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Realistic mathematics education assisted by geogebra: Effective in terms of mathematical literacy and self-directed learning?

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Abstract: This study aims to 1) describe the effectiveness of implementing RME assisted by GeoGebra in terms of students' mathematical literacy and self-directed learning; 2) describe the effectiveness of implementing PBL in terms of students' mathematical literacy and self-directed learning; and 3) describe the differences in effectiveness between GeoGebra-assisted RME and PBL in terms of mathematical literacy and self-directed learning. This study involved 64 eighth-grade students from a public junior high school in Yogyakarta, utilizing a nonequivalent control group design Data were collected through test and non-test instruments and analyzed using one-sample t-tests and Hotelling's T^2 test. The findings show that: 1) GeoGebra-assisted RME learning is effective in enhancing both students' mathematical literacy and self-directed learning; (2) PBL is also proven to be effective in supporting students' mathematical literacy and self-directed learning; (3) A significant difference exists between the effectiveness of GeoGebra-assisted RME and PBL when viewed from the perspectives of mathematical literacy and self-directed learning; (4) GeoGebra-assisted RME does not outperform PBL in improving mathematical literacy; and (5) GeoGebra-assisted RME is more effective than PBL in promoting students' self-directed learning. Therefore, the choice of instructional strategy should align with the intended learning outcomes.

Keywords: Mathematical Literacy; Self-Directed Learning; Realistic Mathematics Education; GeoGebra

Pendidikan matematika realistik berbantuan geogebra: Efektifkah ditinjau dari literasi matematika dan kemandirian belajar?

Abstrak: Penelitian ini bertujuan untuk 1) mendeskripsikan efektivitas penerapan RME berbantuan GeoGebra ditinjau dari literasi matematika dan kemandirian belajar siswa; 2) mendeskripsikan efektivitas penerapan PBL ditinjau dari literasi matematika dan kemandirian belajar siswa; dan 3) mendeskripsikan perbedaan efektivitas antara RME berbantuan GeoGebra dan PBL ditinjau dari literasi matematika dan kemandirian belajar siswa. Penelitian ini melibatkan 64 siswa kelas VIII dari sebuah sekolah menengah pertama negeri di Yogyakarta, menggunakan desain kelompok kontrol non-ekuivalen. Data dikumpulkan melalui instrumen tes dan non-tes, dan dianalisis menggunakan uji t satu sampel dan uji Hotelling's T^2. Hasil penelitian menunjukkan bahwa: 1) Pembelajaran RME berbantuan GeoGebra efektif ditinjau dari literasi matematika dan kemandirian belajar siswa; (2) PBL juga terbukti efektif ditinjau dari literasi matematika dan kemandirian belajar siswa; (3) Terdapat perbedaan yang signifikan antara efektivitas RME berbantuan GeoGebra dan PBL ditinjau dari literasi matematika dan kemandirian belajar siswa; (4) RME berbantuan GeoGebra tidak lebih efektif daripada PBL ditinjau dari literasi matematika; dan (5) RME yang didukung GeoGebra lebih efektif daripada PBL ditinjau dari kemandirian belajar siswa. Oleh karena itu, pemilihan strategi instruksional harus sesuai dengan hasil belajar yang diinginkan.

Kata Kunci: Literasi Matematika; Kemandirian Belajar; Pendidikan Matematika Realistik; GeoGebra

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INTRODUCTION

Mathematical literacy (ML) is widely recognized as an essential competency for navigating everyday problem-solving and participating successfully in modern society day (Genc & Erbas, 2019; Stacey & Turner, 2015). ML plays a significant role not only in schooling but also in broader societal contexts, as emphasized in global educational agendas such as the Sustainable Development Goals 2030 (Grotlüschen et al., 2020). It requires students to formulate real-world problems mathematically, apply appropriate concepts and procedures, and interpret solutions meaningfully (Rosa & Orey, 2015). Thus, ML is a crucial competency expected to be mastered across all education levels.

However, empirical evidence consistently shows that students' ML levels remain low. Previous studies (Nisa & Arliani, 2023; Sari & Wijaya, 2017; Wulandari & Jailani, 2018) report that many students struggle to connect mathematical ideas with real-life contexts, particularly in understanding word problems and translating them into mathematical representations (Holis et al., 2016). One contributing factor is that mathematics instruction often lacks contextual integration (Rusdi et al., 2020), resulting in students being less accustomed to reasoning based on everyday situations. These findings indicate the need for instructional approaches that promote contextualized learning processes while fostering student autonomy.

Alongside ML, self-directed learning (SDL) is increasingly emphasized as a core 21st-century competence (P21, 2019). The Merdeka Curriculum also highlights the importance of independence as part of the Pancasila Student Profile (Satria et al., 2022). Nevertheless, evidence suggests that SDL among Indonesian students is still at a low-to-moderate level (Ahmad et al., 2019; Paramita & Subroto, 2021; Rasmawan & Erlina, 2021). Data from the Indonesian Education Report Card further indicate a decline in student independence from 2023 to 2024 (Kemendikdasmen, 2023). Several factors such as teacher-centered instructional practices, limited learning media, classroom conditions, and students' readiness contribute to low SDL (Sidmewa et al., 2021; Vaičiūnienė & Kazlauskienė, 2023). These findings suggest the need for learning environments that encourage autonomy, exploration, and self-regulation.

One instructional approach that has shown potential for enhancing both ML and SDL is Realistic Mathematics Education (RME). Rooted in Freudenthal (1972) view that mathematics should be experienced as a human activity, RME emphasizes learning through meaningful contexts. Its key characteristics contextual problems, model development, guided reinvention, progressive mathematization, and interactivity (Heuvel-Panhuizen & Drijvers, 2020; Tong et al., 2022) provide opportunities for students to construct their own mathematical ideas. This process may not only support ML but also encourage learners to take ownership of the learning process, thereby supporting SDL.

With increasing access to technology, learning can be further strengthened through digital tools such as GeoGebra. GeoGebra enables dynamic visualization, exploration, and manipulation of mathematical objects, which can deepen students' understanding of mathematical relations (Alves, 2019). Integrating GeoGebra within the RME framework is expected to create richer learning experiences where students interact with realistic contexts while engaging in exploratory and self-regulated learning processes. Previous studies have found that RME positively influences various mathematical competencies including critical thinking (Fadilah & Hakim, 2022), concept understanding (Septianisha et al., 2023), communication (Hayati & Kamid, 2019), and ML (Fauzana et al., 2020). Meanwhile, other studies have shown that RME may improve learning independence (Maslihah et al., 2021). However, these studies typically examine variables in isolation.

Existing literature presents two main gaps. First, the theoretical gap, prior studies have examined RME's effects on ML and SDL separately but have not systematically analyzed how technology-enhanced RME may jointly support both competencies. Limited research integrates RME, GeoGebra, ML, and SDL into a unified theoretical and analytical model, particularly in the Indonesian educational context. Second, the empirical gap, studies combining RME with GeoGebra have largely focused on conceptual understanding or problem-solving but rarely on ML and SDL simultaneously. There is also limited empirical comparison between GeoGebra-assisted RME and other student-centered approaches such as Problem-Based Learning (PBL), despite PBL's established effectiveness in promoting ML and SDL. As a result, it remains unclear whether integrating GeoGebra into RME yields superior effectiveness compared to PBL.

Given these gaps, examining the effectiveness of GeoGebra-assisted RME on ML and SDL both individually and in comparison with PBL is timely and important. Specifically, identifying whether RME provides added value beyond PBL can inform instructional decision-making, particularly for teachers seeking methods that foster both contextual reasoning and student autonomy. In addition, few studies explicitly describe the analytical processes used to evaluate the combined outcomes of ML and SDL. This study addresses this limitation by employing multivariate analyses to examine differences in learning effectiveness comprehensively. Such an approach enables a more robust interpretation of how instructional methods influence multiple learning outcomes simultaneously. Therefore, this study aims to 1) describe the effectiveness of implementing RME assisted by GeoGebra in terms of students' mathematical literacy and self-directed learning; 2) describe the effectiveness of implementing PBL in terms of students' mathematical literacy and self-directed learning; and 3) describe the differences in effectiveness between GeoGebra-assisted RME and PBL in terms of mathematical literacy and self-directed learning.

METHOD

Experimental research using nonequivalent control design. The research design can be seen in Table 1.

Table 1. Research Design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X	O_3
Control	O_2	Y	O_4

Description:

O_1 : Pretest of ML and SDL ability of experimental class treated with RME assisted by GeoGebra

O_2 : Pretest of ML and SDL of control class treated with Problem Based Learning (PBL)

O_3 : Posttest of ML and SDL ability of experimental class treated with RME assisted by GeoGebra

O_4 : Posttest of ML and SDL of control class treated with Problem Based Learning (PBL)

X : Learning with RME assisted by GeoGebra

Y : Learning with Problem Based Learning (PBL)

This study was conducted during the odd semester of the 2024/2025 academic year at a junior high school in Yogyakarta, specifically involving eighth-grade students. Four classes were considered, with two selected as samples through convenience sampling, each comprising 32 students. The research was implemented across three main phases: (1) the preliminary phase, which involved administering a pretest and a baseline self-directed learning questionnaire; (2) the implementation phase; and (3) the final phase, which included the posttest and the follow-up questionnaire. The entire study spanned seven instructional sessions. In the initial session, students completed a pretest to evaluate their baseline mathematical literacy, along with a preliminary questionnaire to measure self-directed learning, prior to engaging in instruction using GeoGebra-assisted RME. In the second session, students explored the concept of linear equations in two variables and how to formulate corresponding mathematical models. The third session focused on finding solutions to these equations using the substitution method. In the fourth session, students learned to solve the system using the elimination method. The fifth session introduced the mixed method as a strategy for solving such equations. Finally, the last session involved administering a posttest to evaluate students' mathematical literacy and SDL after the implementation of the learning intervention.

Mathematical literacy data for this study were gathered through the administration of both pretest and posttests. These tests were given in the form of descriptions to evaluate students' ability to create mathematical models based on problems (formulate), solve problems in various contexts using mathematical concepts (employ), and provide arguments based on the interpretations made (interpret). In addition, data was collected through a pre-sketch and post-sketch of self-directed learning. The questionnaire included 16 items designed to assess various aspects of students' learning, including their readiness, goals, engagement in the learning process, and self-evaluation. Content validity was established through expert review to confirm alignment with the research objectives. Additionally, the reliability coefficients for the mathematical literacy pretest and posttest were found to be 0.689 and 0.711, respectively. Meanwhile, the estimation of the self-directed learning questionnaire is 0.758.

Data analysis consisted of descriptive and inferential techniques. Descriptive analysis includes calculations related to the mean, standard deviation, minimum value, and maximum value obtained by students. The completeness criteria for students' mathematical literacy skills, which is at least 70 according to the criteria minimum used by the school, while for students' SDL if the score reaches more than the minimum limit of the high category, which is 68. This is obtained from the quantitative to qualitative data conversion formula. The formula is taken from Widoyoko (2017) as follows.

Table 2. Quantiative to Qualitative Data Conversion Formula

Interval	Category
$X > \overline{X}_i + 1.8Sb_i$	Very High
$\overline{X}_i + 0.6Sb_i < X \leq \overline{X}_i + 1.8Sb_i$	High
$\overline{X}_i - 0.6Sb_i < X \leq \overline{X}_i + 0.6Sb_i$	Medium
$\overline{X}_i - 1.8Sb_i < X \leq \overline{X}_i - 0.6Sb_i$	Low
$X \leq \overline{X}_i - 1.8Sb_i$	Very Low

Description:

$\overline{X}_i$ (ideal mean) = $\frac{1}{2}$ (ideal maximum score + ideal minimum score)

Sb_i (ideal standard deviation) = $\frac{1}{6}$ (ideal maximum score – ideal minimum score)

$X =$ empirical score

In the inferential analysis, the hypothesis was tested using the Hotelling T^2 test, one sample t-test, and post hoc test (Two Independent Sample t-test). All descriptive and inferential statistical analyses were performed using R software.

RESULTS AND DISCUSSION

Analysis of the results involved the application of both descriptive and inferential approaches. Descriptive analysis showed significant improvement in RME learning class assisted by GeoGebra and PBL learning class.

Table 3. Description of Mathematical Literacy Test Results

Description	GeoGebra-assisted RME		PBL	
	Pretest	Posttest	Pretest	Posttest
Mean	28.12	74.03	33.34	73.41
Standard Deviation	11.92	10.97	11.32	10.55
Ideal Minimum Value	0	0	0	0
Ideal Maximum Ideal	100	100	100	100
Minimum Value	11	52	11	52
Maximum Value	56	95	56	90

Prior to the adoption of RME assisted by GeoGebra and PBL learning, Table 3 demonstrates that the mean pretest scores for students' mathematical literacy skills in both classrooms did not satisfy the minimal school criteria of 70. However, the mean posttest score in both classes increased. The experimental class increased to 74.03 and the control class increased to 73.41. This exceeds the minimum school criteria. Furthermore, the results of the descriptive data analysis of self-directed learning for both classes are presented in Table 4.

Table 4. Description of Self-Directed Learning Questionnaire Results

Description	**GeoGebra-assisted RME**		**PBL**	
	Pre-questionnaire	**Post-questionnaire**	**Pre-questionnaire**	**Post-questionnaire**
Mean	56.81	82.12	53.81	86.5
Standard Deviation	7.04	7.51	5.33	6.08
Ideal Minimum Value	16	16	16	16
Ideal Maximum Value	100	100	100	100
Minimum Value	40	69	44	76
Maximum Value	68	99	64	99

Table 4 shows that the mean pre-questionnaire score in both classes for students' self-directed learning did not meet the minimum criteria of 68 before the implementation of RME assisted by GeoGebra and PBL learning. However, mean of the post-questionnaire in both classes increased. The experimental class increased to 82.12 and the control class increased to 86.5. This exceeded the minimum criteria of the school. Before conducting hypothesis testing, all assumption tests including multivariate normality, univariate normality, covariance matrix homogeneity, and variance homogeneity were satisfied. These findings confirm that the dataset met the requirements for performing Hotelling’s T^2 and t-tests. Furthermore, the hypothesis test is as follows.

Learning Effectiveness Test

This test was conducted using one sample t-test with the help of R. The results of the learning effectiveness test are in Table 5 below.

Table 5. Learning Effectiveness Test Results

Group	**Variables**	**t**	$\mathbf{t_{\alpha(n-1)}}$	**p-value**	**Decision**
Experiment	Mathematical Literacy	2.0844	1.6973	0.02273	H_0 is rejected
	Self-Directed Learning	10.642	1.6973	3.549e-12	H_0 is rejected
Control	Mathematical Literacy	1.8325	1.6973	0.03825	H_0 is rejected
	Self-Directed Learning	17.212	1.6973	2.2e-16	H_0 is rejected

Referring to Table 5, the following findings can be summarized:

1. According to the decision-making rule, if the p-value is less than 0.05, the null hypothesis (H_0) is rejected. Table 10 shows a p-value of 0.02273, which is below the 0.05 threshold. Therefore, at a 5% significance level, it can be concluded that the mathematical literacy of students in the experimental group taught through GeoGebra-assisted RME exceeds 69.99, indicating the effectiveness of this learning approach in improving students' mathematical literacy.
2. Similarly, with a p-value of 3.549e-12, which is also below 0.05, the null hypothesis is rejected. This suggests that students in the experimental group achieved self-directed learning scores higher than 68, implying that GeoGebra-assisted RME is effective in enhancing students' self-directed learning.
3. For the control group receiving PBL instruction, a p-value of 0.03825 was obtained, which is less than 0.05. This indicates that students' mathematical literacy scores exceeded 69.99, confirming the effectiveness of PBL in supporting mathematical literacy development.
4. Lastly, the p-value of 2.2e-16 for self-directed learning in the PBL group is also below 0.05, leading to the conclusion that students' scores surpassed 68. Hence, PBL is also effective in promoting self-directed learning.

Test of Difference in Learning Effectiveness

This test was conducted with the Hotelling T^2 test using the posttest data of mathematical literacy skills and post-questionnaire of students' self-directed learning after being given treatment in both classes. The results are as follows.

Table 6. Test of Difference in Final Ability

Test Result	**Critical Value**	**Hotelling T^2**	**p-value**	**Decision**
After Treatment	6.392	6.749	0.03423	H_0 is rejected

According to the decision-making criteria, when the p-value is less than 0.05 considering multiple dependent variables, the null hypothesis (H_0) is rejected. As shown in Table 6, the p-value of 0.034 falls below the 0.05 threshold, leading to the rejection of H_0. This indicates a significant difference in the effectiveness of learning between GeoGebra-assisted RME and PBL with respect to students' mathematical literacy and self-directed learning. Given the presence of this difference, a post hoc analysis is required to determine which variables contribute most to the observed effect.

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Pos Hoc Test

This test was conducted using the Two Independent Sample t-test presented in Table 7.

Table 7. Results of Two Independendet Sample t-test

Test	Variables	t-test	p-value
Two Independent Sample t-test	Mathematical Literacy	0.23237	0.817
	Self-Directed Learning	-2.5617	0.01286

Referring to Table 7, it is observed that for the mathematical literacy variable, the comparison between the GeoGebra-assisted RME class and the PBL class yields a p-value of 0.817, which is greater than 0.05. This means that the null hypothesis is not rejected. Therefore, at a 5% significance level, it can be concluded that GeoGebra-assisted RME does not show superiority over PBL in terms of students' mathematical literacy. In contrast, for the self-directed learning variable, the p-value obtained from the same comparison is 0.01286, which is below the 0.05 threshold. Thus, the null hypothesis is rejected. This indicates that, at the 0.05 level of significance, GeoGebra-assisted RME is significantly more effective than PBL in enhancing students' self-directed learning.

The one-sample t-test confirmed that both instructional models effectively improved ML and SDL, indicated by p-values below 0.05. These findings reinforce earlier studies reporting that RME and PBL promote active involvement, conceptual understanding, and metacognitive development (Hmelo-Silver, 2004; Putri & Zulkardi, 2018). A comparison between GeoGebra-assisted RME and PBL using Hotelling's T^2 revealed a significant multivariate difference. The Two Independent Sample t-test results showed no significant difference in ML between the two groups. This suggests that both learning approaches were equally effective in enhancing mathematical literacy. This finding is consistent with research indicating that contextual problem-solving whether structured through RME or PBL supports students' abilities to formulate, apply, and interpret mathematical ideas (Fauzan et al., 2013; OECD, 2019). Both models emphasize authentic contexts and reasoning processes, which are essential dimensions of mathematical literacy according to PISA frameworks.

In contrast, a significant difference was found in SDL, with students taught using GeoGebra-assisted RME outperforming those taught with PBL. This highlights the potential of technology integration to strengthen students' autonomous learning abilities. Previous studies have similarly shown that digital tools such as GeoGebra enhance learner autonomy by enabling exploration, hypothesis testing, and self-paced inquiry (Rashid & Asghar, 2016). Furthermore, the reinvention principle in RME provides opportunities for students to build conceptual understanding through guided discovery an approach that aligns well with the personal initiative and self-regulation components of SDL. This synergy between RME and technological tools explains why GeoGebra-assisted RME leads to higher SDL compared to PBL.

Although GeoGebra-assisted RME demonstrated greater effectiveness in developing SDL, the absence of significant superiority in ML suggests that other instructional factors may also influence students' mathematical literacy. ML consists of more complex cognitive processes such as reasoning, argumentation, and interpretation that may benefit from explicit scaffolding. PBL, which emphasizes collaborative problem-solving and reflective dialogue, has been shown to enhance higher-order thinking and communication skills (Dolmans & Loyens, 2016). Thus, PBL may complement the exploratory features of GeoGebra-assisted RME, resulting in similar ML outcomes between the groups.

Several practical implications emerge from these findings. First, integrating GeoGebra into RME-based instruction can effectively increase learner autonomy, which aligns with previous findings showing that technology-supported learning environments promote students' initiative, independence, and responsibility in directing their own learning key components of Self-Directed Learning (SDL). Second, both RME and PBL can be used to strengthen mathematical literacy, as both approaches promote contextual reasoning and conceptual understanding. Teachers can therefore choose either method based on classroom needs, teacher expertise, and resource availability. Third, improving ML may require combining technological exploration with structured reflective activities, consistent with recommendations from earlier studies on effective ML instruction (Stacey & Turner, 2015). Finally, these findings underscore the importance of balancing technology-based exploration with social interaction and reflective reasoning to support comprehensive ML development.

Overall, the results indicate that while both GeoGebra-assisted RME and PBL effectively enhance ML and SDL, the integration of digital exploration tools within RME provides a distinct advantage for building students' self-directed learning. This conclusion aligns with previous research emphasizing the value of combining realistic contexts, interactive technology, and collaborative reasoning in achieving meaningful and sustained improvements in mathematical competencies (Heuvel-Panhuizen & Drijvers, 2020).

CONCLUSION

This study concludes that both instructional models GeoGebra-assisted Realistic Mathematics Education (RME) and Problem-Based Learning (PBL) are effective in improving students' mathematical literacy and self-directed learning. First, GeoGebra-assisted RME was proven effective in enabling students to surpass the minimum competency standards for both outcomes. Second, PBL also showed effectiveness, demonstrating significant improvements in mathematical literacy and self-directed learning.

Regarding differences in effectiveness, no significant difference was found between the two models in terms of mathematical literacy, indicating that both approaches provide comparable opportunities for developing students' ability to formulate, apply, and interpret mathematical ideas. However, a significant difference was observed in self-directed learning, with GeoGebra-assisted RME outperforming PBL. This suggests that integrating digital tools into RME enhances students' independence and initiative in learning. Future research may further explore student characteristics, implementation factors, and hybrid learning designs that combine the strengths of RME, PBL, and technology-based exploration.

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