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Numeracy, verbal skills, learning motivation, and self-regulation as predictors of academic success in high school

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ABSTRACT

This study explores the influence of numerical literacy, verbal ability, learning motivation in science, and self-regulation on academic achievement among high school students. In today's dynamic educational landscape, success requires more than academic knowledge—it also demands motivation and self-directed learning strategies. This research aimed to examine how these four factors interrelate to predict learning outcomes. Employing an ex-post facto quantitative design, data were collected from 119 high school students across four schools using validated questionnaires and learning outcome assessments. The variables included numerical literacy, verbal ability, and science learning motivation as independent variables, self-regulation as a mediating variable, and academic achievement as the dependent variable. The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results showed that all three independent variables significantly and positively affected self-regulation: numerical literacy ($\beta = 0.410$, $p < 0.001$), verbal ability ($\beta = 0.291$, $p < 0.01$), and science learning motivation ($\beta = 0.215$, $p < 0.05$). Furthermore, self-regulation positively influenced academic achievement ($\beta = 0.405$, $p < 0.001$). These findings underscore the critical role of self-regulation as a bridge between cognitive skills and academic performance. By strengthening students' ability to manage their own learning, educators can enhance academic success, especially in numeracy and science-based learning environments.

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Introduction

The dynamics of education in the modern era demand a transformative shift in how student competencies are defined and developed. No longer is academic success solely determined by the mastery of subject content; rather, it is shaped by a blend of cognitive skills, emotional regulation, and motivational readiness that enable students to adapt, think critically, and function independently. In this evolving educational landscape, both cognitive and non-cognitive factors have emerged as critical determinants of student achievement. Among these, numerical literacy (Rosnelli & Ristiana, 2023), verbal ability (Sherkat, 2022), interest in science learning (Trust et al., 2021), and self-regulation (Code, 2020) have gained prominence due to their integrative role in shaping how students perceive, process, and respond to academic tasks.

These four factors are not isolated constructs, but rather interrelated dimensions that contribute collectively to students' academic trajectories. Numerical literacy, for instance, extends beyond the ability to perform calculations—it reflects a student's capacity to analyze data, reason quantitatively, and make informed decisions in real-life contexts. In parallel, verbal ability is foundational not only for academic communication but also for articulating thought processes, engaging in reflective learning, and developing interpersonal competence. Simultaneously, a sustained interest in science learning stimulates curiosity, promotes persistence, and fuels long-term engagement with STEM subjects—an area increasingly vital in the context of global technological advancement. Self-regulation, on the other hand, serves as the internal mechanism that empowers students to set goals, monitor progress, manage time and emotions, and maintain motivation throughout their learning journey.

Together, these competencies form a holistic framework that equips students to thrive in an unpredictable and fast-paced digital world. Despite their recognized importance, however, research exploring the combined predictive power of these four variables—particularly within high school settings—remains limited. This study, therefore, seeks to address this gap by investigating their interrelationships in the context of academic achievement.

Previous research has laid important groundwork for this investigation. For example, the integration of numerical literacy and verbal ability has been shown to significantly enhance conceptual understanding (Suggate et al., 2018). These core cognitive abilities enable students not only to acquire knowledge, but also to process, interpret, and apply it meaningfully across disciplines. Numerical literacy strengthens logical reasoning, quantitative analysis, and the ability to solve complex, real-world problems—skills that are indispensable in the 21st century. Likewise, verbal ability enriches comprehension, critical argumentation, and expression, forming the backbone of academic discourse and collaborative learning. When developed simultaneously, these skills form a cognitive synergy that supports deeper learning and metacognitive awareness.

Equally essential are the motivational and behavioral aspects of learning. Interest in science learning and self-regulation function as powerful drivers that sustain student engagement. A student's interest in science is not simply an emotional preference—it is a deep motivational force that fuels curiosity and persistence in navigating complex scientific ideas (Code, 2020). Meanwhile, self-regulation equips learners with strategies to control impulses, set achievable goals, manage distractions, and evaluate their own progress. These self-directed learning skills are foundational for academic independence.

Focusing more specifically on each construct, numerical literacy has been further emphasized as a key competence in various life domains—ranging from financial decision-making to statistical and scientific reasoning (Afni & Hartono, 2020; N. Maryani & Widjajanti, 2020; Nurwahid & Ashar, 2022). In today's educational settings, numeracy has evolved from basic computation to include complex logical and analytical thinking. Interdisciplinary approaches further broaden its role, connecting numeracy to social reasoning—such as interpreting public data and making informed civic decisions (Raudenbush et al., 2020) and to critical thinking, a foundational pillar of 21st-century learning (Lee-Post, 2019a).

Moreover, the rapid digitalization of education has reshaped numeracy into a more integrated and adaptive paradigm. Technological tools enable dynamic, interactive numeracy instruction, where students engage with simulations, data visualizations, and real-time feedback to deepen their understanding (Díez-Palomar, 2019). This digital integration further highlights the importance of numeracy in preparing students for a data-driven world.

Parallel to this, science learning interest continues to gain attention as a determinant of engagement and academic perseverance. Far from being merely affective, interest functions as a catalyst for sustained exploration and problem-solving in STEM disciplines. Several studies identify that teacher-student interactions (Gares et al., 2020), innovative pedagogies (Sulisworo & Suryani, 2014), and the contextual relevance of scientific content (Hayat et al., 2020) are pivotal in cultivating this interest.

When students perceive the relevance of science in daily life, their intrinsic motivation to learn deepens.

Additionally, inclusive teaching strategies and technology integration have expanded the ways in which science can be taught and learned. Platforms that facilitate virtual experiments and simulation-based learning offer students immersive experiences, allowing them to construct knowledge independently while reinforcing both cognitive and emotional engagement (Loderer et al., 2020). In this ecosystem of learning, self-regulation emerges as a vital self-management skill. It enables learners to take ownership of their learning processes and persevere through challenges. Studies emphasize the importance of embedding self-regulation strategies into classroom instruction to improve learning outcomes and enhance students' overall well-being (Sulisworo, Fatimah, et al., 2020; Ambaryani & Winarti, 2019; Fatmaryanti et al., 2022; I. Maryani et al., 2023). Instructional models that foster metacognitive awareness and self-reflection can significantly improve students' academic resilience (El-Adl & Alkharusi, 2020; Putarek & Pavlin-Bernardić, 2019; Yan, 2019).

Closely related to these skills, verbal ability plays a critical role in shaping students' literacy development and academic communication. It enables the expression and comprehension of abstract and complex ideas–capabilities that underpin success across disciplines (Sermsri et al., 2021). Complementing these cognitive, motivational, and behavioral dimensions, the measurement of academic achievement itself has also evolved. There is a growing shift from conventional testing methods to holistic and formative assessment models that encompass cognitive, affective, and psychomotor domains (Ramachandran et al., 2021). Approaches such as project-based learning (Seibert, 2021), task-based instruction (Amyar et al., 2020), and differentiated learning (Wormeli, 2023) have proven effective in fostering deeper understanding and real-world application of knowledge (Klepsch & Seufert, 2020; Afni & Hartono, 2020; N. Maryani & Widjajanti, 2020).

Despite these promising directions, there remains a notable gap in empirical research examining the combined and mediating influence of numerical literacy, verbal ability, interest in science learning, and self-regulation on student achievement–particularly in high school contexts. Most existing studies tend to focus on these variables in isolation, overlooking how they interact as a unified framework for academic success. To address this gap, the present study aims to investigate the interrelationships among numerical literacy, verbal ability, and interest in science learning as predictors of self-regulation, and how self-regulation, in turn, influences academic achievement. By adopting an ex-post facto design, this research offers a comprehensive model that enhances our understanding of the key determinants of learning outcomes in secondary education. Ultimately, the findings are expected to inform the design of more effective, integrative, and adaptive teaching strategies aligned with the needs of 21st-century learners.

Method

Research Context

This study employed a quantitative approach with an ex-post facto research design, aiming to investigate the predictive relationship between numerical literacy, verbal ability, interest in science learning, self-regulation, and academic achievement.

No treatment or manipulation was applied to the variables, and data were collected based on existing conditions among high school students. The three independent variables investigated are Numerical Literacy (X1), Verbal Ability (X2), and Interest in Science Learning (X3). The mediating variable is Self-Regulation Ability (X4), and the dependent variable is Learning Achievement (Y). Data were collected through questionnaires (X1, X2, X3, X4) and learning outcome tests (Y).

Research Instruments

The instruments used to measure the independent and mediating variables–numerical literacy (X1), verbal ability (X2), science learning interest (X3), and self-regulation ability (X4)–were developed based on a comprehensive literature review to ensure strong content validity. Each instrument was designed to capture specific dimensions of the respective constructs through well-defined indicators, and the entire set of questionnaires was assessed by education experts before being administered in the field.

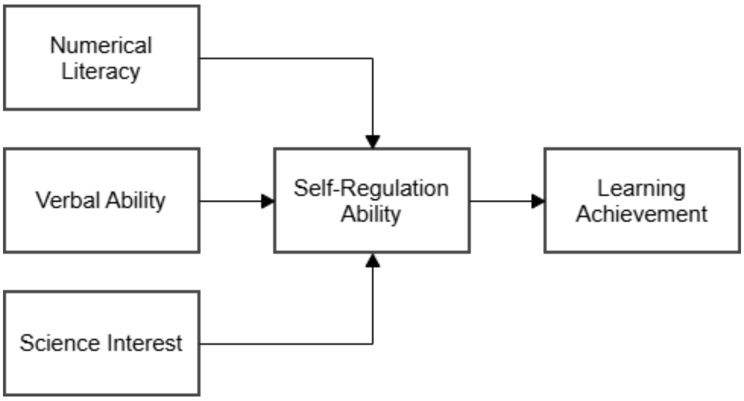

Figure 1. Conceptual Model

The Numerical Literacy Questionnaire was designed to assess students' ability to understand, interpret, and apply mathematical information in everyday situations. It includes eight indicators, covering components such as number sense, application of mathematical operations, graph interpretation, and the use of technological tools. The detailed structure of this instrument can be found in Table 1.

The Verbal Ability Questionnaire aims to measure students' skills in reading comprehension, vocabulary mastery, oral and written communication, as well as their ability to use language in social contexts. This instrument consists of ten indicators, as presented in Table 2.

The Science Learning Interest Questionnaire comprises eight indicators that evaluate both emotional and behavioral dimensions of student engagement in science learning. These include interest in science topics, participation in science activities, and openness to scientific knowledge (see Table 3).

The Self-Regulation Ability Questionnaire includes seven indicators that capture aspects such as impulse control, goal setting, time management, self-monitoring, and reflection. This instrument is outlined in Table 4.

To measure students' academic achievement, a Learning Outcome Test was used, consisting of five essay-based questions aimed at assessing higher-order thinking skills in science subjects. The test was evaluated using a process-oriented rubric with a scale ranging from 1 (incomplete) to 4 (complete). The specific assessment indicators are presented in Table 5.

Table 1. Measurement Instrument Rubric for Numerical Literacy

Factor	Indicators	Code
General Dimensions	1. Understanding Numbers	X1.1
	2. Understanding Mathematical Operations	X1.2
Everyday Life Context	3. Application of Numbers in Daily Life	X1.3
	4. Problem Solving	X1.4
Numerical Communication	5. Understanding and Reading Graphs	X1.5
	6. Use of Mathematical Language	X1.6
Use of Technology	7. Use of Mathematical Tools	X1.7
	8. Ability to Adapt to Technological Advancements	X1.8

All questionnaire items were formatted using a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Each instrument was reviewed and validated by three educational experts specializing in curriculum design, evaluation, and psychological measurement. Their feedback was used to refine the content, structure, and clarity of the items. The results of this expert validation, as well as the subsequent pilot testing for construct validity and reliability, are presented in the Results section of this article.

Table 2. Measurement Instrument Rubric for Verbal Ability

Factor	Indicators	Code
Reading Comprehension Dimensions	1. Understanding Texts	X2.1
	2. Summarizing Information	X2.2
Vocabulary Dimensions	3. Mastery of Vocabulary	X2.3
	4. Use of Synonyms and Antonyms	X2.4
Oral Communication Dimensions	5. Speaking Ability	X2.5
	6. Listening Abilities	X2.6
Written Communication Dimension	7. Essay Writing	X2.7
	8. Report Writing	X2.8
Use of Language in Social Contexts	9. Social Interaction	X2.9
	10. Application of Language in Discussion	X2.10

Table 3. Measurement Instrument Rubric for Science Interest

Factor	Indicators	Code
General Dimensions	1. Interest in Science Topics	X2.1
	2. Involvement in Science Activities	X2.2
Learning Context	3. Participation in Science Lessons	X2.3
	4. Use of Science Learning Resources	X2.4
Extracurricular Engagement	5. Participation in Science Clubs/Communities	X2.5
	6. Achievements in Science Competitions	X2.6
Attitude towards Science	7. Openness to New Knowledge	X2.7
	8. Ability to Explain Science Concepts	X2.8

Table 4. Measurement Instrument Rubric for Self-Regulation Ability

Factor	Indicators	Code
Impulse Control	1. Controlling Impulsive Behavior	X3.1
	2. Responses to Challenges	X3.1
Planning and Organization	3. Setting Clear Goals	X3.1
	4. Organizing Tasks	X3.1
Self-Evaluation	5. Reflecting on Behavior and Decisions	X3.1
	6. Accepting Feedback and Self-Improvement	X3.1
Time Management	7. Managing Time	X3.1

Table 5. Measurement Instrument Rubric for Learning Achievement

Factor	Indicators	Code
Knowledge	1. Understanding Basic Materials	Y.1
	2. Mastery of Intermediate and Advanced Materials	Y.2
Skills	3. Use of Practical Skills	Y.3
	4. Analytical and Evaluative Skills	Y.4
Thinking Process	5. Problem-Solving Ability	Y.5
	6. Critical Thinking and Argumentation	Y.6
Communications	7. Ability to Communicate Understanding	Y.7
	8. Ability to Prepare Reports and Presentations	Y.8

Data Collection Procedure

The data collection process was conducted through several structured steps to ensure uniformity and validity across participants: (1) Preparation and Coordination: The research team contacted school principals and subject teachers to obtain permission and arrange the schedule for data collection across the selected schools; (2) Distribution of Instruments: All questionnaires were distributed in person using printed copies during classroom sessions to ensure consistency in delivery and environment; (3) Response Duration: Students were allocated approximately 45 minutes to complete the instruments. During this time, they were supervised by both the class teacher and a member of the research team to maintain focus and avoid collaboration; (4) Instructional Consistency: To minimize bias and ensure that all participants received the same explanation, a single researcher was assigned to provide instructions across all schools; (5) Collection and Verification: Upon completion, all questionnaires were collected on the same day. The research team immediately reviewed the responses to check for completeness before entering the data for analysis.

Throughout the entire process, the study adhered to ethical research standards, ensuring that participants were informed of the purpose of the study, that their participation was voluntary, and that their responses would remain confidential. As the study used an observational, non-interventional design, no experimental treatment or manipulation was applied to the subjects.

Data Analysis

The research subjects consisted of 119 students from four public and private high schools located in an urban district in Indonesia. Participants were selected using proportional stratified random sampling, ensuring representation from different school types and grade levels. The demographic profile of participants includes 65 female students (54.6%) and 54 male students (45.4%), with age ranges between 15 and 17 years. All students had previously completed science subjects relevant to the study. The conceptual model to be analyzed with PLS is shown in Figure 1.

Results and Discussions

The results of this study are presented in two main stages: the measurement model (outer model) and the structural model (inner model). The outer model evaluates the validity and reliability of the instrument items, while the inner model tests the relationships between latent variables based on the formulated hypotheses. As shown in Tables 6 through 10, all indicators of each construct (numerical literacy, verbal ability, science interest, self-regulation, and learning achievement) demonstrated outer loading values above the threshold of 0.7, indicating good convergent validity. This means that each item significantly represents its respective latent variable, supporting the construct validity of the instruments.

Table 6. Outer Loading for Numerical Literacy Variable (X1)

Indicator	Outer Loading	Parameter Value	Results
X1.1	0.777	≥ 0.7	Valid
X1.2	0.761	≥ 0.7	Valid
X1.3	0.724	≥ 0.7	Valid
X1.4	0.749	≥ 0.7	Valid
X1.5	0.765	≥ 0.7	Valid
X1.6	0.825	≥ 0.7	Valid
X1.7	0.754	≥ 0.7	Valid
X1.8	0.769	≥ 0.7	Valid

Table 6 presents the results of the convergent validity test for the indicators measuring the Numerical Literacy variable (X1) using the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach. Each indicator, labeled from X1.1 to X1.8, corresponds to a specific item in the questionnaire that reflects aspects of students' numerical literacy skills, such as number sense, mathematical operations, and graph interpretation. The outer loading values indicate the strength of the relationship between each indicator and its corresponding latent construct. According to standard measurement criteria, an outer loading value of ≥ 0.7 is considered acceptable, as it shows that the indicator strongly represents the underlying construct. In Table 6, all eight indicators have outer loading values ranging from 0.724 to 0.825, exceeding the minimum threshold.

These results confirm that each item used to measure numerical literacy is valid in terms of convergent validity. This means that the items consistently measure the intended construct and can be confidently used in the subsequent analysis of the structural model. Therefore, the measurement model for numerical literacy meets the necessary criteria for reliability and validity, supporting the robustness of the overall research model.

Table 7. Outer Loading for Verbal Ability Variable (X2)

Indicator	Outer Loading	Parameter Value	Results
X2.1	0.818	≥ 0.7	Valid
X2.2	0.888	≥ 0.7	Valid
X2.3	0.892	≥ 0.7	Valid
X2.4	0.899	≥ 0.7	Valid
X2.5	0.736	≥ 0.7	Valid
X2.6	0.810	≥ 0.7	Valid
X2.7	0.876	≥ 0.7	Valid
X2.8	0.803	≥ 0.7	Valid
X2.9	0.820	≥ 0.7	Valid
X2.10	0.761	≥ 0.7	Valid

Table 7 displays the convergent validity results for the indicators of the Verbal Ability variable (X2), which were evaluated through the PLS-SEM approach. This construct consists of ten indicators, labeled X2.1 to X2.10, each representing different dimensions of students′ verbal skills, including reading comprehension, vocabulary mastery, oral and written communication, and contextual language usage. The outer loading values reflect the degree to which each indicator correlates with the latent construct it is intended to measure. According to the accepted threshold, an outer loading of 0.7 or higher indicates that the indicator sufficiently contributes to explaining the construct. In this table, all ten indicators exhibit strong loading values, ranging from 0.736 to 0.899, thereby surpassing the minimum criterion.

These results confirm that each item within the Verbal Ability questionnaire demonstrates adequate convergent validity, meaning the indicators consistently capture the essence of the verbal ability construct. With all loading values well above the required level, it can be concluded that the measurement model for verbal ability is both valid and reliable. This supports its inclusion in the inner model analysis used to test the research hypotheses.

Table 8. Outer Loading for Learning Interest Variable (X3)

Indicator	Outer Loading	Parameter Value	Results
X3.1	0.764	≥ 0.7	Valid
X3.2	0.775	≥ 0.7	Valid
X3.3	0.800	≥ 0.7	Valid
X3.4	0.787	≥ 0.7	Valid
X3.5	0.832	≥ 0.7	Valid
X3.6	0.754	≥ 0.7	Valid
X3.7	0.792	≥ 0.7	Valid
X3.8	0.811	≥ 0.7	Valid

Table 8 presents the results of the convergent validity test for the indicators associated with the Science Learning Interest variable (X3). This construct is measured through eight indicators, labeled X3.1 to X3.8, which capture students′ emotional and behavioral engagement with science learning. These include interest in science topics, participation in science-related activities, and openness to scientific knowledge.

The outer loading values indicate the extent to which each indicator correlates with the underlying latent variable. Consistent with convergent validity standards, a loading value of ≥ 0.7 is required for an indicator to be considered valid. In this table, all eight indicators show loading values ranging from 0.754 to 0.832, meaning each item exceeds the minimum required threshold.

These findings confirm that all indicators used to assess science learning interest exhibit strong convergent validity. This demonstrates that the items reliably measure the construct they are intended to represent and provide an accurate assessment of students′ interest in science. As a result, the measurement model for this variable is valid and can be confidently used in further structural analysis.

Table 9. Outer Loading for the Self-Regulation Ability Variable (X4)

Indicator	Outer Loading	Parameter Value	Results
X4.1	0.828	≥ 0.7	Valid
X4.2	0.774	≥ 0.7	Valid
X4.3	0.771	≥ 0.7	Valid
X4.4	0.764	≥ 0.7	Valid
X4.5	0.774	≥ 0.7	Valid
X4.6	0.742	≥ 0.7	Valid
X4.7	0.733	≥ 0.7	Valid

Table 9 shows the convergent validity results for the indicators of the Self-Regulation Ability variable (X4). This construct is operationalized through seven indicators, coded X4.1 to X4.7, which represent students' capacities in areas such as impulse control, planning and organization, time management, and self-monitoring during the learning process.

The outer loading values indicate the strength of the relationship between each indicator and the latent variable of self-regulation. According to standard guidelines for convergent validity, an outer loading of 0.7 or higher is considered acceptable. In this case, all indicators demonstrate outer loading values ranging from 0.733 to 0.828, surpassing the minimum threshold required for validity.

These results confirm that the indicators effectively capture the construct of self-regulation with strong and consistent measurement quality. Each item significantly contributes to explaining the underlying construct, indicating that the instrument possesses good convergent validity. With these reliable indicators, the self-regulation construct can be confidently included in the structural model for hypothesis testing.

Table 10. Outer Loading for Learning Achievement Variable (Y)

Indicator	Outer Loading	Parameter Value	Results
Y.1	0.757	≥ 0.7	Valid
Y.2	0.712	≥ 0.7	Valid
Y.3	0.845	≥ 0.7	Valid
Y.4	0.886	≥ 0.7	Valid
Y.5	0.847	≥ 0.7	Valid

Based on Table 10, all indicators have an outer loading value ≥ 0.7 so all these indicators can be continued for the next stage of testing. Based on the results of convergent validity testing for each of the variables above, it can be seen that most of the outer loading values for each indicator are ≥ 0.7. Next in the test for the Measurement Model (Outer model) is the Discriminant Validity Test. The condition for fulfilling discriminant validity is an Average Variance Extracted (AVE) value ≥ 0.5. Table 11 shows these results.

Table 11. Discriminant Validity Test Results

Variable		AVE	Parameter	Results
X1	Numerical Literacy	0.587	≥ 0.5	Fulfilled
X2	Verbal Ability	0.692	≥ 0.5	Fulfilled
X3	Interest in Learning	0.624	≥ 0.5	Fulfilled
X4	Self-Regulation Ability	0.593	≥ 0.5	fulfilled
Y	Learning achievement	0.659	≥ 0.5	fulfilled

Table 11 shows that the Average Variance Extracted (AVE) values for all variables exceed 0.5, indicating that the constructs have adequate discriminant validity. This means that each construct shares more variance with its indicators than with other constructs, ensuring that the constructs are distinct and well-defined.

Apart from the two tests that have been carried out, analysis was also carried out for *the Reliability Test.* In this research, the reliability test parameters are said to be reliable if the Cronbach's alpha and composite reliability values must be ≥ 0.7. The results of this test are shown in Table 12.

Table 12. Reliability Test Results

Variables		Cronbach's Alpha	Composite Reliability	Parameter	Results
X1	Numerical Literacy	0.899	0.919	≥ 0.7	Reliable
X2	Verbal Ability	0.950	0.957	≥ 0.7	Reliable
X3	Interest in Learning	0.914	0.930	≥ 0.7	Reliable
X4	Self-Regulation Ability	0.885	0.910	≥ 0.7	Reliable
Y	Learning achievement	0.869	0.906	≥ 0.7	Reliable

Table 12 presents the results of the reliability testing for each latent variable used in the study, namely Numerical Literacy (X1), Verbal Ability (X2), Science Learning Interest (X3), Self-Regulation Ability (X4), and Learning Achievement (Y). Reliability was assessed using two key statistical measures: Cronbach′ s Alpha and Composite Reliability (CR).

Cronbach′ s Alpha is a widely accepted indicator of internal consistency, reflecting the extent to which all items in a construct measure the same underlying concept. A value of 0.7 or above is considered acceptable. Similarly, Composite Reliability assesses the overall reliability of a construct based on the outer loadings of its indicators, with values above 0.7 indicating strong consistency.

As shown in Table 12, all five constructs recorded Cronbach′ s Alpha values ranging from 0.869 to 0.950, and Composite Reliability values ranging from 0.906 to 0.957. These results exceed the established thresholds, confirming that each set of indicators is highly reliable and internally consistent. The high reliability scores indicate that the instruments used to measure each variable are stable and dependable across items. Therefore, the measurement model is supported by both validity and reliability, strengthening the accuracy and credibility of subsequent analyses in the structural model.

After testing the measurement model (outer model) of each variable with its indicators, the next step is testing the structural model (inner model). In testing the inner model, the test statistics used are the coefficient of determination test (R-squared) and the influence test between variables. One of the parameters in goodness of fit testing is testing the coefficient of determination (R-squared). This coefficient of determination shows how much the independent variables can describe the dependent variable. Based on the SmartPLS output results, it can be seen that the r-squared value for Self-Regulation Ability (X4) is 0.623. This means that Numerical Literacy (X1), Verbal Ability (X2), and Interest in Learning (X3) have a simultaneous influence of 62.3% as independent variables on Self-Regulation Ability (X4) as the dependent variable, while the remaining is 37, 7% can be obtained from other variables not used in this research. Meanwhile, the r-squared value for Learning Achievement (Y) is 0.164. This means that Self-Regulation Ability (X4) has an influence of 16.4% as an independent variable on Learning Achievement (Y) as a dependent variable, while the remaining 84.6% can be obtained from other variables not used in this research.

In testing this hypothesis, it can show how much influence (significance) an independent variable has on the dependent variable. As the hypothesis testing criteria in the t-statistical test states if the path coefficient is positive and the p-value is < the significance level α (0.05), then there is a positive significant influence between the independent variable and the dependent variable. On the other hand, if the path coefficient is negative and the p-value is < significance level α (0.05), then there is a significant negative influence between the independent variable and the dependent variable.

The coefficient of determination (R^2) for self-regulation is 0.623, which indicates that 62.3% of the variance in self-regulation is explained by numerical literacy, verbal ability, and science interest. Meanwhile, the R^2 value for academic achievement is 0.164, meaning that self-regulation contributes 16.4% to the variance in students′ learning outcomes. These findings reflect a moderate effect size for self-regulation prediction and a small but significant contribution to academic performance, suggesting the presence of additional influencing factors beyond this model.

Table 13. Hypothesis Test Results

	Hypothesis	Original Sample	p-values
H_1	Numerical Literacy (X1) →Self-Regulation Ability (X4)	0.410	0.000
H_2	Verbal Ability (X2) →Self-Regulation Ability (X4)	0.291	0.003
H_3	Interest in Learning (X3) →Self-Regulation Ability (X4)	0.215	0.010
H_4	Self-Regulation Ability (X4) →Learning Achievement (Y)	0.405	0.000

From the results of data processing, as shown in Table 13, a model was obtained that can explain the relationship between these variables as in Figure 2.

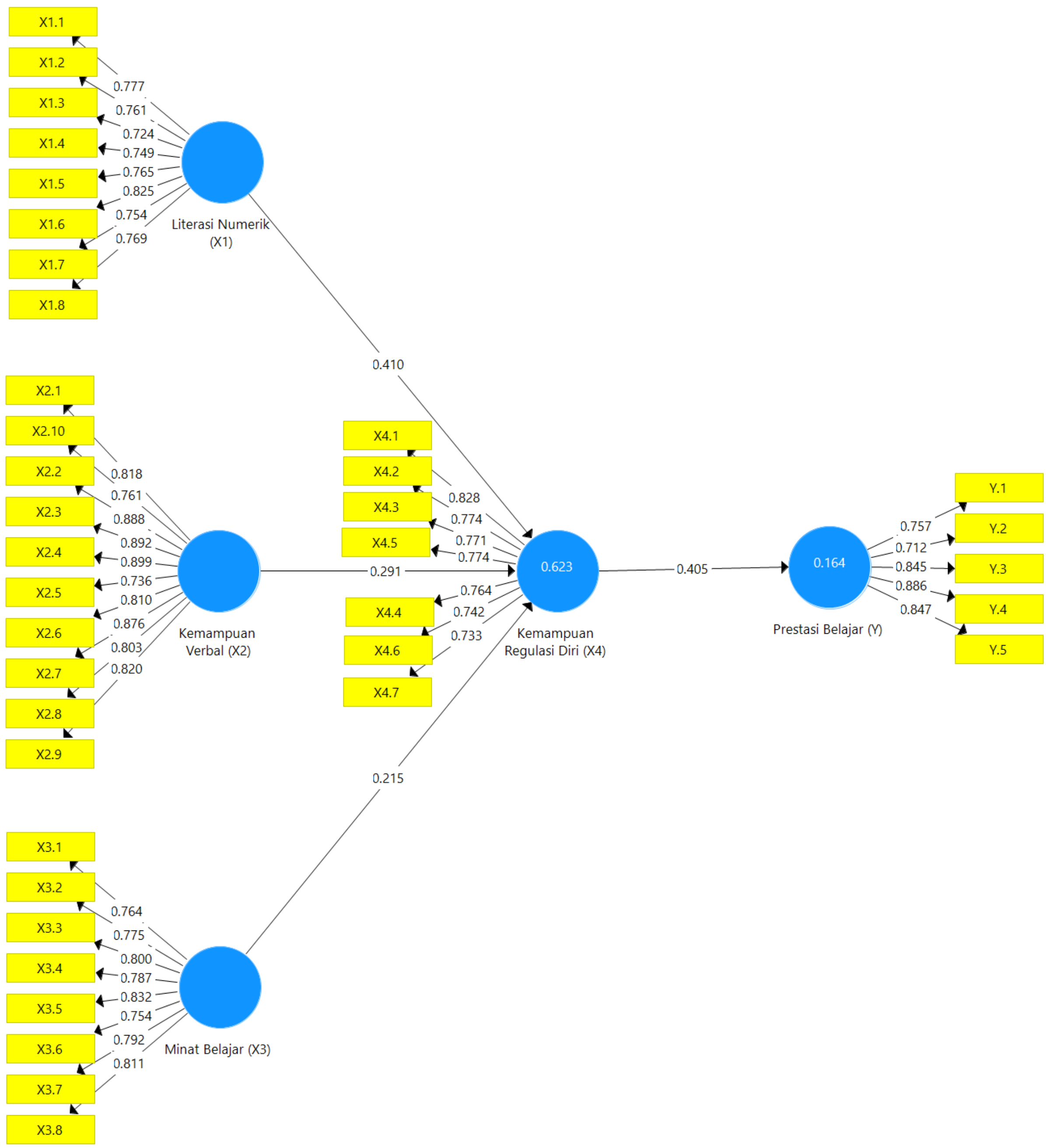

Figure 2. Model from the SEM-PLS Analysis

H1: The Influence of Numerical Literacy (X1) on Self-Regulation Ability (X4). The results show a significant positive relationship between numerical literacy and self-regulation ability. The path coefficient is 0.410 and the p-value is 0.000, which is lower than the significance threshold (α = 0.05).

This confirms that numerical literacy has a strong and statistically significant influence on students' self-regulation.

Numerical literacy, defined as the ability to understand and apply numbers in daily contexts, plays a crucial cognitive and psychological role in fostering self-regulation (Dresel & Haugwitz, 2006; Gabriel et al., 2020). It enhances key cognitive functions such as problem-solving, logical reasoning, and decision-making (Cokely et al., 2018; Iswara et al., 2022; Lee-Post, 2019b), which are directly linked to one's capacity for planning, emotional control, and impulse regulation. Strong numeracy skills are associated with improved executive functioning, including goal setting, cognitive flexibility, and self-monitoring (Peters & Shoots-Reinhard, 2022). These abilities strengthen students' capacity to delay gratification, make thoughtful decisions, and persist in challenging tasks. Furthermore, numeracy fosters metacognitive awareness and enhances self-efficacy, both of which are integral to effective self-regulated learning (Otero et al., 2022).

H2: The Influence of Verbal Ability (X2) on Self-Regulation Ability (X4). The analysis indicates a significant positive relationship between verbal ability and self-regulation, with a path coefficient of 0.291 and a p-value of 0.003. This suggests that verbal ability contributes meaningfully to students' self-regulatory capabilities.

Verbal ability facilitates emotional expression, cognitive processing, and communication, all of which are essential for developing self-regulation (Code, 2020; Sherkat, 2022). Students who are able to articulate thoughts and emotions tend to have greater emotional awareness and are better equipped to manage their behaviors (Clark et al., 2021; Frick et al., 2019). Verbal ability supports internal dialogue and reflective thinking, which are fundamental for goal-setting and self-monitoring. Through self-talk, individuals can navigate stress, consider alternative responses, and make deliberate choices rather than reacting impulsively (Clark et al., 2021). Additionally, strong verbal skills enhance social interactions and problem-solving—key contexts in which self-regulation is developed and reinforced (Liebermann et al., 2007; Sirota et al., 2021; Otero et al., 2022).

H3: The Influence of Science Learning Interest (X3) on Self-Regulation Ability (X4). The findings also reveal a significant positive effect of science learning interest on self-regulation ability, with a path coefficient of 0.215 and a p-value of 0.010. This confirms that students who show strong interest in science are more likely to develop self-regulated learning behaviors.

Interest in science learning increases intrinsic motivation and cognitive engagement, which are both critical for self-regulation (Code, 2020; Dumitru, 2021). When students are genuinely interested in learning, they are more likely to establish goals, monitor their progress, and maintain persistence in the face of challenges (Hayat et al., 2020; Krapp, 1999). According to self-determination theory, such interest fosters autonomy, resilience, and proactive problem-solving—behaviors that support sustained effort and adaptability (Cho et al., 2021; Lauermann & Butler, 2021; Syefrinando et al., 2020; Zheng et al., 2021).

H4: The Influence of Self-Regulation Ability (X4) on Learning Achievement (Y) The last hypothesis testing shows a strong and significant positive influence of self-regulation on learning achievement. The path coefficient is 0.405 and the p-value is 0.000 (< 0.05), indicating a robust relationship between these variables.

Self-regulation enables students to manage their time, emotions, and learning behaviors effectively, leading to improved academic outcomes (Ali, 2011; El-Adl & Alkharusi, 2020; Putarek & Pavlin-Bernardić, 2019). Students with high self-regulation are more goal-oriented, organized, and focused, resulting in better study habits and performance (Code, 2020; Liebermann et al., 2007; Zheng et al., 2021). They also possess the ability to evaluate their learning strategies and adapt when necessary, contributing to continuous improvement. Emotional regulation, a core component of self-regulation, reduces stress and enhances resilience, allowing students to remain motivated and persistent (El-Adl & Alkharusi, 2020). Additionally, students with well-developed self-regulation show greater autonomy and ownership over their learning processes, which further drives academic success (Bala et al., 2020; Gabriel et al., 2020).

The findings confirm that self-regulation acts as a central mediator between cognitive skills (numerical literacy and verbal ability), motivational factors (science learning interest), and learning achievement. This underscores the importance of developing self-regulation skills through integrated teaching approaches that not only build foundational cognitive abilities but also foster motivation and self-directed learning. Strengthening self-regulation can significantly enhance students' ability to face academic challenges, sustain long-term learning goals, and achieve better academic outcomes across diverse contexts.

Conclusions

This study emphasizes the pivotal role of self-regulation ability as a mediating factor in the relationship between numerical literacy, verbal ability, and science learning interest with learning achievement. The findings demonstrate that self-regulation—through key components such as goal-setting, self-monitoring, and self-reflection—significantly enhances students′ ability to manage their learning independently and effectively. Students who possess strong self-regulation are better equipped to set clear academic goals, adjust learning strategies when needed, and sustain motivation over time. These competencies directly contribute to improved academic performance across subject areas. In the context of numerical literacy, self-regulation supports continuous development in mathematical reasoning by fostering persistence, accuracy, and problem-solving focus. For verbal ability, self-regulation enables students to sharpen their comprehension and communication skills through reflective thinking and self-directed language practice. Regarding science learning interest, self-regulation strengthens intrinsic motivation and encourages deeper cognitive engagement, allowing students to explore scientific concepts with curiosity and resilience. This study underscores that fostering self-regulation is essential not only for enhancing specific academic skills, but also for promoting holistic student success. Educational interventions should therefore prioritize the development of self-regulatory capacities alongside cognitive and motivational competencies to achieve optimal learning outcomes in secondary education.

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