Journal Numeracy
Volume 12, Number 2, 2025 pp. 227-241
P-ISSN: 2355-0074 E-ISSN: 2502-6887
Open Access: https://ejournal.bbg.ac.id/numeracy

IMPLEMENTATION OF A HOTS-BASED PROJECT BASED LEARNING (PjBL) MODEL TO IMPROVE MATHEMATICAL LITERACY OF SENIOR HIGH SCHOOL STUDENTS

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ARTICLE INFO

Article history:
Received : Aug 20, 2025
Revised : Sep 25, 2025
Accepted : Oct 27, 2025
Available online : Oct 31, 2025

Keywords:
Project Based Learning, HOTS, Scientific Approach, Mathematical Literacy.

ABSTRACT

This study aims to develop a Project Based Learning (PjBL) model integrated with Higher Order Thinking Skills (HOTS) and the scientific approach to enhance high school students' mathematical literacy skills. The research employed a research and development (R&D) design based on the Dick & Carey model. The participants were 32 eleventh-grade students at SMA Dharma Pancasila Medan, selected using total sampling. Research instruments included expert validation sheets, mathematical literacy tests, student response questionnaires, observation sheets, and interviews. Expert validation results indicated that the developed learning model was highly valid with an average score of 89.7%. The implementation results revealed a significant improvement, with students' average pre-test scores increasing from 51.4 to 83.5 in the post-test, and a gain score of 0.66 categorized as moderate–high. Indicators of mathematical literacy, namely *formulating situations mathematically*, *employing concepts, facts, procedures, and reasoning*, and *interpreting and evaluating outcomes*, all showed significant improvements. Students' responses to the learning model were highly positive, with more than 87% stating that the learning process was more engaging, facilitated concept understanding, and enhanced critical thinking and collaboration skills. Therefore, the PjBL-based HOTS model integrated with the scientific approach has been proven effective in improving students' mathematical literacy while supporting the achievement of 21st-century competencies and the Sustainable Development Goal 4: Quality Education.

INTRODUCTION

The development of education in Indonesia is currently facing major challenges along with the implementation of the *Merdeka Belajar* Curriculum and the demands of the Society 5.0 era. This curriculum emphasizes student-centered learning and the development of critical thinking skills as essential provisions for the future. (Abidah et al.,

2022) emphasize that teachers are required to design learning activities oriented toward 21st-century skills so that students are able to adapt to emerging societal changes. In line with this view, (Zaharah et al., 2023) highlight the importance of educational synergy in equipping the younger generation to face global challenges in the Society 5.0 era.

One of the core competencies needed in this era is Higher Order Thinking Skills (HOTS). HOTS plays a crucial role in preparing learners to deal with complex and non-routine problems. (Dilah, 2023) explains that HOTS-based learning is an effective strategy for preparing students to face the challenges of Society 5.0. This argument is supported by (Indarta et al., 2022) who emphasize the relevance of the *Merdeka Belajar* Curriculum in fostering 21st-century competencies.

(Kementerian Pendidikan dan Kebudayaan, 2017) outlines four key components of 21st-century skills: critical thinking and problem solving, communication skills, creativity and innovation, and collaboration. These competencies are not only essential in academic contexts but are also required in everyday life. Therefore, school learning processes must be directed toward strategies that encourage students to master these skills.

The *Merdeka Belajar* Curriculum is expected to serve as a solution for restoring educational quality in the post-pandemic period. (Susilawati & Sarifuddin, 2021) assert that this curriculum emphasizes project-based learning to support the development of the Pancasila Student Profile. Furthermore, (Jojor & Sihotang, 2022) argue that the flexibility of content and structure in the *Merdeka Belajar* Curriculum allows it to accommodate diverse student learning needs. (Nugraha, 2022) also notes that this curriculum provides significant opportunities for innovation and breakthroughs in learning across various disciplines.

In the context of mathematics education, its role is particularly important because it is closely related to logical, critical, and scientific thinking skills. (Safna & Asriati, 2023) emphasize that continuous innovation in mathematics learning at the senior high school level is necessary to improve learning quality. The selection of an appropriate learning model is therefore a crucial factor. (Kumalasari et al., 2022) state that the success of mathematics learning is strongly influenced by the suitability of the learning model employed. Similarly, (Mardhatillah, 2017) highlights that innovations based on interactive multimedia can support meaningful learning at both primary and secondary education levels. Meanwhile, (Asriati, 2019) underscores the role of teachers in selecting effective learning models to ensure that learning objectives are optimally achieved.

One learning model considered highly relevant is Project Based Learning (PjBL). (Huda et al., 2023) emphasize that PjBL is an important approach for preparing students' skills in the era of the Industrial Revolution 4.0. (Izzah et al., 2021) add that PjBL can be integrated with various teaching materials, thereby enhancing learning effectiveness in the classroom. (Sumilat et al., 2023) further elaborate on the stages of PjBL implementation, which require active student involvement in observing, designing, implementing, and evaluating learning projects.

On the other hand, mathematical literacy is also a critical competency that must be developed. Mathematical literacy refers to the ability to formulate, use, and interpret mathematics in various contexts. (Nuurjannah et al., 2018) found that low levels of mathematical literacy have implications for weak reasoning ability, argumentation skills, and students' capacity to solve real-life problems. Therefore, mathematical literacy is not merely concerned with mastering content but also with applying mathematical concepts and procedures in everyday situations.

In addition, the application of a scientific approach serves as an important foundation in learning. (Sukatin et al., 2022) explain that this approach involves the stages of observing, questioning, collecting data, reasoning, and communicating results. The scientific approach provides broader opportunities for students to actively construct knowledge.

The integration of HOTS into learning offers substantial benefits. (Tasrif, 2022) explains that HOTS helps students develop critical, creative, and analytical thinking skills. (Rahayu et al., 2020) add that HOTS can improve learning outcomes while simultaneously shaping students' character. Furthermore, (Yen & Halili, 2015) emphasize that HOTS-based learning is effective in improving the quality of the teaching and learning process across various levels of education. (Widayana, 2017) details the steps for designing HOTS-oriented assessment items, which can serve as a reference for teachers in developing appropriate evaluation instruments.

Based on the above considerations, this study aims to develop a Project Based Learning (PjBL) model based on Higher Order Thinking Skills (HOTS), integrated with a scientific approach, to enhance the mathematical literacy of senior high school students. The research questions addressed in this study are: (1) how is the process of developing a HOTS-based PjBL learning model integrated with a scientific approach that is valid and practical, and (2) to what extent is the effectiveness of the model in improving students' mathematical literacy.

This study offers scientific novelty, as there is still limited research that explicitly integrates a HOTS-based PjBL model with a scientific approach in the context of senior high school mathematics learning in Indonesia. Most previous studies have focused on the implementation of PjBL or HOTS separately, without examining their integration within the *Merdeka Belajar* Curriculum framework. Therefore, this research addresses an existing research gap by proposing a learning model that combines the strengths of PjBL in fostering authentic learning experiences with the power of HOTS in developing higher-order thinking skills, which is expected to enhance students' mathematical literacy in a more comprehensive and contextual manner.

RESEARCH METHODOLOGY

Type of Research

This study employed a Research and Development (R&D) approach using the Dick and Carey instructional design model. This model was selected because it provides a systematic framework for developing instructional products, starting from needs analysis through product evaluation. Through its sequential stages, this research was directed toward producing a Project Based Learning (PjBL) instructional model based on Higher Order Thinking Skills (HOTS) integrated with a scientific approach.

Stages of the Dick and Carey Development Model (Steps 1–10)

In general, the Dick and Carey development model consists of ten main stages, as described below:

No	Dick and Carey Model Stage	Description of Activities	Implementation in This Study
1	Identifying Instructional Goals	Determining instructional goals based on curriculum analysis and students' needs.	Implemented
2	Conducting Instructional Analysis	Describing the sequence of skills that students must master to achieve the instructional goals.	Implemented
3	Analyzing Learners and Contexts	Analyzing students' characteristics and the learning context at school.	Implemented
4	Writing Performance Objectives	Formulating measurable and operational learning objectives and indicators.	Implemented
5	Developing Assessment Instruments	Developing assessment instruments aligned with learning objectives and indicators.	Implemented
6	Developing Instructional Strategy	Designing PjBL–HOTS–based instructional strategies integrated with a scientific approach.	Implemented
7	Developing and Selecting Instructional Materials	Developing instructional materials (lesson plans, student worksheets, and digital learning materials).	Implemented

No	Dick and Carey Model Stage	Description of Activities	Implementation in This Study
8	Designing and Conducting Formative Evaluation	Conducting limited trials (one-to-one, small group, and limited field testing).	Implemented up to this stage
9	Revising Instruction	Revising the product based on the results of the limited trials.	Implemented
10	Designing and Conducting Summative Evaluation	Testing the effectiveness of the product on a broader population.	Not implemented (limited to formative evaluation)

Research Location and Subjects

The research was conducted at SMA Dharma Pancasila, Medan City, with Grade XI students as the research subjects. The selection of this location was based on the condition that the school had not optimally implemented PjBL- and HOTS-based learning models in mathematics instruction. The sampling technique used was total sampling; therefore, the entire population of the class was included as the research sample.

Research Procedures

The development process was carried out through four main stages. First, analysis of the existing instructional model, which included curriculum review, classroom conditions, instructional tools, and assessment instruments used by teachers. Second, development of the instructional model by designing HOTS-based PjBL learning tools integrated with a scientific approach. Third, model standardization, which involved validating and testing the reliability of the developed product through expert judgment by five validators according to their respective areas of expertise. Fourth, model evaluation, consisting of limited trials and field testing to assess the practicality, effectiveness, and students' responses to the developed instructional model.

Research Instruments

The instruments used in this study consisted of:

1. Mathematical literacy ability test
2. Student response questionnaire
3. Interview guidelines
4. Observation sheets for learning implementation

Instrument Validity and Reliability

The content validity of the assessment instruments was examined using Aiken's V formula with a rating scale of 1–5 by expert validators. A V value of ≥ 0.80 was categorized as highly valid (Azwar, 2019).

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

Information:

V : Aiken's V content validity coefficient.

∑s : The sum of the scores assigned by each expert to each item. The value of *s* is obtained by multiplying the score given by the expert by the weight of that score. For example, if an expert assigns a score of 3 (*Highly Relevant*), then the value of *s* is 3.

N : The total number of raters or experts.

c : The highest score on the rating scale used. For instance, if the scale consists of *Highly Relevant* (4), *Relevant* (3), *Fairly Relevant* (2), and *Less Relevant* (1), then *c* = 4.

Test reliability was analyzed using Cronbach's Alpha (α) with the assistance of SPSS software. An α value of ≥ 0.70 indicates high reliability. In addition, item analysis included the difficulty index (p) and discrimination index (D) to ensure that the test items were of good quality and capable of significantly distinguishing students' ability levels.

Research Ethics

This study was conducted in accordance with ethical principles in educational research, including:

1. Obtaining official permission from the school principal and subject teachers to conduct the research within the school environment.
2. Maintaining the confidentiality of students' data by not disclosing personal identities in published reports.
3. Conducting the research while avoiding conflicts of interest and focusing on improving the quality of learning.

Data Collection Techniques

Data were collected using several techniques. First, a mathematical literacy test administered to students before and after the implementation of the model (pre-test and post-test) to measure improvements in mathematical literacy. Second, questionnaires were distributed to students to assess their responses and motivation levels. Third, interviews were conducted with teachers and students to strengthen qualitative data. Fourth, classroom observations were carried out to examine the implementation of the learning model directly. Validation was conducted by five experts in mathematics education, instructional media, and educational evaluation. Quantitative data were analyzed using Hake's gain score calculation and MANOVA to examine the effect of the model on improvements in mathematical literacy.

Data Analysis Techniques

Data analysis was conducted using both quantitative and qualitative approaches.

a. Quantitative Analysis

1. **Validity and Reliability Analysis of Test Items:** Conducted using Aiken's V and Cronbach's Alpha.
2. **Effectiveness Analysis:** Performed by comparing pre-test and post-test results using an independent samples *t*-test after meeting the assumptions of normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test).
3. **N-Gain Calculation:** Used to determine the improvement in learning outcomes using the following formula:

$$\mathrm{N-Gain} = \frac{(\mathrm{Spost} - \mathrm{Spre})}{(\mathrm{Smax} - \mathrm{Spre})}$$

Categories of Improvement: Improvement categories are classified as high (> 0.70), moderate (0.30–0.70), and low (< 0.30).

1. **Effect Size (Cohen's d)** was calculated to determine the strength of the effect of the assessment on the improvement of mathematical literacy, with the following interpretation: small (0.2), medium (0.5), and large (≥ 0.8).

b. Qualitative Analysis

Data obtained from questionnaires, interviews, and observations were analyzed through data reduction, data display, and conclusion drawing. Source and method triangulation were applied to enhance the trustworthiness of qualitative data, ensuring that the interpretations were valid, credible, and in-depth.

RESULTS AND DISCUSSION

Research Results

This study resulted in the development of a Project Based Learning (PjBL) instructional model based on Higher Order Thinking Skills (HOTS), integrated with a scientific approach, aimed at improving the mathematical literacy of Grade XI students at SMA Dharma Pancasila, Medan City. The development process followed the Dick and Carey research and development model, which included identifying student characteristics, needs analysis, model design, expert validation, limited trials, product revision, and final implementation.

The initial stage involved identifying student characteristics. Observation results indicated that most students had visual (68%) and kinesthetic (56%) learning styles. However, higher-order thinking skills (HOTS) were still relatively low, with 74% of students experiencing difficulties in analysis, synthesis, and evaluation tasks. The average pre-test score for mathematical literacy was 51.4, indicating that students' literacy skills were at a moderate level.

Table 1. Initial Student Characteristics

Aspect	Main Findings	Percentage
Visual Learning Style	Preference for images, diagrams, and videos	68%
Kinesthetic Learning Style	Preference for hands-on activities and experiments	56%
Low HOTS Skills	Difficulty in analysis, evaluation, and synthesis items	74%
Moderate Learning Motivation	Motivated when tasks are related to real-life contexts	62%

Field trials were conducted with all Grade XI students by comparing pre-test and post-test results. The average mathematical literacy score increased from 51.4 in the pre-test to 83.5 in the post-test. The average gain score of 0.66 indicated a significant improvement in the moderate-to-high category.

Table 2. Recapitulation of Mathematical Literacy Scores

Statistics	Pre-test	Post-test	Average Gain Score
Lowest Score	47	79	0.60
Highest Score	55	86	0.69
Mean Score	51.4	83.5	0.66
Literacy Category	Moderate	High	Moderate–High
Number of Students	32	32	–

In addition to score improvements, students' responses were highly positive. A total of 87.5% of students stated that the learning process was more engaging than conventional methods, and 90.6% reported that the learning model enhanced their critical thinking skills.

Table 3. Student Responses to the Learning Model

Assessed Aspect	Agree (%)	Disagree (%)
Learning is more engaging	87.5%	12.5%
Facilitates conceptual understanding	84.3%	15.7%
Improves critical thinking skills	90.6%	9.4%
Enhances group collaboration	93.7%	6.3%

Analysis of mathematical literacy indicators showed improvements across all aspects. For instance, the indicator *formulating situations mathematically* increased from 52.3 to 83.1; *employing concepts, facts, and reasoning* increased from 50.8 to 82.7; and *interpreting and evaluating outcomes* increased from 51.1 to 81.9.

Table 4. Improvement in Scores by Mathematical Literacy Indicators

Mathematical Literacy Indicator	Pre-test	Post-test	Improvement (%)
Formulating situations mathematically	52.3	83.1	30.8
Employing concepts, facts, procedures, and reasoning	50.8	82.7	31.9
Interpreting and evaluating outcomes	51.1	81.9	30.8

Inferential Statistical Analysis Results

To examine the significance of improvements in students' mathematical literacy, a paired-sample t-test and MANOVA were employed to assess the simultaneous effects across indicators. In addition, effect size (Cohen's d) was calculated to determine the strength of the learning model's impact.

Table 5. Paired Sample t-Test Results

Variable	Mean Pre-test	Mean Post-test	t-value	Sig. (p)
Mathematical Literacy	51.4	83.5	15.72	0.000 < 0.05

Interpretation:

The obtained t value (15.72) was greater than the critical t value (2.04), and the significance level was $p = 0.000 < 0.05$. Thus, it can be concluded that the HOTS-based PjBL model had a significant effect on improving students' mathematical literacy..

MANOVA Results

MANOVA was conducted to examine the effect of the HOTS-based PjBL model integrated with a scientific approach on three main indicators of mathematical literacy: (1) formulating situations mathematically, (2) employing concepts, facts, procedures, and reasoning, and (3) interpreting and evaluating outcomes. This analysis was appropriate because the three dependent variables are simultaneous and interrelated components of mathematical literacy.

Prior to conducting MANOVA, prerequisite tests were performed. Multivariate normality tests using the Kolmogorov–Smirnov and Shapiro–Wilk methods indicated significance values > 0.05, confirming normal data distribution. Box's M test yielded a significance value of 0.214 > 0.05, indicating that the homogeneity of covariance matrices assumption was met. Correlation tests among variables showed significant relationships without multicollinearity (VIF < 10), confirming the suitability of the indicators for MANOVA analysis. The MANOVA results are presented in Table 6 below.

Table 6. MANOVA Results of Mathematical Literacy Ability

Effect	Statistik	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pembelajaran	Pillai's Trace	0.782	15.112	3.000	29.000	.000	.764
	Wilks' Lambda	0.246	14.873	3.000	29.000	.000	.754
	Hotelling's Trace	2.217	15.042	3.000	29.000	.000	.756
	Roy's Largest Root	2.217	21.421*	1.000	31.000	.000	.823

Interpretation:

Significance values across all multivariate statistics indicated $p < 0.05$, demonstrating that the HOTS-based PjBL model exerted a significant simultaneous effect on all three mathematical literacy indicators. Wilks' Lambda value of 0.246 indicated a strong effect, as lower lambda values reflect greater treatment effects. Furthermore, partial eta squared values ranged from 0.74 to 0.76, indicating that the contribution of the learning model to improvements in mathematical literacy fell within the very large effect category.

Based on these findings, it can be concluded that the HOTS-based PjBL model integrated with a scientific approach not only improved overall mathematical literacy scores but also exerted a strong and significant simultaneous effect on all three literacy indicators.

Discussion

The discussion of the research findings indicates that the HOTS-based Project-Based Learning (PjBL) model integrated with the scientific approach is effective in improving students' mathematical literacy skills. The increase in test scores, positive student responses, and the high level of implementation of the PjBL syntax demonstrate that the model is capable of providing meaningful learning experiences. These findings are consistent with the results of a scoping review conducted by Cruz, Viseu, and Lencastre, which revealed that PjBL consistently enhances mathematical concept understanding, process skills, and the development of a student-centered learning environment. (Cruz et al., 2022). Therefore, the effectiveness of the model developed in this study aligns with the established success patterns of PjBL across various mathematics learning contexts..

From a constructivist theoretical perspective, the success of this model is influenced by students' active engagement in constructing knowledge through real-world projects. Learning is no longer focused on procedural memorization; instead, it encourages students to analyze, evaluate, and create new solutions. This condition is in line with the study by Chistyakov et al., which emphasizes that PjBL facilitates active, collaborative, and problem-based learning, thereby promoting the formation of new knowledge through authentic experiences and meaningful scientific practices (Chistyakov et al., 2023).

The integration of Higher Order Thinking Skills (HOTS) within this model has been proven to support students in developing critical, analytical, and creative thinking skills. This finding is consistent with the review by Guo et al., which indicates that PjBL enhances higher-level cognitive abilities, including analysis, evaluation, and knowledge construction, particularly when projects require tangible products and deep reflection (Guo et al., 2020). Furthermore, the application of the scientific approach through the stages of observing, questioning, experimenting, reasoning, and communicating further strengthens students' abilities to construct data-based arguments. This is in accordance with the characteristics of PjBL proposed by Krajcik and Czerniak, as cited in Chistyakov et al., which highlight the importance of scientific inquiry, data utilization, and artifact creation as core components of project-based learning (Chistyakov et al., 2023).

Positive student responses toward this model indicate that PjBL is not only academically effective but also affectively engaging. This finding is supported by the study of Rehman et al., which found that PjBL enhances student engagement, positive attitudes toward mathematics, and intrinsic motivation in participating in authentic project-based learning activities (Rehman et al., 2024). Students' involvement in real-world projects makes learning more relevant to everyday life. This is aligned with the objectives of the Merdeka Curriculum, which emphasizes contextual, project-based learning to foster the Pancasila Student Profile.

Moreover, the improvement in mathematical literacy across all indicators demonstrates that this model is capable of preparing students to face global challenges. Students not only understand mathematical concepts but are also able to apply them in real-life situations. This consistency is also evident in the findings of Cruz et al., who emphasized that PjBL enhances the integration of mathematical concepts within real-world contexts and facilitates the development of soft skills such as collaboration and communication (Cruz et al., 2022).

In addition, the success of the model in this study aligns with the findings of Rehman et al., which indicate that PjBL significantly improves 21st-century skills such as collaborative learning, problem-solving, and critical thinking in mathematics classrooms through active, reflective, and collaborative learning experiences (Rehman et al., 2024). These findings further strengthen the position of this model as an approach that not only develops academic competencies but also prepares students to face the dynamics of the 21st-century global environment.

Thus, this study contributes to innovations in mathematics learning at the secondary school level. The HOTS-based PjBL model integrated with the scientific approach can be recommended as an alternative instructional strategy capable of improving the quality of education while supporting the achievement of Sustainable Development Goal (SDG) 4 on Quality Education. These findings also extend empirical evidence regarding the effectiveness of PjBL, as demonstrated in various international studies, which consistently report that PjBL has a positive impact on students’ cognitive abilities, affective aspects, and collaborative skills across different levels of education.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the research findings and discussion, the following conclusions can be drawn:

1. Identification of student characteristics revealed that most students had visual (68%) and kinesthetic (56%) learning styles. However, higher-order thinking skills (HOTS) remained low, with 74% of students experiencing difficulties in analysis, synthesis, and evaluation tasks. This condition provided a strong rationale for developing an innovative learning model to enhance students’ mathematical literacy.
2. The developed research instruments—including mathematical literacy tests, observation sheets, and student response questionnaires—demonstrated high validity scores ranging from 87.3% to 90.5%, indicating that the instruments were highly valid and reliable for educational research.
3. Implementation of the learning model resulted in a significant improvement in students’ mathematical literacy. The mean pre-test score of 51.4 increased to 83.5 in the post-test, with an average gain score of 0.66, categorized as moderate–high according to Hake’s classification. This confirms that the developed model effectively enhanced

conceptual understanding, critical thinking skills, and contextual problem-solving abilities.

4. Student responses to the learning process were highly positive. More than 87% of students reported that learning was more engaging, increased motivation, and facilitated understanding of mathematical concepts. These responses indicate that the HOTS-based PjBL model integrated with a scientific approach successfully created an active, collaborative, and meaningful learning environment.

Recommendations

Based on the research findings, the following recommendations are proposed:

1. **For Teachers:** It is recommended that teachers implement the HOTS-based PjBL model integrated with a scientific approach across various contextual mathematics topics. Teachers should consistently develop project-based learning tools to habituate students to critical, creative, and real-world problem-solving thinking.
2. **For Schools:** Schools are encouraged to provide support by facilitating adequate learning infrastructure, particularly digital tools and supporting technologies. In addition, schools may organize professional development programs to enhance teachers' understanding and skills in implementing PjBL and HOTS-based instruction.
3. **For Future Researchers:** Future studies may extend this research to other subjects or educational levels to examine the broader effectiveness of the model. Further research may also incorporate additional variables such as collaboration skills, creativity, or digital literacy to enrich the scope of investigation.

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