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Comparing Problem-Based Learning and Discovery Learning on Students' Numeracy Literacy: A Quasi-Experimental Study

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abstract

Background: Numeracy literacy is an essential competency in 21st-century education because it supports students' ability to analyze information, solve contextual problems, and make data-based decisions. However, previous studies have mostly examined Problem-Based Learning (PBL) and Discovery Learning (DL) separately, so direct comparative evidence regarding their effectiveness in developing students' numeracy literacy remains limited, particularly at the junior secondary level in Indonesia.
Aims: This study aimed to compare the effectiveness of PBL and DL in improving students' numeracy literacy skills.
Methods: This study employed a quantitative quasi-experimental method with a posttest-only control group design. The participants were 58 eighth-grade students from one of the public junior high school in Soppeng Regency, South Sulawesi divided into two groups: one group was taught using PBL and the other using DL. Data were collected through numeracy literacy tests, observation sheets, and documentation, and analyzed using descriptive and inferential statistics through an independent samples t-test.
Results: The results showed a significant difference between the two learning models (Sig. = 0.001 < 0.05). Students taught using PBL demonstrated higher numeracy literacy performance than those taught using DL. The findings indicate that contextual problem-solving, collaborative discussion, and structured scaffolding in PBL more effectively support students' abilities to interpret, analyze, and apply mathematical information in real-life contexts.
Conclusions: This study strengthens the view that numeracy literacy develops more effectively through contextual and socially mediated learning experiences. Practically, the findings suggest that mathematics teachers should integrate authentic problems and collaborative learning activities to improve students' numeracy literacy skills.

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1. Introduction

Numeracy literacy is an essential 21st-century competency that involves the ability to understand, use, interpret, and evaluate numerical information in a various contexts (Dowker, 2016; Grotlüschen et al., 2020; OECD, 2012). It goes beyond basic arithmetic skills and encompasses mathematical reasoning that supports decision-making in social, economic, and educational settings (Billington & Foldnes, 2021; Malloy-Weir et al., 2016; PIAAC, 2009). Furthermore, numeracy literacy is closely linked to other key 21st-century skills, including critical thinking, creativity, communication, and collaboration.

In the Indonesian education system, mathematics is a fundamental subject that plays a crucial role in the advancement of science and technology (Arista & Karimah, 2022). One of the primary goals of mathematics education is to develop students' numeracy literacy, which refers to their ability to apply mathematical concepts to understand and solve real-life problems (Asmara et al., 2026; Ate & Lede, 2022; Rosyadi et al., 2024). Numeracy literacy includes the ability to understand, evaluate, and use numerical information to support reasoning and decision-making processes (Peters & Shoots-Reinhard, 2023). It also involves interpreting quantitative data, analyzing numerical relationships, and using representations such as graphs, tables, diagrams, and mathematical models (Cooper & Vallée-Tourangeau, 2021; Faridah et al., 2022).

The importance of strengthening numeracy literacy has become increasingly evident following the release of the PIAAC 2023 results, which revealed that literacy, numeracy, and problem-solving skills among adults have stagnated or declined in many countries (OECD, 2023a). Similarly, the PISA 2022 report showed that many students still struggle to apply mathematical concepts in contextual and non-routine situations (OECD, 2023b). This issue is partly attributed to learning practices that continue to emphasize memorization and procedural tasks, limiting the development of higher-order thinking skills (Beyer et al., 2025; Dowker, 2016; Grotlüschen et al., 2020).

A similar situation was identified at one of the public junior high school in Soppeng Regency, South Sulawesi. Based on teacher interviews and preliminary observations, classroom instruction is still largely dominated by lecture-based methods, providing students with limited opportunities to develop critical thinking and problem-solving skills. Students also experience difficulties in applying mathematical symbols to real-world contexts, analyzing data presented in graphs or tables, and interpreting results for decision-making purposes. These findings indicate that students' numeracy literacy skills remain below the expected level.

Previous studies have shown that low numeracy literacy is often associated with learning environments that are insufficiently contextual and do not actively engage students in the learning process (Farda et al., 2025; Indah et al., 2016;Sitaresmi et al., 2023). In contrast, innovative, contextual, and interactive learning approaches have been found to enhance both student engagement and numeracy literacy skills (Deda et al., 2023; Hakiki et al., 2022; Minoza et al., 2025; Pongsophon, 2023; Rahmania et al., 2024).

Among the instructional approaches that show promise in improving numeracy literacy are Problem-Based Learning (PBL) and Discovery Learning (DL). PBL emphasizes collaborative problem-solving through authentic real-world problems, enabling students to connect mathematical concepts with everyday situations (Hakiki et al., 2022; Nasruddin & Jahring, 2024). Meanwhile, DL encourages students to discover concepts independently through exploration and inquiry, which can strengthen conceptual understanding and learning autonomy (Abdullah, 2023; Asri & Maysarah, 2024). This approach also contributes to the development of conceptual understanding and self-directed learning, both of which are important components of numeracy literacy (Judijanto et al., 2024; Nurjaman et al., 2025). Compared with teacher-centered approaches such as direct instruction and drill-based learning, both PBL and DL provide broader opportunities for students to actively engage in higher-order thinking processes (Irsyad et al., 2024; Pasaribu et al., 2020). Furthermore, both approaches are aligned with the demands of 21st-century education, particularly in fostering critical thinking, collaboration, communication, creativity, and problem-solving skills (Hafizah et al., 2024; Nurjaman et al., 2025; Wiono & Siregar, 2024).

Although numerous studies have demonstrated the positive effects of PBL and DL on mathematics achievement, conceptual understanding, and problem-solving abilities, research directly comparing their impact on students' numeracy literacy remains limited. Therefore, this study aims to compare the effects of PBL and DL on students' numeracy literacy based on the indicators established by the Indonesian Ministry of Education and to identify which instructional model is more effective in enhancing these skills.

1.1. Numeracy literacy

Numeracy literacy is recognized as an essential competency in the twenty-first century, enabling individuals to understand, interpret, evaluate, and apply mathematical information in various real-life contexts. Numeracy literacy extends beyond basic computational skills and encompasses the ability to reason quantitatively, analyze data, solve problems, and make informed decisions based on available numerical information (OECD, 2023; Peters & Shoots-Reinhard, 2023). Geiger et al. (2015) describe numeracy as a multidimensional construct that integrates mathematical, critical, technological, financial, and social aspects, allowing individuals to participate effectively in modern society. Similarly, Nurmasari et al. (2023) emphasize that contemporary perspectives on numeracy literacy focus on real-world competencies, highlighting the importance of applying mathematical knowledge in authentic situations rather than merely mastering procedural calculations. Therefore, numeracy literacy has become a key indicator of students' readiness to face the challenges of a data-driven and increasingly complex world.

The literature further suggests that numeracy literacy is closely associated with logical thinking and mathematics achievement. A literature review conducted by Pratiwi et al. (2024) revealed that numeracy literacy, reading literacy, and logical thinking are interconnected competencies that collectively support students' understanding of mathematical concepts and problem-solving abilities. In addition, various innovative instructional approaches have been reported to improve students' numeracy literacy by providing opportunities for exploration, reasoning, and contextual problem-solving activities (Isnaintri & Novaliyosi, 2024; Sektiwulan et al., 2024; Sektiwulan et al., 2025). Nalle et al. (2025) further argue that numeracy literacy plays a crucial role in preparing students for twenty-first-century challenges because it contributes to scientific reasoning, critical thinking, and data-driven decision-making. Despite its recognized importance, international assessments continue to indicate that many students experience difficulties in applying mathematical concepts to real-world situations, suggesting the need for more effective instructional strategies to strengthen numeracy literacy development (OECD, 2023). Consequently, identifying learning models that effectively promote students' numeracy literacy remains an important focus of contemporary mathematics education research.

1.2. Problem-based learning

Problem-based learning (PBL) is a student-centered instructional model that emphasizes learning through the investigation and resolution of authentic problems. The model is grounded in constructivist learning theory, which views knowledge as actively constructed through experience, interaction, and reflection. According to Barrows (1986), PBL engages students in solving real-world problems that serve as the starting point for learning, enabling them to develop conceptual understanding, critical thinking, and problem-solving skills simultaneously. In mathematics education, PBL encourages students to identify problems, analyze relevant information, formulate alternative solutions, and evaluate outcomes through collaborative inquiry processes. The implementation of PBL generally follows several stages, namely problem orientation, organizing students for learning, guiding individual and group investigations, developing and presenting solutions, and evaluating problem-solving processes (Arends, 2012). Through these stages, students actively construct mathematical knowledge while connecting concepts with meaningful real-life situations.

Numerous studies have reported that PBL positively influences students' mathematical achievement, critical thinking, problem-solving ability, and numeracy literacy. By engaging students in contextual and authentic problems, PBL provides opportunities for learners to interpret quantitative information, analyze evidence, and make reasoned decisions based on mathematical concepts (Yew & Goh, 2016). Recent studies also indicate that PBL significantly improves students' mathematical literacy and higher-order thinking skills because learning activities require active participation, collaboration, and reflective reasoning (Hafizah et al., 2024; Nasruddin & Jahring, 2024). These characteristics align closely with the objectives of numeracy literacy, which emphasize the application of mathematical knowledge in contextual situations. However, the implementation of PBL also presents several challenges, including the need for longer instructional time, effective classroom management, and students' readiness to engage in collaborative inquiry activities. Therefore, the success of PBL depends on well-structured learning design, teacher facilitation, and the selection of contextual problems that are relevant to students' experiences and learning needs.

1.3. Discovery learning

Discovery learning is an instructional model grounded in Jerome Bruner's constructivist theory, which emphasizes that knowledge becomes more meaningful when learners discover it independently through exploration, investigation, and problem-solving activities. According to Bruner (1961), learning that involves the process of discovery enables students to develop a deeper conceptual understanding because they actively engage in organizing information and identifying relationships among concepts. In practice, discovery learning generally consists of six main stages: stimulation, problem statement, data collection, data processing, verification, and generalization, which allow students to construct concepts independently through scientific and investigative thinking processes (Khoiriyah & Murniyati, 2021). This model positions students as the center of the learning process, while teachers serve as facilitators who provide guidance and scaffolding throughout the discovery process.

Numerous studies have demonstrated that discovery learning is effective in improving students' conceptual understanding, critical thinking skills, mathematical reasoning, and learning independence. Through exploration and discovery activities, students are encouraged to analyze information, identify patterns, and construct mathematical concepts based on the results of their active investigations (Wildaniati et al., 2024). These characteristics are closely aligned with the objectives of numeracy literacy, which emphasize the ability to interpret quantitative information, apply mathematical reasoning, and solve contextual problems effectively. Nevertheless, Discovery Learning also has several limitations, as it requires relatively more instructional time and a certain level of student readiness to engage in independent discovery processes. Furthermore, discovery-based instruction with minimal guidance may lead to misconceptions and increased cognitive load if adequate teacher support is not provided (Alfieri et al., 2011; Kirschner et al., 2006). Therefore, the effectiveness of Discovery Learning largely depends on the quality of teacher facilitation, instructional design, and the provision of appropriate scaffolding that meets students' learning needs.

2. Methods

2.1 Research design

This study employed a quantitative approach using a quasi-experimental design with a posttest-only control group design. The study was conducted at one of the public junior high school in Soppeng Regency, South Sulawesi during the second semester of the 2024/2025 academic year. Quantitative research aims to provide a clearer understanding of research phenomena through the collection and analysis of measurable numerical data (Ardiansyah et al., 2023).

A quasi-experimental design was selected because the researcher could not conduct full randomization of participants in a natural classroom setting, as the classes had been administratively determined by the school. Therefore, intact classes were used to maintain the authenticity of the learning environment and avoid disruption to the existing instructional process. The posttest-only control group design was considered appropriate because the study focused on comparing the effects of two learning models after treatment implementation. In addition, the design minimized the potential testing effect that may occur when participants are exposed to similar pretest and posttest items, which could influence students' responses and learning behavior during the treatment process. The design of the study is presented in Table 1.

Table 1. Posttest-only control group design

Group	Treatment	Posttest
Experimental Group I	X_1: Problem-Based Learning	O_1
Experimental Group II	X_2: Discovery Learning	O_2

2.2 Research procedures

The study was conducted over six meetings for each experimental group, with each meeting lasting 2 × 40 minutes. The first meeting was used for orientation and introduction to the learning procedures, four meetings were allocated for treatment implementation, and the final meeting was used for administering the posttest. In the PBL class, the learning procedures followed the stages proposed by Arends (2012), namely: (1) orienting students to contextual problems, (2) organizing students for learning activities, (3) guiding individual and group investigations, (4) developing and presenting solutions, and (5) analyzing and evaluating the problem-solving process. Students were encouraged to discuss authentic mathematical problems collaboratively and relate mathematical concepts to real-life situations.

Meanwhile, the DL class implemented the stages of discovery learning, consisting of: (1) stimulation, (2) problem statement, (3) data collection, (4) data processing, (5) verification, and (6) generalization (Bruner, 1961; Kemendikbud, 2014). In this model, students independently explored concepts through guided discovery activities and concluded mathematical principles based on the learning experiences provided. To reduce potential bias, both classes were taught by the same teacher, used the same learning materials and instructional duration, and were assessed using identical instruments and scoring criteria.

2.3 Participants

The population of this study consisted of all eighth-grade students at one of the public junior high school in Soppeng Regency, South Sulawesi, totaling 106 students. The sample was selected using simple random sampling, resulting in two classes consisting of 58 students in total. Class VIII A, consisting of 29 students, was assigned as Experimental Group I and taught using the PBL model, while Class VIII B, consisting of 29 students, was assigned as Experimental Group II and taught using the DL model. The participants were generally aged between 13–14 years old and came from relatively similar academic and socio-educational backgrounds based on school records and teacher information. The use of comparable classroom characteristics was intended to minimize differences in students' initial academic conditions.

2.4 Instruments

This study employed several research instruments, namely a numeracy literacy test, observation sheets, and documentation guidelines. The numeracy literacy test was used as the primary instrument to measure students' numeracy literacy skills after the implementation of the PBL and DL models. The test was developed based on numeracy literacy indicators proposed by Kemendikbudristek (2021), including: (1) the ability to use numbers or mathematical symbols in solving contextual problems, (2) the ability to analyze information presented in graphs, tables, and diagrams, and (3) the ability to interpret analytical results for decision-making purposes. The numeracy literacy test consisted of five essay items administered at the end of the treatment sessions. Essay questions were selected because they enabled students to demonstrate reasoning, interpretation, and problem-solving processes more comprehensively. The instrument blueprint of numeracy literacy test is presented in Table 2.

Table 2. Blueprint of numeracy literacy posttest instrument

No.	Test Item Indicator	Cognitive Level	Numeracy Literacy Indicator
1	Determining the maximum number of package sets that Rina can sell while meeting snack stock limitations and the minimum requirement for "Ceria" packages	C4 (Analysis)	(1) the ability to use numbers or mathematical symbols in solving contextual problems (2) the ability to analyze information presented in graphs, tables, and diagrams, (3) the ability to interpret analytical results for decision-making purposes
2	Determining the number of correct and incorrect answers obtained by Diana based on an examination score scenario	C4 (Analysis)	
3	Calculating the area of a rectangular playground based on the known perimeter, where the length is twice the width	C3 (Application)	
4	Determining the price of one guitar pick based on the total purchase price and additional information related to product exchange	C4 (Analysis)	
5	Determining the prices of adult and children's tickets for offline purchases based on discounted payment totals from two booking scenarios	C5 (Evaluation)	

Before being administered, the instrument underwent content validation through expert judgment involving mathematics education lecturers and mathematics teachers to evaluate the relevance, clarity, and suitability of the items with the numeracy literacy indicators. Based on the experts' evaluation, the instrument was declared appropriate for use after minor revisions. In addition, construct validity was analyzed using the Pearson Product-Moment correlation test. The results showed that all item correlation coefficients exceeded the minimum criterion of $r > 0.30$, indicating that all test items were valid and met the construct validity requirements. Instrument reliability was further analyzed using Cronbach's Alpha, which yielded a coefficient of 0.986. Since the coefficient exceeded the acceptable reliability criterion of $\alpha = 0.786 > 0.70$, the instrument was categorized as having very high reliability and strong internal consistency. One example of the numeracy literacy test item is presented in Table 3.

Table 3. Sample of numeracy literacy test item

Item	Post-test question
5	*Pembelian tiket untuk pertunjukan teater di Taman Kalong kini bisa dilakukan secara online, memudahkan para penonton untuk mendapatkan tiket tanpa perlu antri. Sebagai bentuk promosi, pengelola teater menawarkan diskon 10% untuk pemesanan tiket secara online. Tiket pertunjukan dibagi menjadi dua kategori, yaitu tiket dewasa dan tiket anak-anak (untuk usia di bawah 15 tahun). Siti ingin membawa kedua anaknya ke pertunjukan teater tersebut, memesan satu tiket dewasa dan dua tiket anak-anak secara online dengan total biaya Rp110.000,00 setelah diskon. Di sisi lain, Pak Amir, berencana menonton pertunjukan bersama istri dan anaknya yang berusia 12 tahun. Ia memesan secara online dua tiket dewasa serta satu tiket anak-anak dengan harga total Rp130.000,00. Dengan informasi ini, berapakah harga tiket pertunjukan untuk dewasa dan tiket anak anak (usia di bawah 15 tahun) jika dibeli secara offline?*

The scoring rubric used an analytic scale ranging from 0–4 based on the accuracy of answers, reasoning, procedural completeness, and interpretation of results, as presented in Table 4.

Table 4. Scoring rubric for numeracy literacy test

Score	Criteria
4	Answer is correct, reasoning and interpretation are complete and accurate
3	Answer is generally correct, but explanation or interpretation is less complete
2	Partial understanding is shown, but important reasoning steps are missing
1	Answer shows limited understanding and inaccurate interpretation
0	No answer or completely incorrect response

Observation sheets were used to examine the implementation fidelity of the learning models during classroom instruction, while documentation was employed to support administrative and learning process data.

2.5 Data collection

Data were collected through tests, observation, and documentation techniques. The numeracy literacy test was administered after the completion of the treatment sessions to measure students' numeracy literacy skills in both experimental groups. Experimental Group I received instruction using PBL model, whereas Experimental Group II was taught using the DL model during five meetings for each group over 3 weeks. Classroom observations were conducted throughout the implementation process to examine the fidelity of the learning models and students' engagement during learning activities. The combination of these techniques was intended to provide comprehensive data regarding both the learning process and learning outcomes.

2.6 Data analysis

The collected data were analyzed using descriptive and inferential statistics. Descriptive statistics included the calculation of mean, standard deviation, maximum score, minimum score, and variance to describe students' numeracy literacy performance in each group. Inferential statistical analysis consisted of prerequisite tests and hypothesis testing. The prerequisite tests included the Kolmogorov–Smirnov normality test and Levene's homogeneity test. After the assumptions were fulfilled, an independent samples t-test was conducted to determine whether there was a significant difference between students taught using the PBL model and those taught using the DL model. To strengthen the interpretation of findings, the effect size was also calculated using Cohen's d to determine the magnitude of the treatment effect between the two learning models. The criteria for Cohen's d were interpreted as small (0.20), medium (0.50), and large (0.80). Because this study employed a posttest-only design, N-Gain analysis was not conducted, as it requires both pretest and posttest scores to measure learning improvement. The statistical hypotheses of this study were formulated as follows:

$H_0: \mu_1 = \mu_2$ (There is no significant difference in the mean numeracy literacy skills between students taught using the PBL model and those taught using the DL model).

$H_1: \mu_1 \neq \mu_2$ (There is a significant difference in the mean numeracy literacy skills between students taught using the PBL model and those taught using the DL model).

3. Results

This study aimed to compare the effectiveness of the Problem-Based Learning (PBL) model and the Discovery Learning (DL) model on students' numeracy literacy skills at one of the public junior high school in Soppeng Regency, South Sulawesi. Because this study employed a posttest-only control group design, the analysis focused on differences in students' final numeracy literacy performance after the implementation of the two learning models. In addition to statistical comparison, classroom observations were used to support the interpretation of the findings and explain how the implementation of each learning model contributed to the results obtained. The descriptive statistics of students' numeracy literacy posttest scores are presented in Table 5.

Table 5. Posttest results of numeracy literacy skills

Statistics	Group	
	Experimtenal Group I (PBL)	Experimtenal Group II (DL)
Minimum Score	14	12
Maximum Score	57	40
Mean Score	34,28	25,66
Standard Deviation	10,50	7,51
Variansi	110,14	56,45

Table 5 shows that students taught using the PBL model obtained a higher mean score (34.28) than those taught using the DL model (25.66). In addition, the PBL group achieved a higher maximum score, indicating that several students demonstrated stronger numeracy literacy performance after participating in contextual problem-solving activities. Although the PBL class showed a larger standard deviation, this finding indicates greater variation in students' performance levels within the group. Overall, the descriptive results suggest that the PBL model provided a more substantial contribution to the development of students' numeracy literacy skills compared to the DL model. To facilitate comparison between the two groups, the distribution of mean posttest scores is illustrated in Figure 1.

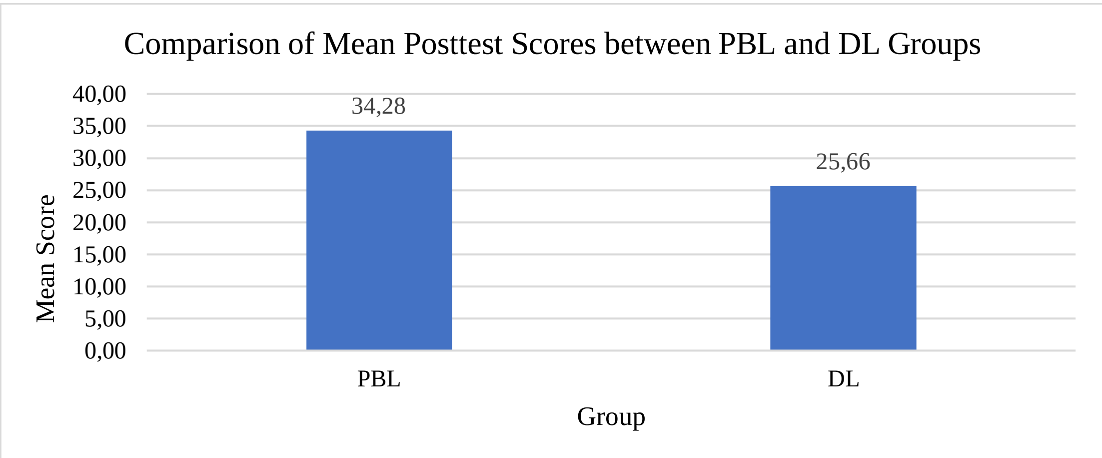

Figure 1. Comparison of mean post-test scores between PBL and DL groups

Before conducting hypothesis testing, prerequisite analyses consisting of normality and homogeneity tests were performed. The results of the independent samples t-test are presented in Table 6.

Table 6. Results of normality test of post-test data

Group	Shapiro-Wilk	df	Sig.
Experimental I	0,968	29	0,499
Experimental II	0,971	29	0,578

Based on Table 6, the Shapiro–Wilk normality test shows that the significance values of both groups are greater than 0.05. Therefore, the posttest data of students' numeracy literacy skills in both groups were normally distributed.

Table 7. Results of homogeneity test of post-test data

Levene Statistic	df1	df2	Sig.
1,982	1	56	0,165

Based on Table 7, the significance value of the Levene test was $0.165 > 0.05$, indicating that the variances of the two groups were homogeneous. Since the assumptions of normality and homogeneity were fulfilled, hypothesis testing using the independent samples t-test could be conducted.

Table 8. Independent samples t-test results

	t	df	Sig. (2-tailed)
t-test	3,597	56	0,001

Based on Table 8, the significance value was $0.001 < 0.05$, indicating that H_0 was rejected. Therefore, there was a statistically significant difference in numeracy literacy skills between students taught using the PBL model and those taught using the DL model.

Table 9. Effect size analysis

Analysis	Cohen's *d*	Interpretation
PBL vs DL	0.95	Large Effect

To strengthen the interpretation of the findings, the effect size was calculated using Cohen's d to determine the magnitude of the difference between the two groups. The analysis produced a Cohen's d value of approximately 0.95, which falls into the large effect category. This result indicates that the difference between the PBL and DL groups was not only statistically significant but also practically meaningful in influencing students' numeracy literacy skills.

Classroom observations revealed differences in the implementation characteristics of the two learning models. In the PBL class, students were actively involved in discussing contextual problems, exchanging ideas, and collaboratively constructing solutions. The learning process encouraged students to connect mathematical concepts with real-life situations, thereby supporting critical thinking and decision-making skills related to numeracy literacy.

Meanwhile, students in the DL class tended to rely more on individual exploration during concept discovery activities. Although several students demonstrated good conceptual understanding, some students experienced difficulties in independently identifying problem-solving strategies and drawing conclusions systematically. Limited interaction and insufficient scaffolding during several learning stages appeared to reduce students' engagement in numeracy-based reasoning activities. These findings indicate that the contextual and collaborative characteristics of PBL contributed more effectively to the development of students' numeracy literacy skills than the independent concept-discovery process emphasized in DL.

4. Discussion

The findings showed that students taught using Problem-Based Learning (PBL) achieved significantly higher numeracy literacy scores than those taught using Discovery Learning (DL). The independent samples t-test indicated a significant difference between groups (Sig. = 0.001 < 0.05) with a large effect size (Cohen's d = 0.95), suggesting that the difference was both statistically and educationally meaningful. PBL provided a stronger environment for developing students' abilities to interpret information, analyze contextual problems, and make data-based decisions in real-life situations (Asmara et al., 2026; Farda et al., 2025; Fitriani et al., 2025; Rosyadi et al., 2024). Classroom observations also showed that students in the PBL class were more actively engaged in discussing strategies, evaluating solutions, and interpreting contextual information than those in the DL class. These findings support previous studies emphasizing that contextual and collaborative learning better aligns with the cognitive demands of 21st-century numeracy literacy (Ferdiani, 2024; Hakiki et al., 2022; Pongsophon, 2023; Rahmania et al., 2024).

The superiority of PBL can be explained through social constructivist and cognitive engagement perspectives. PBL encourages students to actively construct knowledge through authentic problem-solving and collaborative interaction (Hmelo-Silver et al., 2007; Vygotsky, 1978). In this study, students were required to interpret information, justify arguments, evaluate solutions, and communicate reasoning during group discussions, which correspond to the numeracy literacy dimensions of formulate, employ, and interpret mathematics proposed in PISA (OECD, 2023b). Repeated exposure to contextual mathematical situations may stimulate deeper cognitive processing because students continuously connect mathematical concepts with meaningful real-life contexts (Asmara et al., 2026; Fitriani et al., 2025; Hakiki et al., 2022; Pongsophon, 2023; Rosyadi et al., 2024). In addition, collaborative interaction and guided reflection in PBL likely enhanced students' cognitive engagement, which is strongly associated with conceptual understanding and higher-order thinking development (Fredericks, 2004; (Hafizah et al., 2024; Olsen, 2025; Pongsophon, 2023; Son et al., 2026).

Another important finding is that although Discovery Learning (DL) theoretically promotes active learning and independent concept construction, it did not produce numeracy literacy outcomes as high as those achieved through PBL. This finding suggests that student-centered learning alone does not automatically result in optimal numeracy literacy development, particularly when students are required to construct knowledge independently without sufficient instructional support (Kirschner et al., 2006; Mayer, 2004). Several students in the DL class were able to identify mathematical patterns and formulate conclusions independently, indicating that DL still supports conceptual understanding and learner autonomy (Asri & Maysarah, 2024; Judijanto et al., 2024; Nurjaman et al., 2025). However, classroom observations showed that many students experienced difficulties in organizing information, verifying findings, and systematically interpreting contextual problems. Similar findings have been reported in previous studies showing that the effectiveness of DL strongly depends on students' readiness, metacognitive ability, and the quality of scaffolding provided by teachers (Asani et al., 2024; Deda et al., 2023; Nuryami, 2024; Rediani et al., 2024; Sitaresmi et al., 2023).

One possible explanation can be understood through Cognitive Load Theory, which states that learning effectiveness is influenced by the limited capacity of working memory during complex cognitive tasks (Raghubar et al., 2010; Schuessler et al., 2026; Sweller, 2010; Sweller et al., 2019). In the DL class, students were required to explore information, identify patterns, formulate concepts, and draw conclusions independently. For students with low prior knowledge, these activities may increase extraneous cognitive load, which may reduce available cognitive resources for meaningful learning (Skulmowski & Xu, 2022), namely cognitive burden caused by instructional processes that are insufficiently structured (Mayer, 2004; Schmidt et al., 2007; Schuessler et al., 2026; Sweller, 2024; Sweller et al., 2019). Consequently, students' cognitive resources may have been directed more toward managing the discovery process itself rather than developing numeracy reasoning and contextual interpretation skills (David et al., 2024). This finding is particularly relevant because numeracy literacy requires simultaneous abilities in mathematical representation, contextual interpretation, and data-based decision-making (Dowker, 2016; Grotlüschen et al., 2020; Malloy-Weir et al., 2016; OECD, 2023b).

In contrast, PBL appeared to provide more effective cognitive support through contextual problem orientation, collaborative discussion, and teacher scaffolding. These elements may reduce unnecessary cognitive load and help students focus on analyzing and applying mathematical concepts in real-life situations (Fredricks et al., 2004; Hafizah et al., 2024; Hmelo-Silver et al., 2007; Pongsophon, 2023). Previous studies similarly report that students in problem-based environments tend to demonstrate deeper conceptual understanding and stronger analytical reasoning because they actively negotiate meaning through social interaction and guided inquiry (Asani et al., 2024; Hakiki et al., 2022; Olsen, 2025; Rahmania et al., 2024; Varga et al., 2025). Therefore, the superiority of PBL in this study may reflect differences not only in instructional models but also in how each model manages cognitive load, scaffolding, and student engagement during learning. This finding contributes theoretically by indicating that constructivist learning approaches are not equally effective in developing numeracy literacy unless accompanied by adequate cognitive and instructional support, particularly for students with lower initial abilities and weak self-regulation skills (Seufert et al., 2024).

The findings of this study are also not entirely consistent with all previous research. While many studies report the superiority of PBL over DL in developing higher-order thinking and numeracy-related abilities (Ferdiani, 2024; Fitriani et al., 2025; Rosyadi et al., 2024), other studies indicate that DL can achieve comparable outcomes under certain instructional conditions (Deda et al., 2023; Minoza et al., 2025). This inconsistency suggests that the effectiveness of instructional models is strongly influenced by contextual variables such as classroom culture, teacher facilitation skills, students' prior abilities, and scaffolding intensity (Asani et al., 2024; Nuraini et al., 2025; Olsen, 2025; Pongsophon, 2023; Rahmania et al., 2024). Therefore, this study contributes by providing empirical evidence that numeracy literacy development may depend on the interaction between contextual problem-solving, collaborative engagement, and instructional guidance rather than solely on the choice of instructional model.

This study also contributes theoretically by reinforcing the view that numeracy literacy develops not only through individual conceptual mastery but also through socially mediated and contextually meaningful learning experiences (Fredricks et al., 2004; Grotlüschen et al., 2020; Hmelo-Silver et al., 2007; OECD, 2023b; Vygotsky, 1978). Practically, the findings imply that mathematics teachers should integrate authentic contextual problems, collaborative learning opportunities, and structured scaffolding into classroom instruction to better support numeracy literacy development (Asmara et al., 2026; Hafizah et al., 2024; Nurjaman et al., 2025; Wiono & Siregar, 2024). Such strategies may help students move beyond procedural computation toward analytical reasoning and data-based decision-making skills required in 21st-century learning.

5. Limitations and future research

This study has several limitations should be considered when interpreting these findings. First, this study employed a posttest-only quasi-experimental design; therefore, it identified differences in posttest achievement rather than directly measuring improvement over time. Second, the sample was limited to one junior secondary school, which may restrict the broader generalizability of the findings. Third, external variables such as prior mathematical ability, motivation, and teacher implementation skills were not fully controlled. Limited instructional time also affected the optimization of reflection activities during learning. Although the findings cannot be generalized universally, they may provide relevant insights for mathematics instruction in contexts characterized by teacher-centered learning traditions and relatively low numeracy literacy achievement (Dowker, 2016; Grotlüschen et al., 2020; OECD, 2023a, 2023b).

Future research is therefore recommended to employ pretest–posttest designs, involve more diverse educational settings, and examine mediating variables such as cognitive engagement, metacognitive regulation, collaboration quality, and scaffolding intensity to provide a more comprehensive explanation of how instructional models influence numeracy literacy development (Hmelo-Silver et al., 2007; Olsen, 2025; Varga et al., 2025).

6. Conclusion

This study demonstrates that the Problem-Based Learning (PBL) model provides a more effective learning environment for developing students' numeracy literacy skills than the Discovery Learning (DL) model in the context of junior secondary mathematics learning. The findings indicate that contextual problem-solving activities, collaborative interaction, and structured scaffolding within PBL better support students in interpreting quantitative information, analyzing contextual problems, and making mathematical decisions. In contrast, independent discovery activities implemented with limited guidance may increase students' cognitive burden, particularly for those with lower prior knowledge, thereby limiting the development of numeracy literacy. The study contributes theoretically by strengthening the perspective that numeracy literacy development is closely related to cognitive engagement, social interaction, and instructional support rather than solely to independent concept discovery. Practically, these findings suggest that mathematics instruction should integrate authentic contextual problems and collaborative scaffolding to better support students' higher-order thinking and numeracy literacy skills in 21st-century learning contexts.

Author Contributions

Nur Na'ilah Mallu: conceived and designed the study, collected the data, conducted the statistical analysis, and drafted the manuscript. Lisnasari Andi Mattoliang: supervised the research process and critically revised the manuscript for important intellectual content. A. Sriyanti: contributed to the research supervision, methodological refinement, and manuscript review. Andi Dian Angriani: contributed to the conceptual development of the study and provided critical feedback on the manuscript.

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