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Differentiated Problem-Based Learning: Effects on Mathematical Literacy and Learning Motivation in Secondary Education

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Abstract

Mathematical literacy skills and learning motivation are two key components of 21st-century mathematics learning that need to be optimally developed. This study aimed to investigate the effect of implementing differentiated instruction within the Problem Based Learning (PBL) model on the learning motivation and mathematical literacy skills of senior high school students. A quasi-experimental design with a pretest-posttest control group was employed. The sample consisted of 72 Year 10 students at SMAN 7 Pinrang selected via cluster random sampling: class X.4 as the experimental group (PBL with process differentiation) and class X.6 as the control group (PBL without differentiation). Instruments included a learning implementation observation sheet, a 15-item Likert-scale learning motivation questionnaire, and a mathematical literacy test based on the formulate-employ-interpret process. Inferential analysis used one-sample t-tests, binomial tests, and independent sample t-tests in IBM SPSS 26. Results showed that: (1) the experimental group's motivation increased from a mean of 41.00 to 50.36 (N-Gain = 0.50; moderate), with 97% of students meeting mastery criteria; (2) mathematical literacy improved from 44.72 to 83.61 (N-Gain = 0.72; high), with 94% achieving the minimum score threshold (≥75); (3) the experimental group's motivation gain and literacy gain were significantly higher than the control group ($p < .001$), with Cohen's d effect sizes of 0.86 (large) and 0.97 (large), respectively. It is concluded that differentiated instruction within the PBL model has a significant and practically meaningful effect on both learning motivation and mathematical literacy skills of senior high school students.

Keywords: Differentiated Instruction; Problem-Based Learning; Learning Motivation; Mathematical Literacy

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INTRODUCTION

Mathematical literacy skills are one of the critical competencies of the 21st century that determine students' readiness to face real-life challenges. The Organisation for Economic Co-operation and Development (OECD) defines mathematical literacy as an individual's ability to formulate, use, and interpret mathematics in a variety of real-life contexts (OECD, 2023). The concern about low mathematics literacy is not only a problem for Indonesia but is a systemic challenge in the Southeast Asian region at large. A comparative study of ASEAN cross-country shows that most countries in the region still record math scores that are far below the OECD average — as an illustration, the Philippines obtained an average math score of 355 in PISA 2022, reflecting a similar pattern to the conditions in Indonesia (Diola, 2026). In the national context, the PISA 2022 results put Indonesia in a still worrying ranking, with the average math score below the OECD country average, continuing a similar trend in PISA 2018 where Indonesia was ranked 74th out of 79 countries with an average score of 379 (OECD, 2019). This condition is not only reflected in international assessments but is also documented in real terms at the grade level. Classroom-based research at SMPN 33 Makassar shows that students' numeracy competencies are still in the special intervention category — characterized by limited mathematical knowledge, partial mastery of concepts, and limited computing skills (Nasrullah, 2023). This condition is closely related to the weak mathematical reasoning ability of students; As shown by Hamda et al. (2025), students who have low mathematical reasoning skills experience significant difficulties in solving numeracy literacy problems, which ultimately has a direct impact on the overall low achievement of mathematical literacy.

On the other hand, learning motivation is an internal and external factor that drives, directs, and maintains students' active participation in the learning process (Rambe, 2022). Low motivation to learn mathematics has a direct impact on weak mastery of concepts and problem-solving skills. A regional study in Southeast Asia confirms that learning systems that are not responsive to the diversity of students' abilities tend to result in passive attitudes and reduce active involvement in the learning process (Diola, 2026). At the classroom level, a classroom action study conducted by Nasrullah (2023) confirms that teacher-implemented learning activities have not been effective in helping students achieve the expected level of numeracy competence, and that students need activities that encourage them to understand phenomena and relate them to mathematical concepts — a need that cannot be met by a uniform learning approach without taking into account the diversity of students' abilities. This problem was also found in the field: the results of interviews with mathematics teachers in class X of SMAN 7 Pinrang revealed that

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most students had difficulty understanding the material classically, were passive in discussions, and lacked motivation when learning was teacher-centered.

Various efforts to improve the quality of mathematics learning continue to be developed, one of which is through the application of the Problem Based Learning (PBL) model. PBL is a real-world problem-based learning model that encourages students to think critically, build knowledge actively, and develop collaboration skills (Redhana, 2019; Anggraini et al., 2023). The mathematical reasoning skills that are demanded in the 21st century have proven to be a critical component in solving the problem of numeracy literacy; students with weak mathematical reasoning consistently show difficulty in formulating and interpreting contextual problems (Hamda et al., 2025). The urgency of implementing this approach is further strengthened by comparative studies in the Southeast Asian region that explicitly recommend curriculum reform towards project-based learning and inquiry-based learning as key strategies to improve mathematics and science literacy at the regional level (Diola, 2026). In line with that, Nasrullah (2023) emphasizes that students need learning activities that encourage understanding of real phenomena and relate them to mathematical concepts — a characteristic inherent in the PBL model. However, PBL that is applied uniformly without considering the diversity of students' abilities is considered not optimal in accommodating all learning needs.

Differentiated learning is present as a responsive strategy that adapts the learning process based on students' readiness, interests, and learning profiles (Tomlinson, 2014; Faiz et al., 2022). The integration of differentiated learning in PBL—especially process differentiation—has the potential to create a more personalized learning experience while maintaining the cognitive challenges necessary for the development of mathematical literacy (Ardiyansyah et al., 2023).

Several studies have shown the positive influence of differentiated learning on mathematical literacy (Farinta Nanda, 2024; Shidqiya et al., 2023) and on learning motivation (Kusumawati et al., 2024; Setyaningrum et al., 2023). However, studies that simultaneously examine the influence of these two variables in the context of the Three-Variable Linear Equation System (SPLTV) material at the high school level are still limited. SPLTV was chosen because it contains a rich real-world problem context to measure the process of mathematical literacy (formulate-employ-interpret) while challenging students at various skill levels.

Based on this background, this study aims to: (1) describe students' learning motivation and mathematical literacy ability before and after differentiated learning in PBL; (2) describe the learning motivation and mathematical literacy ability of the control class; and (3) test the effect of differentiated learning in PBL on the two variables inferentially.

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METHOD

1. Research Type and Design

This study uses a quantitative approach with a quasi-experimental design, namely pretest-posttest control group design. This design was chosen because the selection of sample classes could not be done completely randomly considering that the classes in schools are groups that have been formed. There were two groups in the study: the experimental class that received treatment in the form of process-differentiated PBL learning, and the control class that received non-differentiated PBL learning.

Table 1. Research Design

Groups	Pretest	Treatment	Posttest
Eksperimen	O_1	X_1 (PBL-D)	O_2
Control	O_3	X_2 (PBL)	O_4

Remarks: PBL-D = process differentiated PBL; PBL = non-differentiated PBL

2. Population and Sample

The research population is all students of class X of SMAN 7 Pinrang for the 2025/2026 Academic Year, which consists of 8 classes with a total of 288 students. The school implements random class divisions without superior classes, so that the initial ability between classes is assumed to be homogeneous. The sample was determined using cluster random sampling technique by draw, resulting in class X.4 as the experimental class (n = 36) and class X.6 as the control class (n = 36).

3. Research Variables and Instruments

The independent variables are the learning model: (a) PBL learning with process differentiation in the experimental class, and (b) PBL learning without differentiation in the control class. Process differentiation is operationalized through grouping students based on pretest scores into three ability categories (low, medium, high), with variations in the level of scaffolding in LKPD: LKPD-A (low ability) with examples of completion, LKPD-B (medium) containing step guides, and LKPD-C (high) in the form of open-ended questions without assistance.

The dependent variables are: (1) learning motivation, measured using a 4-point Likert scale questionnaire (15 items, maximum score of 60) which has been validated in content by two expert lecturers of the Department of Mathematics of FMIPA UNM; and (2) mathematical literacy ability, measured through a 2-question description test based on the formulate-employ-interpret process on SPLTV material (maximum score of 100), which was also validated in content by two expert

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lecturers. Increase was measured using normalized gain (N-Gain) according to Hake (1999) classification: high (≥0.7), medium (0.3–0.7), low (<0.3).

4. Data Analysis Techniques

Descriptive analysis included average, standard deviation, N-Gain, and classical completeness (≥75% of students achieved a score of ≥75 for literacy; ≥75% achieved a score of ≥45 or 75% of a max score of 60 for motivation). Inferential analysis begins with a prerequisite test of normality (Shapiro-Wilk) and homogeneity of variance (Levene). Hypothesis testing uses: one-sample t-test (average and gain test of reference value), binomial test (classical completeness proportion test), and independent sample t-test (comparison test between classes). The size of the influence was calculated using Cohen's d: small (<0.5), medium (0.5–0.8), large (>0.8) (Cohen, 1988). All analyses were conducted with IBM SPSS Statistics 26 at a significance level of 5%.

RESULTS AND DISCUSSION

1. Initial Equivalence of Two Classes

Before treatment, the initial ability equivalence of the two classes was statistically verified. Average pretest mathematics literacy in experimental classes (M = 44.72; SD = 13.79) and control class (M = 39.72; SD = 13.01) did not differ significantly (t(70) = 1.58; p = 0.118). Similarly, the average pretest motivation for experimental learning (M = 41.00; SD = 2.46) and control (M = 42.28; SD = 1.64) did not differ significantly. The implementation of learning in both classes was in the very good category, namely 92% (experiment) and 91% (control).

2. Descriptive Analysis

A summary of descriptive statistics for both variables in both classes is presented in Table 2.

Table 2. Descriptive Statistics of Learning Motivation and Mathematical Literacy Ability

Variables/Classes	Pretest			Posttest			N-Gain (Category)
	M	SD	Min-Max	M	SD	Min-Max	
Motivation – Experiment	41,00	2,46	34–47	50,36	3,52	44–57	0.50 (Medium)
Motivation –	42,28	1,64	38–46	48,50	3,37	42–55	0.36

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Control							(Medium)
Literature – Experiments	44,72	13,79	10–65	83,61	8,95	60–100	0.72 (High)
Literacy – Control	39,72	13,01	10–65	75,83	9,01	55–95	0.60 (Medium)

M = Average; SD = Standard Deviation; N-Gain according to Hake (1999)

Table 2 shows that the experimental class experienced a greater increase in both variables than the control class. In learning motivation, the average experimental posttest (50.36) was higher than the control (48.50), with the experimental N-Gain (0.50) higher than the control (0.36)—both in the moderate category. In mathematics literacy ability, the experimental class achieved an N-Gain of 0.72 (high category) compared to the control of 0.60 (medium category), with an average posttest difference of 7.78 points.

The distribution of literacy ability categories showed a dramatic shift in the experimental class: before the treatment, 78% of students were in the low category; After treatment, 75% reached the high category and 25% the medium category—there were no students left in the low category. Meanwhile, the post-treatment control class still had 58% of students in the medium category and 42% in the high category.

3. Classical Completeness

The classical completeness of the experimental classroom learning motivation reached 97% (35 out of 36 students obtained a score ≥ 45 or 75% of the maximum score), exceeding the target of 75%. In the control class, the classical completeness of motivation was 86%. For mathematics literacy ability, the classical completeness of the experimental class was 94% (34 out of 36 students achieved a score of ≥ 75 according to the KKTP), while the control class was only 72%—below the classical completeness limit of at least 75%.

4. Inferential Analysis Results

The Shapiro-Wilk normality prerequisite test showed that all data were normally distributed ($p > 0.05$), and the Levene test confirmed the homogeneity of the variance of motivational gain ($F = 0.096$; $p = 0.757$) and literacy gain ($F = 0.020$; $p = 0.888$). The results of the hypothesis test are presented in Table 3.

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Table 3. Summary of Hypothesis Test Results

Hipotesis	Statistical Test	t/z	Say.	Verdict
H1.1: Average posttest motivation for class E ≥ 37.5	One-sample t-test	21,906	0,000	H_o rejected
H1.2: Proportion of complete motivation ≥ 75% (obs. 97%)	Binomial	–	0,000	H_o rejected
H1.3: Motivational N-Gain class E ≥ 0.3	One-sample t-test	7,029	0,000	H_o rejected
H1.4: Posttest motivasi E > K (d = 0.54)	Indep. t-test	3,553	0,001	H_o rejected
H2.1: Average literacy posttest for class E ≥ 75	One-sample t-test	5,695	0,000	H_o rejected
H2.2: Literacy completion rate ≥ 75% (obs. 94%)	Binomial	–	0,003	H_o rejected
H2.3: N-Gain of literacy class E ≥ 0.3	One-sample t-test	20,218	0,000	H_o rejected
H2.4: Literacy gain E > K (d = 0.97)	Indep. t-test	4,107	0,000	H_o rejected

Class E = Experiment; Class K = Control; d = Cohen's d

All eight minor hypotheses were rejected ($p < 0.05$), meaning that all aspects of the test were met, so that the first major hypothesis (effect on learning motivation) and the second major hypothesis (effect on mathematical literacy ability) were accepted.

The measure of influence (Cohen's d) obtained showed a large effect on both learning motivation gain (d = 0.86) and mathematical literacy gain (d = 0.97), indicating that the difference between the two groups was not only statistically significant, but also practically significant.

5. Discussion

Influence on Learning Motivation. The increase in learning motivation in the experimental class (N-Gain = 0.50; d = 0.86) which was significantly higher than that of the control class (N-Gain

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= 0.36) confirmed that the integration of process differentiation in PBL was able to increase students' internal motivation to actively participate in learning. When students receive a level of scaffolding that matches their abilities, their sense of competence increases, which is one of the main predictors of intrinsic motivation according to Self-Determination theory (Deci & Ryan, 2000).

These findings are consistent with Kusumawati et al. (2024) and Setyaningrum et al. (2023) who show that differentiated PBL increases students' motivation to learn. In a broader framework, responsive learning opportunity design is proving to be key to increasing student active engagement; Nasrullah et al. (2025) show that the implementation of learning opportunity-based learning design makes a positive contribution to the development of mathematical abilities through the creation of meaningful conceptual trajectories and learning flexibility that is adaptive to the diversity of abilities — principles that are in line with the process differentiation applied in this study. On a broader level, the Southeast Asian regional perspective put forward by Diola (2026) confirms that learning that does not accommodate the diversity of students' abilities consistently results in low motivation and learning engagement—the findings of this study, with an increase in motivation N-Gain of 0.50 in the experimental class, provide empirical evidence that process differentiation is able to address these challenges in real terms in the context of the high school classroom. Interestingly, the control class also showed an increase in motivation (N-Gain = 0.36; medium category), indicating that PBL itself—with its real-world problem-based characteristics and active group work—already has a positive contribution to learning motivation, in line with Redhana (2019). Process differentiation provides added value by ensuring that no student feels overwhelmed (low-ability students) or bored (high-ability students).

Influence on Mathematical Literacy Ability**.** A significant increase in the mathematical literacy ability of the experimental class (N-Gain = 0.72; d = 0.97) showed that differentiated PBL effectively trained three mathematical literacy processes: formulating, employing, and interpreting in the context of real SPLTV problems. LKPD differentiation allows each student to engage in the literacy process according to his or her ability level—low-ability students are helped to understand mathematical representations through examples, while high-ability students are challenged to construct their own models without guidance. The relevance of this finding is further strengthened by a regional comparative study which concludes that countries in Southeast Asia that adopt active learning strategies accompanied by scaffolding differentiation show a more consistent and meaningful increase in literacy achievement than those that still rely on conventional teaching methods (Diola, 2026).

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The striking difference with the control class (N-Gain = 0.60, medium category) suggests that PBL without differentiation, despite improving literacy, has not been able to maximize the potential of the entire spectrum of students' abilities. Low-ability students in the control class may not get enough scaffolding to successfully formulate problems mathematically, while high-ability students are not challenged enough to develop more complex literacy reasoning. This is in line with the findings of Hamda et al. (2025) who show that students' mathematical reasoning abilities are directly correlated with their ability to solve numeracy literacy problems—students with low reasoning consistently fail to reach the level of interpretation which is the highest process in mathematical literacy. This achievement is very meaningful when considering the initial conditions similar to those reported by Nasrullah (2023), where students who participate in conventional learning are still classified in the special intervention category with partial mastery of concepts. The fact that 75% of the experimental class students in this study successfully moved to the post-treatment category of high literacy confirms that scaffolding differentiation in PBL is the appropriate pedagogical response to the mathematics literacy problem that has been documented locally. These results are in line with Ardiyansyah et al. (2023) and Farinta Nanda (2024) who show the advantages of differentiated learning in improving mathematical literacy.

Practical Implications. The operationalization of process differentiation through three types of LKPD (A, B, C) based on the pretest ability profile is a practical implementation model that can be adapted by teachers. This model does not require changes to the material or learning objectives, but only adjustments to the level of support (scaffolding) provided—in line with the principles of Universal Design for Learning (UDL). The findings of Nasrullah (2023) provide an important lesson in this regard: although teacher-facilitated cognitive, affective, psychomotor, and learning opportunities are considered close to the best scores by observers, students' numeracy achievement remains in the low category and requires special intervention. This indicates that the quality of teacher activities alone is not enough without an adjustment of the scaffolding level that is in accordance with the ability profile of each student — this is precisely the main advantage of the process-differentiated PBL model in this study. Excellent learning implementation (≥91%) confirms that this model can be implemented consistently in real school conditions.

Research Limitations. This research has several limitations that need to be acknowledged. First, the sample was limited to one school (SMAN 7 Pinrang), so the generalizability of the findings needed to be confirmed in a wider population. Second, differentiation is applied only to the process aspect; Advanced research can explore the impact of content and product differentiation.

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Third, the motivational questionnaire instrument was only validated in terms of content (expert judgment) without being equipped with a quantitative reliability test in this research sample.

CONCLUSION

Based on the results of the research and discussion, it can be concluded that the application of differentiated learning in the Problem Based Learning model has a significant and practically meaningful influence on the learning motivation (Cohen's d = 0.86) and mathematical literacy ability (Cohen's d = 0.97) of high school class X students. The experimental class achieved an N-Gain of learning motivation of 0.50 (medium category) and an N-Gain of mathematical literacy ability of 0.72 (high category), with classical completeness of 97% and 94%, respectively—exceeding the minimum limit of 75%. Both outcomes were significantly higher than the control class that applied PBL without differentiation.

These findings confirm that process differentiation through LKPD scaffolding variations tailored to students' ability profiles is an effective approach to optimize problem-based learning. Further research is suggested to explore the influence of content and product differentiation, test this model on other mathematics materials and different levels of education, and complement the validation of the instrument with question item analysis and quantitative reliability tests.

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