questionnaire based on eight indicators: learning initiative, learning discipline, self-confidence, responsibility, ability to manage learning time, clear learning goals, independent search for learning resources, and self-evaluation of learning outcomes. The intervention consisted of SQ5R-based learning across five sessions on the Pythagorean Theorem: discovering the concept of the Pythagorean Theorem; understanding and determining Pythagorean triples; ratios of sides in special-angle triangles; contextual word-problem applications; and the distance formula.

Data were collected periodically at each session using a combination of quantitative and supporting qualitative techniques. Data were obtained through structured observation of the implementation of the seven SQ5R stages, essay tests (pretests and posttests) in each session, and closed Likert-scale questionnaires for students' self-assessment. As supporting data, periodic semi-structured explanatory interviews were selectively conducted with six subjects (two high-performing, two low-performing, and two anomalous cases) to explore psychological reasons or cognitive constraints underlying distinctive fluctuations in their quantitative profiles.

Before use, the essay test (holistic score 0–4) and questionnaire (four-point scale) were piloted in a homogeneous class outside the research sample. Item validity was examined logically through expert judgment and quantitatively using the Karl Pearson Product Moment correlation. Reliability was tested using Cronbach's Alpha because the instruments used graded scales, with the reliability coefficient required to reach at least the high category ($r > 0.60$) to ensure consistent use in the one-group time-series design.

The implementation of learning was analyzed using the percentage achieved at each session to ensure consistency of the intervention. The dynamics of mathematical communication skills were analyzed using the class mean daily score (100-point scale) and Hake's Normalized Gain (N-gain)—high ($g > 0.70$), moderate ($0.30 \leq g \leq 0.70$), or low ($g < 0.30$)—and displayed in line graphs. For self-regulated learning, cumulative questionnaire scores were categorized as high (≥ 92.4), moderate (84.0–92.3), or low (< 84.0) and mapped into daily trend graphs. Finally, the relationship between variables was tested using the global Pearson correlation coefficient and strengthened with descriptive narratives from explanatory interviews with six subjects to explain factors underlying trends or data anomalies.

RESULTS

The implementation of the SQ5R-based mathematics learning model was observed systematically from Session 1 to Session 5 in Class VIII A of UPT SMP Negeri 1 Kurra. The observation focused on the seven stages of the syntax using an observation rating scale from 1 to 4. A summary of the development of component scores and the percentage of implementation feasibility is presented in Table 1.

Table 1. Recapitulation of SQ5R Learning Model Implementation Scores

Session/ Topic	Syntax Score							Total	Implementation %
	Survey	Question	Read	Recite	Record	Review	Reflect		
P 1 Discovering the Pythagorean Theorem	3	3	3	3	3	2	3	20	71,43%
P 2 Understanding & Determining Pythagorean Triples	3	3	3	4	2	3	3	21	75,00%
P 3 Side Ratios (Special Angles)	4	2	4	3	3	4	3	23	82,14%
P 4 Applications of the Pythagorean Theorem	4	3	4	3	4	3	4	25	89,29%
P 5 Distance Formula	3	4	4	3	4	4	4	26	92,86%

The data in Table 1 show that the percentage of intervention implementation increased progressively and adaptively from 71.43% in P1 to 75.00% in P2, 82.14% in P3, 89.29% in P4, and reached an optimum level of 92.86% in P5. During the first two sessions, students experienced technical and behavioral adjustment difficulties. In Session 1, the Review component received a score of 2 because students were not yet accustomed to conducting autonomous evaluation before submitting their work. In Session 2, the Record component received a score of 2 because of time-allocation difficulties in recording proofs of Pythagorean triple patterns. These obstacles were overcome in Sessions 4 and 5, when

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habituation to the SQ5R sequence enabled all stages to be implemented more consistently at higher levels of process performance as students' metacognitive engagement matured.

Descriptive statistical analysis was conducted on the distribution of pretest and posttest scores on a 100-point scale to examine the development of written mathematical thinking among the 25 students in Class VIII A. The descriptive parameters are summarized in Table 2.

Table 2. Descriptive Statistics of Mathematical Communication Skills Scores

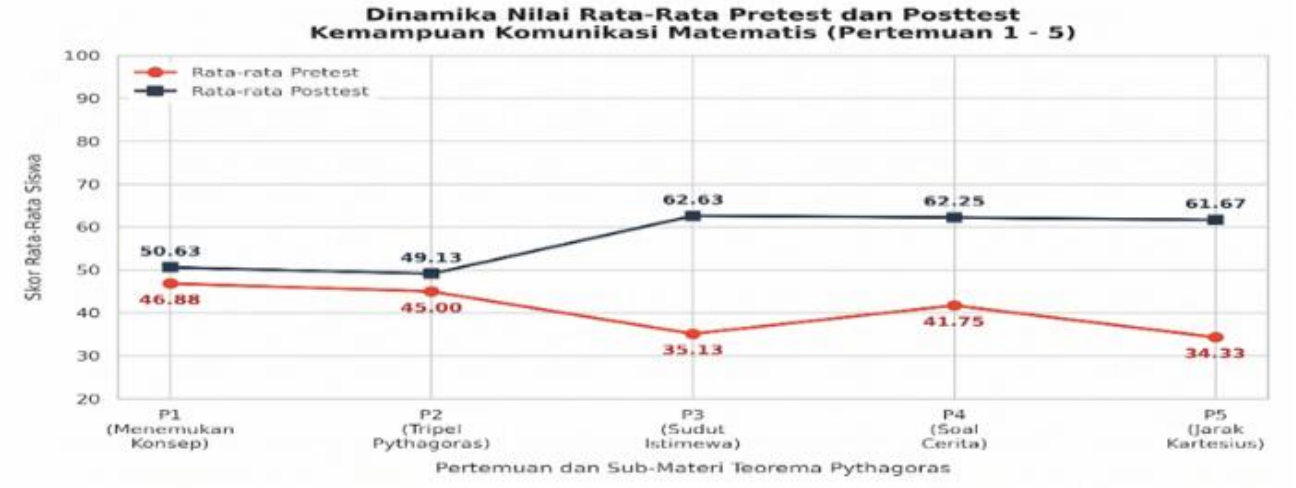
Session / Subtopic	Test Type	Minimum Score	Maximum Score	Mean Score	Standard Deviation (SD)
Discovering the Concept	Pretest	31,25	59,38	46,88	5,85
	Posttest	37,50	62,50	50,63	6,44
Pythagorean Triples	Pretest	37,50	53,13	45,00	4,69
	Posttest	43,75	59,38	49,13	3,67
Special Angles	Pretes	31,25	43,75	35,13	3,53
	Posttest	40,63	78,13	62,63	10,46
Application/Word Problems	Pretest	34,38	50,00	41,75	4,32
	Posttest	40,63	84,38	62,25	14,15
Cartesian Distance Formula	Pretest	29,17	41,67	34,33	2,76
	Posttest	41,67	87,50	61,67	12,27

To measure the magnitude of cognitive change occurring during each learning session after the SQ5R-based intervention, Hake's Normalized Gain (N-gain) formula was used. The results of the analysis of mean absolute gain and the N-gain index are presented in Table 3.

Table 3. Summary of Students' Gain Scores and N-Gain Index Analysis

Session/ Subtopic	Mean Pretest Score	Mean Posttest Score	Mean Absolute Gain	Mean N-Gain Index	N-Gain Category
Discovering the Concept	46,88	50,63	3,75	0,07	Low
Tripel Pythagoras	45	49,13	4,13	0,07	Low
Special Angles	35,13	62,63	27,5	0,42	Moderate
Application/Word Problems	41,75	62,25	20,5	0,36	Moderate
Cartesian Distance Formula	34,33	61,67	27,33	0,41	Moderate

A visual comparison of the periodic changes in the class mean scores between the pretest and posttest is presented in Figure 1.



The data in Tables 2 and 3 and Figure 1 reveal that students' cognitive development progressed through three phases. First was the Baseline and Homogeneous Score Phase (P1 and P2), in which the mean scores changed only slightly and remained in the low range (50.63 and 49.13), with the N-gain remaining at 0.07 (low

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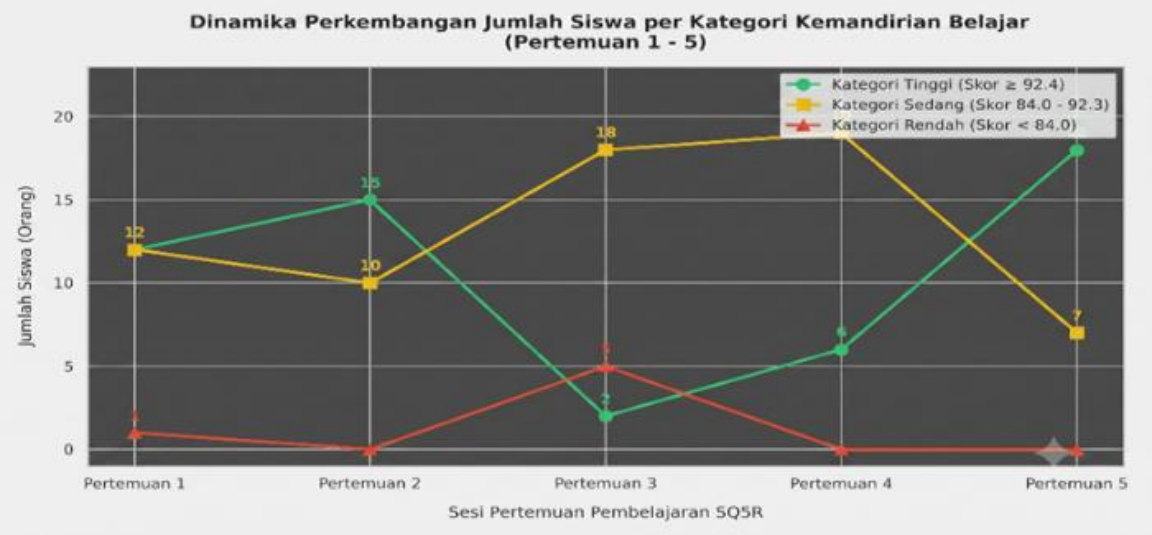
category). The relatively small standard deviations (3.67–6.44) indicate that students' written mathematical communication abilities remained closely clustered and homogeneous because of initial adaptation difficulties with structured reading instructions. Second was the Score Polarization and Acceleration Phase (P3), in which the special-angle subtopic produced a large increase in absolute gain (27.50 points), raising the class mean to 62.63 and increasing the N-gain to 0.42 (moderate category). This acceleration was accompanied by a wider standard deviation of 10.46, indicating increasing differentiation in students' cognitive performance. Third was the Performance Stabilization Phase for Complex Content (P4 and P5). Although the content became more abstract through algebraic modeling of contextual word problems and visualization on the Cartesian coordinate plane, the mean posttest scores remained meaningfully stable above 61 (62.25 and 61.67), with N-gain values consistently in the moderate category (0.36 and 0.41).

The mapping of the affective dimension of autonomy among Class VIII A students during the SQ5R intervention was based on cumulative daily self-assessment questionnaire scores. These cumulative class scores were converted into frequencies and percentages according to three standard intervals of self-regulated learning: high (≥ 92.4), moderate (84.0–92.3), and low (< 84.0). A summary of the distribution of students' autonomous learning attitudes is presented in Table 4.

Table 4. Descriptive Statistics of Cumulative Class Self-Regulated Learning Scores (N = 25)

Session / Subtopic	Minimum Cumulative Score	Maximum Cumulative Score	Mean Total Score	Standard Deviation (SD)
Discovering the Concept	82	96	91,6	3,28
Tripel Pythagoras	88	101	93,84	3,04
Special Angles	80	94	86,96	3,98
Application	84	99	90,84	3,12
Distance Formula	84	101	95,04	5,54

Changes in the distribution of the number of students across the daily self-regulated learning categories are visualized sequentially in Figure 2.



The data in Table 4 and Figure 2 provide a measurable picture of the dynamic and non-linear trajectory of students' self-regulated learning during the SQ5R implementation cycle, which can be divided into three major phases. First was the Initial Enthusiasm and Classroom Adjustment Phase (P1 and P2), characterized by an increase in students in the high category from 48% to 60% and the complete absence of students in the low category. This initial pattern reflects strong intrinsic motivation and self-confidence when students were introduced to visual illustrations through the Survey and Question stages. Second was the Self-Regulation Crisis Due to Content Pressure (P3), when the affective dimension experienced a sharp decline. The proportion of students in the high category dropped from 60% to only 8% (two students), the low category increased to 20% (five students), and 72% of the class concentrated in the moderate category. This crisis was associated with the high cognitive complexity of the special-angle subtopic, which affected students' self-efficacy and confidence and increased dependence on teacher guidance. Third was the Affective Resilience and Autonomous Maturity Phase (P4 and P5). After passing through the crisis, students' autonomous attitudes recovered substantially. In the final session (P5), 72% of students (18 students) were in the high category and the low category declined to 0%, indicating that the metacognitive habits developed through Record, Review, and Reflect had become more firmly internalized in students' affective behavior.

The global Pearson correlation analysis revealed an unusual empirical finding: a near-zero relationship between written mathematical communication skills and students' self-regulated learning ($r = 0.068$), which even became weakly negative in the fifth session ($r = -0.043$). This quantitative finding indicates a research gap in which the cognitive aspect of written communication and the affective aspect of self-regulated learning

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developed relatively independently in the mathematics classroom. To explain this weak relationship, data from confirmation interviews with six selected subjects representing different performance quadrants were integrated, as summarized in Table 5.

Table 5. Selection Matrix of Six Confirmation Interview Subjects

No	Subject Code	Quadrant Category	Basis for Subject Selection (Data Characteristics)	Data Status
1	S-01	High Extreme	Student with consistently high mathematical communication posttest scores and self-regulated learning questionnaire scores at every session.	Supplementary (Positive Confirmation)
2	S-02	High Extreme	Student with the most progressive cognitive and affective development trend (the most stable upward trajectory).	Supplementary (Positive Confirmation)
3	S-03	Low Extreme	Student whose mathematical communication posttest and self-regulated learning scores consistently remained at the lower end of the class.	Supplementary (Obstacle Confirmation)
4	S-04	Low Extreme	Student whose test and questionnaire trends showed resistance (low stagnation) from the early to middle phases of the SQ5R cycle.	Supplementary (Obstacle Confirmation)
5	S-05	Contradictory Anomaly	Student with very high daily self-regulated learning scores but low mathematical communication test performance.	Supplementary (Anomaly Confirmation)
6	S-06	Contradictory Anomaly	Student with high mathematical communication test performance but low/moderate self-regulated learning questionnaire scores.	Supplementary (Anomaly Confirmation)

The explanatory interview transcripts revealed several psychological and cognitive mechanisms underlying this quantitative separation:

High-Performing Group (S-01 & S-02):

These students demonstrated positive adaptation in which the active-reading stages of SQ5R operated synchronously. Strong self-regulation initiative supported independent algebraic modeling without excessive dependence on the teacher.

Low-Performing Group (S-03 & S-04):

These students confirmed fundamental learning obstacles. Their low performance was associated with acute procedural difficulties in square operations and extracting square roots, which triggered mathematics anxiety from the beginning of the topic.

Anomalous Subject A (S-05 / High Independence–Low Performance):

Although S-05 demonstrated strong learning initiative, discipline, and very high affective self-regulation at home, the student's written mathematical communication scores consistently remained near the lower end of the class. The interview revealed a misconception related to spatial disorientation in geometry: the student was confused about identifying the hypotenuse when a right-triangle figure was rotated on the Cartesian plane, causing the algebraic equation structure to be repeatedly constructed incorrectly. This finding shows that an independent attitude does not automatically eliminate epistemological barriers in mathematics.

Anomalous Subject B (S-06 / Low Independence–High Performance):

In contrast, S-06 had very low daily self-regulated learning scores, tended to be passive and anxious during group work, and showed limited self-confidence; however, the student's written mathematical communication posttest performance was consistently high and systematic. The interview confirmed that S-06 possessed strong logical-mathematical ability and procedural calculation skills. This enabled the student to complete Pythagorean algorithms accurately despite unstable affective self-regulation.

DISCUSSION

The slow and non-linear dynamics of eighth-grade students' written communication skills at the beginning of the cycle (N-gain = 0.07) support the view that spatial ability and literacy in geometry require gradual habituation to systematic learning processes and cannot accelerate instantly. This phenomenon is reinforced by procedural error analysis showing that the transition toward more independent learning may initially constrain cognitive scores because of difficulties in basic algebraic modeling. However, the stabilization of scores above 61 in the final two sessions (P4 and P5) indicates that the Record and Review components functioned as effective cognitive scaffolding through structured note-taking and reflective checking. The findings suggest that sustained SQ5R practice can support longer-term conceptual understanding, although the pattern does not necessarily follow an immediate linear increase.

In the affective dimension, the sharp decline in the high self-regulated learning category to only 8% in Session 3 provides important support for the metacognitive perspective that highly difficult content can impose substantial intrinsic cognitive load, temporarily reducing intrinsic motivation and self-efficacy for self-regulation. The fluctuating pattern is consistent with the view that self-regulated learning in mathematics is not static but is a dynamic affective process influenced by instructional situations. Nevertheless, the recovery of affective resilience at the end of the intervention, when 72% of students reached the high category in P5, suggests that the Record, Review, and Reflect stages can contribute to the long-term development of discipline and autonomous initiative.

The major research gap revealed by the very weak global correlation coefficient (r = 0.068) constitutes an important contribution of this study. The finding differs from earlier correlational studies that reported strong positive relationships

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between self-regulated learning and mathematical communication skills. One possible explanation is methodological: many earlier studies used one-shot cross-sectional designs that collected data only once, whereas the One-Group Time-Series Design used in this study captured day-to-day cognitive and affective dynamics across repeated sessions. The anomalous cases of S-05 (High Independence–Low Performance) and S-06 (Low Independence–High Performance) further indicate that affective independence and cognitive communication competence do not necessarily develop in a rigid linear relationship. Their relationship appears dynamic, contextual, and individually variable among junior high school students.

CONCLUSION

The dynamics of Class VIII A students' mathematical communication skills were non-linear, progressing through a slow initial phase (N-gain = 0.07), acceleration in the third session (N-gain = 0.42), and stabilization at the end of the cycle (N-gain = 0.41), supported by cognitive scaffolding through the Record and Review stages. In contrast, the trajectory of self-regulated learning experienced a crisis due to the high cognitive load of the special-angle topic in the third session, when the high category declined to 8%, but later demonstrated strong affective resilience and reached 72% in the final session through the internalization of the Reflect stage. Crucially, the global Pearson correlation analysis revealed a very weak relationship (r = 0.068), indicating that the cognitive aspect of written mathematical communication and the affective aspect of self-regulated learning can develop relatively independently and non-linearly. This independence was illustrated by anomalous cases of students who were highly independent but whose performance was constrained by spatial disorientation in rotated geometric figures, as well as students who were anxious and dependent but possessed strong procedural logical-calculation skills.

Based on these findings, mathematics teachers are recommended to provide sufficient transition time for students to understand the SQ5R syntax at the beginning of a learning unit and to provide more intensive affective scaffolding when the content reaches a high level of difficulty in order to maintain students' self-confidence. Schools are expected to support an active numeracy-literacy climate by integrating SQ5R strategies into curriculum programs and providing mathematics modules rich in authentic visual representations to reduce mathematics anxiety. Future researchers are encouraged to expand the sample across different educational levels to improve the reliability of the findings and to investigate external psychological factors or specific learning-style modalities that interact with the cognitive load associated with each SQ5R stage.

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