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OPTIMIZING MATHEMATICAL PROBLEM SOLVING ABILITY THROUGH DEEP LEARNING INTEGRATION ORIENTED TOWARDS SELF-REGULATED LEARNING

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ABSTRACT

Mathematical problem-solving ability is an essential competency in mathematics learning; however, research conducted during 2022–2025 consistently indicates that junior high school students' problem-solving ability remains in the low category. Students tend to apply formulas without understanding the problem context and rarely verify their solutions. This study aims to examine: (1) whether there is a significant difference in mathematical problem-solving ability between students taught using the Deep Learning approach and those taught using a conventional approach; and (2) whether the improvement in mathematical problem-solving ability of students using the Deep Learning approach is better than that of students using the conventional approach. This study employed a quantitative method with a quasi-experimental design (Nonequivalent Pretest-Posttest Control Group Design), involving 61 eighth-grade students at SMP Negeri 1 Jatiwangi: 31 students in the experimental class (VIII-E) and 30 students in the control class (VIII-H). Data were collected through essay tests based on Polya's problem-solving indicators and analyzed using independent samples t-test and Welch's T' test via IBM SPSS Statistics 26.0. The results show that: (1) there is a significant difference in posttest scores between the two classes (sig./2 = 0.0115 < 0.05), with the experimental class mean (56.42) higher than the control class (51.33); and (2) the improvement of the experimental class (N-Gain = 0.3013; moderate category) is significantly better than the control class (N-Gain = 0.1920; low category), based on Welch's T' test (sig./2 = 0.0015 < 0.05). These findings confirm that the Deep Learning effectively enhances students' mathematical problem-solving ability.

Keywords: deep learning approach; mathematical problem-solving ability; n- gain; problem based learning; quasi-experimental.

ABSTRAK

Kemampuan pemecahan masalah matematika merupakan kompetensi penting dalam pembelajaran matematika; namun, penelitian yang dilakukan selama tahun 2022–2025 secara konsisten menunjukkan bahwa kemampuan pemecahan masalah siswa SMP masih berada pada kategori rendah. Siswa cenderung menerapkan rumus tanpa memahami konteks masalah dan jarang memverifikasi solusi mereka. Penelitian ini bertujuan untuk menguji: (1) apakah terdapat perbedaan signifikan dalam kemampuan pemecahan masalah matematika antara siswa yang diajar menggunakan pendekatan Deep Learning dan siswa yang diajar menggunakan pendekatan konvensional; dan (2) apakah peningkatan kemampuan pemecahan masalah matematika siswa yang menggunakan pendekatan Deep Learning lebih baik daripada siswa yang menggunakan pendekatan konvensional. Penelitian ini menggunakan metode kuantitatif dengan desain kuasi-eksperimental (Desain Kelompok Kontrol Non-ekuivalen Pretest-Posttest), yang melibatkan 61 siswa kelas delapan di SMP Negeri 1 Jatiwangi: 31 siswa di kelas eksperimen (VIII-E) dan 30 siswa di kelas kontrol (VIII-H). Data dikumpulkan melalui tes esai berdasarkan indikator pemecahan masalah Polya dan dianalisis menggunakan uji t sampel independen dan uji T Welch melalui IBM SPSS Statistics 26.0. Hasil menunjukkan bahwa: (1) terdapat perbedaan signifikan pada skor posttest antara kedua kelas (sig./2

= 0,0115 < 0,05), dengan rata-rata kelas eksperimen (56,42) lebih tinggi daripada kelas kontrol (51,33); dan (2) peningkatan kelas eksperimen (N-Gain = 0,3013; kategori sedang) secara signifikan lebih baik daripada kelas kontrol (N-Gain = 0,1920; kategori rendah), berdasarkan uji T Welch (sig./2 = 0,0015 < 0,05). Temuan ini menegaskan bahwa Deep Learning secara efektif meningkatkan kemampuan pemecahan masalah matematika siswa.

Kata kunci*: kemampuan pemecahan masalah matematis; n-gain; pendekatan deep learning; problem based learning; quasi-eksperimental.*

Introduction

This study examines the effectiveness of the Deep Learning approach in a pedagogical context, rather than artificial intelligence focused on Self-Regulated Learning (SRL) plays a significant role in enhancing the mathematical problem-solving abilities of junior high school students. Through a quasi-experimental design involving 61 eighth-grade students, this study tests whether the integration of the three pillars of Deep Learning (mindful, meaningful, and joyful learning) with the three phases of SRL (forethought, performance, and self-reflection) can improve problem-solving skills in a more structured and measurable way at each stage of Polya's model compared to conventional learning.

Mathematical problem-solving skills are an essential competency that continues to be emphasized in national education policies and international standards. PISA 2022 data ranks Indonesia 70th out of 81 countries in mathematics proficiency (average score of 366 vs. the OECD average of 472), while the 2023 ANBC results reveal that more than 60% of junior high school students have not yet achieved the minimum numeracy proficiency (OECD, 2023; Ministry of Education, Culture, Research, and Technology, 2023). Various local studies from 2022 to 2025 consistently show that junior high school students tend to apply formulas procedurally without understanding the problem context, struggle with non-routine problems, and rarely verify their solutions (Aulia & Hidayati, 2023; Hafizah et al., 2025; Manjaniawati et al., 2024; Ramlah et al., 2024; Sriwahyuni & Maryati, 2022). This situation is exacerbated by the dominance of conventional, teacher-centered learning, in which students merely receive content without developing the thinking skills needed to apply knowledge to new situations (Prihandhika et al., 2022). In this study, it was found that students who have visual, auditory and kinesthetic learning styles have different ways of solving problems (Ningrum et al., 2025). Based on the results of the problem-solving ability to complete statistical questions, students who have high and medium problem-solving abilities (Vahlia et al., 2022).

The ability to solve mathematical problems is fundamentally based on Polya's (1973) four traditional phases: grasping the problem, devising a strategy, carrying out the strategy, and verifying the outcomes. Santos-Trigo (2024) emphasizes that current research no longer focuses solely on the final answer, but rather on how students formulate, represent, explore, and communicate the problem-solving process. Mathematics learning should not only be oriented toward improving student learning outcomes, but also toward improving problem-solving skills (Komariya et al., 2018). Schoenfeld (1985) adds a metacognitive dimension as a determining factor of success, while the NCTM (2000) underscores that problem-solving is the primary vehicle for meaningful mathematics learning thus its development requires an approach that fosters deep conceptual understanding, not merely procedural mastery.

The Deep Learning approach in a pedagogical context refers to a process that enables students to deeply understand the meaning of the material, connect new knowledge with prior experiences, and use it to solve real-world problems (Marton & Saljo, 1976; Fullan et al., 2014), grounded in three pillars: mindful learning, meaningful learning, and joyful learning. Self-Regulated Learning (SRL) is defined as the ability to actively participate in learning through metacognitive, motivational, and behavioral processes (Zimmerman, 1990), across three phases: forethought, performance, and self-reflection. The integration of these two creates pedagogical synergy: mindful learning supports the forethought phase (understanding and planning), meaningful learning strengthens the performance phase (implementing contextual strategies), and joyful learning drives the self-reflection phase (examining and evaluating solutions). SRL contributes 40.1% to problem-solving ability with a correlation coefficient of 0.634 (Alyani & Ramadhina Ramadhina, 2022).

Numerous pertinent studies support this research. Showed that pedagogical Deep Learning has a beneficial effect on problem-solving abilities and motivation to learn (Bambang et al., 2025;Trisnawati & Wijayanto 2025) confirmed the effectiveness of the Flipped Classroom when integrated with Deep Learning; Salsabila & Asih (2024) demonstrated through a meta-analysis that PBL has a significant effect on problem-solving skills; and Ley Leana & Khofial Luthfi (2024) and Pratiwi et al. (2025) confirmed the significant role of SRL in managing the mathematical problem-solving process.

Although these studies provide a strong foundation, a significant gap remains: no study has explicitly integrated pedagogical Deep Learning with SRL as a unified framework for junior high school students, nor has it systematically tested its impact on each of Polya's indicators (Santiani, 2025; Girsang & Rahayu, 2025). This study aims to address this gap.

The novelty of this study lies in the explicit mapping of the integration of Deep Learning–SRL to each of Polya's indicators: mindful learning–forethought supports understanding the problem and formulating a plan; meaningful learning–performance supports executing the plan; and joyful learning–self-reflection supports reviewing the process. Based on this background, this study aims to: (1) test whether there is a significant difference in mathematical problem-solving ability between students using the SRL-based Deep Learning approach and those using the conventional approach; and (2) test whether the improvement in mathematical problem-solving ability among students using the SRL-based Deep Learning approach is greater than that of the conventional approach.

Based on the above discussion, the hypotheses of this study are as follows: (1) there is a difference in the mean mathematical problem-solving ability between students taught using the Integrated Deep Learning and Self-Regulated Learning approach and students taught using the conventional approach; and (2) the improvement in mathematical problem-solving ability among students taught using the Integrated Deep Learning and Self-Regulated Learning approach is greater than that of students taught using the conventional approach.

Research Methods

This study adopts a quantitative approach with a quasi-experimental design, namely the Nonequivalent Pretest–Posttest Control Group Design (Creswell, 2023), which is suitable for educational settings where random assignment is impractical while still enabling the control of internal validity threats, such as history and maturation effects, through the use of a control group and pretest measures. The design framework is presented in Table 1.

Table 1. Nonequivalent Pretest-Posttest Control Group Design

Class	**Pretest**	**Treatment**	**Posttest**
Eksperiment (A)	O_1	X_1	O_2
Control (B)	O_3	X_2	O_4

Explanation :
O_1 : Pretest (before treatment) in the experimental group
O_2 : Posttest (after treatment) in the experimental group
O_3 : Pretest (before treatment) in the control group
O_4 : Posttest (after treatment) in the control group
X_1 : Implementation of Deep Learning Approach Based on Self-Regulated Learning
X_2 : Implementation of Teacher-Centered Learning Approach

The study was conducted at SMP Negeri 1 Jatiwangi, Majalengka Regency, during the second semester of the 2025/2026 academic year. The research subjects were 61 eighth-grade students, consisting of Class VIII-E as the experimental class (n = 31) and Class VIII-H as the control class (n = 30). The sample was selected using purposive sampling based on the equivalence of mathematics report card scores from the odd semester, homogeneity in class size, and the school's readiness. Confirmation of equivalence in initial ability was conducted via a t-test on pretest data, which indicated no significant difference in the initial ability of the two classes before the intervention was administered.

The study was conducted over six sessions (each 2 × 40 minutes): one session for the pretest, four treatment sessions, and one session for the posttest. The pretest and posttest were administered during regular class hours in their respective classrooms, with a duration of 80 minutes, in a closed room, and under the supervision of the researcher and the teacher. The pretest and posttest questions used identical instruments to ensure a fair comparison.

The control class (VIII-H) received instruction using the Teacher-Centered Learning (TCL) approach, or teacher-centered direct instruction. This approach was chosen as the comparison condition because it represented the mathematics teaching practices commonly implemented at SMP Negeri 1 Jatiwangi prior to the research intervention. The control class's instructional design differed structurally from that of the experimental class in three main aspects: the teacher's role, the students' role, and the learning mechanisms.

The instructional practices implemented in the experimental and control groups differed substantially. In the experimental group, learning was conducted through a problem-based constructivist approach in which the teacher served as a facilitator, while students actively engaged in solving problems and managing their own learning. In contrast, the control group received instruction through a transmissive approach, where the teacher functioned as the primary source of knowledge and students assumed a more passive role in receiving information. This difference lies not in the content of the SPLDV material which is the same for both but in the process, the depth of cognitive engagement, and the presence or absence of self-regulation mechanisms facilitated during learning.

Control of external variables was achieved through several strategies. First, the researcher personally taught both classes to minimize differences in teaching style. Second, the curriculum, time allocation, and number of practice questions were standardized across both classes. Third, the class schedules for the two classes were designed to avoid overlap to prevent cross-class contamination. Fourth, during the study, there were no special school events (national exams, sports week, or long holidays) that could potentially disrupt the learning process unevenly. The flowchart of the study is presented in Figure 1.

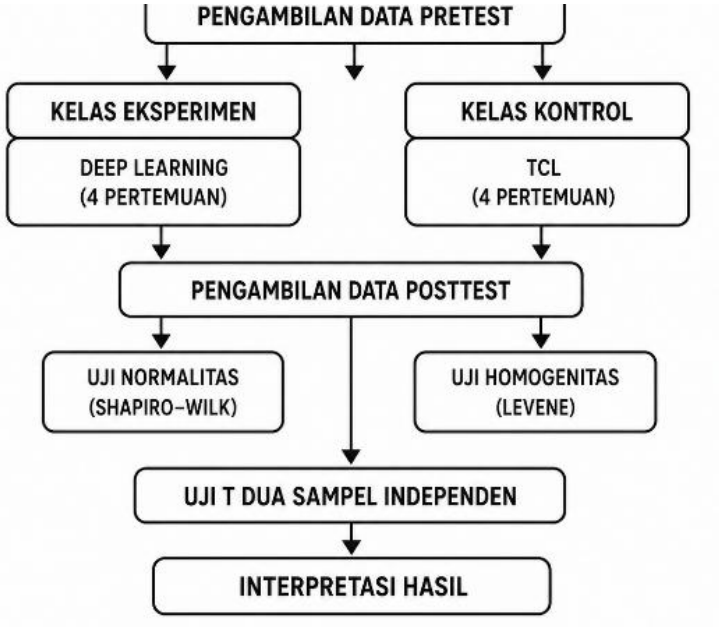


Figure 1. Research Flowchart

The instrument used in this study was a mathematical problem-solving test comprising essay questions related to the System of Linear Equations in Two Variables (SPLDV). The instrument was developed through a systematic procedure comprising three main stages: development, validation, and empirical testing.

Development Stage. The instrument was developed based on Polya's (1973) four indicators: understanding the problem, formulating a plan, executing the plan, and reviewing the solution. Initially, four contextual essay items on SPLDV were developed using a rubric that included core competencies, Bloom's cognitive levels, and score allocation, to enable selection based on empirical quality.

Validation Stage. Two mathematics education specialists reviewed and validated the instrument. from Singaperbangsa Karawang University, covering content, construct, and linguistic validity (Likert scale 1–4). Based on the validators' feedback, editorial revisions were made to the questions and scoring rubric to ensure the score descriptors were more operational and consistent.

Scoring uses an item-by-item analytical rubric with a maximum score of 12 per item (maximum total score = 24 for the two selected items), with the following breakdown: (1) understanding the problem score 0–2 (0 = did not identify any information; 0<x<2 = partial information; 2 = all information identified); (2) planning the solution score 0–3 (0 = no mathematical model; 0<x<2 = correct variables but incomplete model; 1<x<3 = 1–2 correct equations; 3 = all equations correct and complete); (3) implementing the plan score 0–4 (0 = no calculations; 0<x<2 = incorrect method; 1<x<3 = correct method but incorrect result; 2<x<4 = one variable value correct; 4 = the entire solution is systematic and correct); (4) checking score 0–3 (0 = no verification; 0<x<2 = calculation errors or incorrect conclusions; 1<x<3 = verification is correct but conclusions are incomplete; 3 = verification of the original equations is correct and conclusions are complete). The student's final score is obtained by converting the total score to a 0–100 scale. This rubric was validated by two mathematics education experts before use.

Before use, the instrument was pilot-tested on 30 ninth-grade students in Class IX-D at SMPN 1 Jatiwangi who had studied SPLDV in the previous grade level. The pilot test results showed that all test items met the validity criteria, as presented in Table 2.

Table 2. Summary of Instrument Quality Analysis Results

Item	Validity (r)	Reliability(α)	Difficulty Index (IK)	Discriminant Power (DP)
Soal 1	0,747 (Tinggi/Baik)	0,779 (Tinggi/Baik)	0,533 (Sedang)	0,450 (Baik)
Soal 2	0,837 (Tinggi/Baik)		0,527 (Sedang)	0,669 (Baik)
Soal 3	0,826 (Tinggi/Baik)		0,541 (Sedang)	0,699 (Baik)
Soal 4	0,780 (Tinggi/Baik)		0,642 (Sedang)	0,664 (Baik)

Based on the results of the instrument pilot test in Table 2, it was found that all items in the test of students' mathematical problem-solving skills were valid, had good reliability, and demonstrated good discriminative power. In addition, all items fell into the moderate difficulty category. Based on the results of the pilot test of the 4 test items that met the criteria for validity, reliability, discriminative power, and difficulty level, 2 test items were selected for use in the study, namely item number 1 and item number 3.

Data analysis was performed using inferential statistics via IBM SPSS Statistics 26.0, following a step-by-step procedure as described below. First, prerequisite tests were conducted prior to hypothesis testing, including: (a) the Shapiro-Wilk normality test at the α level of 0.05 (selected because n < 50 per class, which is more sensitive than the Kolmogorov-Smirnov test for small samples); and (b) Variance homogeneity was assessed through Levene's test at the 0.05 significance level. The results of the assumption tests then guided the choice of inferential analysis. Data that fulfilled the assumptions of normality and equal variances were analyzed using the Independent Samples t-test. When normality was satisfied but homogeneity of variance was violated, Welch's t-test was applied. In cases where the normality assumption was not fulfilled, the Mann–Whitney U test was selected for statistical analysis.

Three sets of data were analyzed: (1) pretest score to test the equivalence of initial ability; (2) posttest scores to test the first hypothesis regarding differences in final ability between classes; (3) normalized N-Gain scores to test the second hypothesis regarding differences in ability improvement between classes. The selection of statistical tests was based on the characteristics of the data distribution obtained from the prerequisite tests. The Independent Samples t-test was applied when the data satisfied both the normality and homogeneity of variance assumptions because this test is the most appropriate and efficient parametric procedure for comparing two independent groups under those conditions (Creswell, 2023). Conversely, When the data were normally distributed but exhibited unequal variances across groups, Welch's t-test was selected. As an adaptation of the conventional t-test, it is less sensitive to violations of the homogeneity of variance assumption and provides more valid results in the presence of heteroscedasticity (Creswell, 2023).

This study complied with applicable ethical procedures. Before the research was carried out, permission was obtained from the Principal of SMP Negeri 1 Jatiwangi to conduct the study. The eighth-grade mathematics teacher was involved in the planning and supervision of the study. Parents and guardians were informed about the study's objectives and the students' participation. All students participated voluntarily without coercion, and student identities were kept confidential in the reporting of results. The data collected was used solely for scientific purposes and did not interfere with the students' regular learning process.

Results and Discussion

This study was conducted at SMP Negeri 1 Jatiwangi during the second semester of the 2025/2026 academic year, involving two eighth-grade classes. Grade 8-E, as the experimental class (n = 31), received instruction using a Deep Learning approach integrated with Self-Regulated Learning (SRL) through the Problem-Based Learning (PBL) framework, while Grade 8-H, as the control class (n = 30), received conventional instruction based on Teacher-Centered Learning. Both classes studied the topic of Systems of Linear Equations with Two Variables (SPLDV) over four sessions with equal time allocation. Data were collected through pretests and posttests using essay questions based on Polya's problem-solving indicators and analyzed using IBM SPSS Statistics 26.0.

The experimental class learning was implemented through five PBL stages that integrated the Deep Learning pillars and SRL phases: (1) Problem Orientation (mindful learning—forethought): identification of variables and context of SPLDV problems; (2) Group Organization (forethought—performance): heterogeneous discussions to agree on strategies; (3) Independent/Group Investigation (meaningful learning performance): construction of contextual mathematical models; (4) Presentation of Results (joyful learning—performance): presentation and comparison of solutions between classes; and (5) Analysis and Evaluation (joyful learning self-reflection): verification of answers and writing of learning reflections. The control class received Teacher-Centered Learning without a structured SRL mechanism.

The study findings suggest that integrating Deep Learning with Self-Regulated Learning (SRL) produces a stronger positive effect on students' mathematical problem-solving performance than conventional teaching methods. Students in the experimental group obtained a higher average posttest score (56.42) than those in the control group (51.33), and the independent samples t-test demonstrated that this difference was statistically significant ($p = 0.023 < 0.05$). From an educational perspective, this 5.09-point difference—though numerically small reflects a meaningful distinction in students' ability to move beyond the procedural application of formulas toward an understanding of the actual problem context, structured planning, and solution verification.

The experimental group obtained an average N-Gain score of 0.3013, which falls within the moderate category, whereas the control group achieved an average N-Gain of 0.1920, categorized as low. The results of Welch's t-test confirmed that the difference in improvement between the two groups was statistically significant (sig./2 = $0.0015 < 0.05$). From an educational perspective, these findings suggest that students in the experimental group experienced a normalized learning gain approximately 57% higher than those in the control group, reflecting a meaningful difference in the depth and quality of learning attained. Students in the experimental class progressed from superficial procedural responses toward more reflective, structured, and metacognitively aware problem-solving. It is worth noting that neither class reached the high N-Gain threshold (>0.70), indicating that while this integrated approach is effective, there is still room for further optimization for example, by increasing the frequency of structured SRL sessions or integrating digital scaffolding tools. These findings reinforce the study's main argument: pedagogically integrating Deep Learning with SRL, operationalized through the PBL framework, creates learning conditions that systematically support each stage of Polya's problem-solving framework.

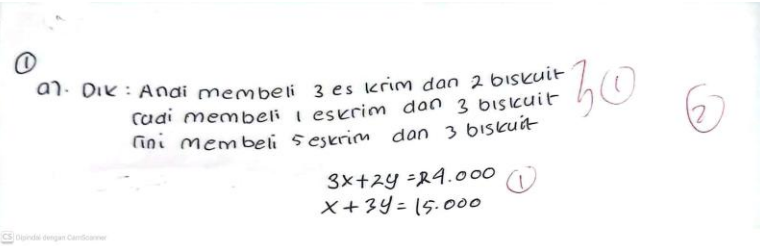
From a constructivist perspective, these findings align with Vygotsky's (1978) Zone of Proximal Development: a PBL-based Deep Learning environment provides scaffolding that guides students from procedural tasks toward more complex problem-solving. Ausubel's (1968) theory of meaningful learning explains this improvement: linking SPLDV problems to real-world contexts allows for the assimilation of new knowledge into existing cognitive structures. Flavell's (1979) metacognitive theory explains the experimental class's advantage: the structured SRL phase provides explicit metacognitive triggers goal setting (forethought), strategy monitoring (performance), and evaluative reflection (self-reflection) that are absent in teacher-led learning. Santos-Trigo (2024) reinforces this by asserting that contemporary problem-solving research shifts the emphasis from final answers to the processes of formulation, representation, and communication. This study fills a gap by mapping mindful learning to forethought, meaningful learning to performance, and joyful learning to self-reflection resulting in a more structured theoretical integration compared to previous research. Documentation of learning activities reflecting the implementation of these three pillars of Deep Learning and the SRL phases is presented in Figure 2.

Figure 2. Documentation of Deep Learning Instructional Activities Based on Self-Regulated Learning

Documentation of the Deep Learning-based Self-Regulated Learning activities in the experimental class is presented in Figure 2. The figure shows group discussion activities and presentations of problem-solving results. In the left image, students are discussing how to solve the given problem, reflecting the performance phase as students actively exchange ideas, test strategies, and apply problem-solving procedures. In the right image, students present the results of their discussion with the teacher's guidance, which supports the self-reflection phase through evaluation and feedback on learning outcomes. These activities reflect active, collaborative, meaningful, and enjoyable learning in line with the three pillars of Deep Learning: mindful learning, meaningful learning, and joyful learning (Piscayanti et al., 2022; Raup et al., 2022).

The enhanced performance of the experimental group can be understood through the synergy between the three stages of Self-Regulated Learning and the three pillars of Deep Learning embedded in the Problem-Based Learning framework. In the forethought phase, which aligns with mindful learning, students set goals, identify variables, and formulate a plan before performing calculations supporting the first two of Polya's indicators: understanding the problem and formulating a plan. In the performance phase, which aligns with meaningful learning, students construct mathematical models from real-life contexts and monitor strategies independently, fulfilling Ausubel's (1968) principle of subsumption and supporting the indicator of executing a plan. Xie et al. (2024) confirm that SRL feedback during task execution enhances problem-solving performance through the reinforcement of metacognitive monitoring. In the self-reflection phase, aligned with joyful learning, students present solutions, receive feedback, and verify answers fostering metacognitive capacity to evaluate and revise strategies as conceptualized by Schoenfeld (1985). A positive collaborative atmosphere also reduces psychological barriers to acknowledging mistakes, which, according to Hallarte et al. (2024), is positively associated with self-regulation in mathematics learning. The PBL framework is thus not merely a mechanism for delivering content, but a structural medium that enables each pillar of Deep Learning and the SRL phase to be operationalized simultaneously across each measurable Polya indicator.

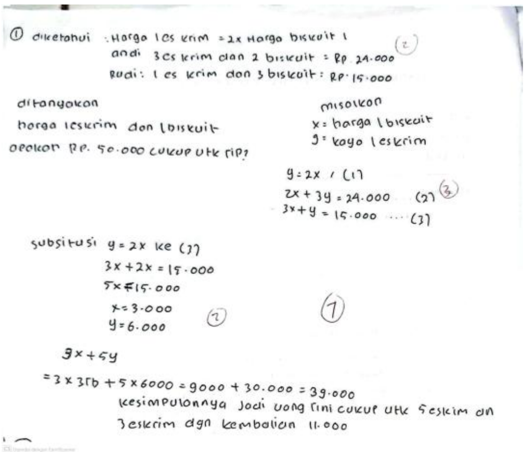
The improvement in the problem-solving skills of students in the experimental class can be observed qualitatively by comparing their answers on the pretest and posttest. Figures 2 and 3 below present examples of students' answers to SPLDV questions in the experimental class.



①
a). Dik : Andi membeli 3 es krim dan 2 biskuit
Rudi membeli 1 eskrim dan 3 biskuit
Tini membeli 5eskrim dan 3 biskuit
3 ①
②

$3x+2y=24.000$ ①
$x+3y=15.000$

Figure 3. Pretest Answers from Students in the Experimental Class



① diketahui : Harga 1es krim = 2x Harga biskuit 1
andi 3es krim dan 2 biskuit = Rp 24.000 ②
Rudi : 1 es krim dan 3 biskuit : RP·15.000

ditanyakan
harga 1eskrim dan 1biskuit
apakah RP. 50.000 cukup utk tini?

misalkan
x = harga 1biskuit
y = kaya 1eskrim

$y=2x$ ... (1)
$2x+3y=24.000$ ... (2) ③
$3x+y=15.000$ ... (3)

subsitusi $y=2x$ ke (3)
$3x+2x=15.000$
$5x=15.000$
$x=3.000$
$y=6.000$ ②
①

$3x+5y$
$=3\times 3rb+5\times 6000=9000+30.000=39.000$
kesimpulannya Jadi uang tini cukup utk 5eskim an 3eskrim dgn kembalian 11.000

Figure 4. Posttest Answers of Students in the Experimental Class

A comparison of the two figures shows a significant improvement in the students' problem-solving skills. In Figure 3 (pretest), students' answers only reached the stage of identifying known information (Given) and formulating a model of a two-variable linear equation, namely 3x + 2y = 24,000 and x + 3y = 15,000; however, they had not yet solved the system of equations and had not reached the verification stage. This condition reflects a weakness in the "executing the plan" stage (Polya, 1973), which is a common achievement level among students before receiving intervention. Conversely, in Figure 4 (posttest), students' answers demonstrate a much more complete and structured problem-solving process: students were able to identify all known information (including the price relationship 1 ice cream = 2x the price of a biscuit), assign variables appropriately, formulate three equations, apply the substitution method systematically to obtain x = 3,000 and y = 6,000, and then use these values to answer the question regarding whether Tini has enough money to buy 5 ice creams and 3 biscuits, resulting in a total of Rp39,000 and change of Rp11,000. This improvement aligns with the findings of Anita Anggriyani & Zulkarnaen (2023), which show that explicit scaffolding at each stage of Polya's model significantly improves the quality of students' answers on SPLDV material. Furthermore, Xie et al. (2024) assert that SRL-based feedback during the learning process encourages students not merely to execute procedures, but to monitor their strategies and verify their solutions a trend clearly reflected in these students' posttest responses. This qualitative progression from incomplete answers toward coherent, contextual, and verified solutions serves as concrete evidence of the effectiveness of integrating SRL-based Deep Learning in fostering deeper problem-solving skills.

A critical analysis of the low gain in the control group (N-Gain = 0.1920) reveals three main explanations. First, the Teacher-Centered Learning approach eliminates metacognitive triggers: the teacher demonstrates procedures, students copy the steps, and exercises are repetitive developing procedural fluency but not metacognitive regulation. Anita Anggriyani & Zulkarnaen (2023) document that students taught conventionally struggle with the “checking” and “planning” stages because these metacognitive capacities are never explicitly trained. Second, the absence of structured self-reflection mechanisms causes students to stop once a numerical answer is obtained, without verifying whether the solution is mathematically and contextually valid. Third, external variables such as intrinsic motivation and parental support which were not formally measured in this study potentially weaken the control group’s performance, and future research needs to integrate validated instruments to measure these covariates in order to isolate the effects of the learning approaches more precisely.

The results of this study have several implications for mathematics instruction in junior high school. First, teachers need to supplement direct instruction on SPLDV material with a PBL sequence that explicitly incorporates SRL triggers: goal-setting worksheets (forethought), monitoring checklists (performance), and self-assessment rubrics (self-reflection). Second, the arrangement of heterogeneous group discussions (4–5 students) should be a standard feature in junior high school algebra lessons. Third, not a single class achieved a high N-Gain category (>0.70), suggesting that the integration of technology-assisted feedback tools could accelerate progress further (Setiawan et al., 2024). The novelty of this study is threefold: (a) the first study to operationalize the integration of Deep Learning and SRL within the PBL framework in Indonesian junior high schools; (b) the direct mapping of each pillar of Deep Learning and phase of SRL to Polya’s indicators; and (c) double confirmation using two rigorous statistical tests addressing both achievement gaps and growth gaps simultaneously. Recognized limitations include the scope being limited to a single school and a single subject; the absence of an SRL questionnaire instrument; and the inability to fully control for external variables such as motivation and parental support. These limitations point to a clear agenda for future research, as outlined in the recommendations section.

Conclusion and Suggestion

Based on the findings obtained from the study on the topic of Systems of Linear Equations in Two Variables (SPLDV), it can be inferred that the Deep Learning approach integrated with Self-Regulated Learning positively influences students' mathematical problem-solving abilities. Evidence for this effect is reflected in the posttest results, which revealed a statistically significant difference between the experimental and control groups ($p = 0.023 < 0.05$). The experimental group achieved a higher mean posttest score (56.42) than the control group (51.33). Furthermore, the enhancement of mathematical problem-solving skills was greater among students in the experimental group. Analysis of the N-Gain scores using Welch’s T′ Test yielded a significance value of 0.0015, which is below the 0.05

threshold, indicating a significant difference in improvement between the two groups. The experimental group obtained an average N-Gain score of 0.3013, categorized as medium, whereas the control group achieved an average of 0.1920, categorized as low. These results suggest that combining the Deep Learning approach with Self-Regulated Learning supports students in comprehending problems, formulating solution strategies, implementing appropriate procedures, and evaluating their answers more effectively.

This study has several limitations. First, the research sample was limited to two classes in one school in Majalengka Regency, so generalizing the results needs to be done with caution. Second, the measurement of mathematical problem-solving ability was limited to the use of a written assessment, without using a Self-Regulated Learning questionnaire to explicitly measure students' level of self-regulation. Third, this study was only focused on the eighth-grade SPLDV material, so it cannot yet reflect the effectiveness of the approach on different materials or grade levels. Fourth, this study did not fully control for external variables such as intrinsic learning motivation and parental support, which could affect student learning outcomes.

A Deep Learning approach oriented towards Self-Regulated Learning is recommended as an alternative for learning mathematics at the junior high school level, especially for material that requires higher-order thinking skills. Further research is suggested to: (1) expand the scope of the material, grade levels, and sample size so that the results can be generalized more broadly; (2) use standardized Self-Regulated Learning questionnaire instruments so that students' self-regulation levels can be measured more explicitly and linked to problem-solving abilities; (3) combine the Deep Learning approach with digital technology to enhance student engagement and motivation; and (4) conduct further studies on the long-term effects of integrating Deep Learning and SRL on other mathematical abilities such as critical thinking and mathematical communication skills.

Reference

Alyani, F., & Ramadhina, A. L. (2022). The relation between self-regulated learning and mathematical problem-solving during Covid-19. *Journal of Educational Research and Evaluation, 6*(4), 645–652. https://doi.org/10.23887/jere.v6i4.47593

Anggriyani, A. & Zulkarnaen, R. (2023). Studi Kasus Kemampuan Pemecahan Masalah Matematis Materi Sistem Persamaan Linear Dua Variabel. Didactical Mathematics, 5(2), 494–501. https://doi.org/10.31949/dm.v5i2.6595

Aulia, Z., & Hidayati, N. (2023). Analisis Kemampuan Pemecahan Masalah Matematis dengan Materi Himpunan Pada Siswa SMP. *Jurnal Didactical Mathematics*, *5*(2), 580–590. https://ejournal.unma.ac.id/index.php/dm

Ausubel, D. P. (1968). *Educational psychology: A cognitive view.* Holt, Rinehart and Winston.

Bambang, M., Irmawati, Nurhikma, Pajria, P., & Amelia, R. (2025). Pendekatan Deep Learning Dalam Meningkatkan Kemampuan Pemecahan Masalah Dan Motivasi Belajar Siswa Pada Materi Komposisi Fungsi. *Pedagogy : Jurnal Pendidikan Matematika*, *10*(4), 1519–1532. https://doi.org/10.30605/pedagogy.v10i4.7116

Creswell, J. (2023). *Research Design Qualitative, Quantitative, and Mixed Methods Approaches* (6th ed.).

Desi Trisnawati, & Zainnur Wijayanto. (2025). *The Effect of Flipped Classroom Model Integrated with Deep Learning Approach on Students' Mathematical Problem-solving Ability Article Information*. *10*(2), 236–248. https://doi.org/10.22437/gentala.v4i1.xxxxx

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*(10), 906–911. https://doi.org/10.1037/0003-066X.34.10.906

Fullan, Michael., Langworthy, Maria., & Barber, Michael. (2014). *A rich seam : how new pedagogies find deep learning*. MaRS Discovery District.

Girsang, M. K., & Rahayu, C. (2025). Bagaimana Pengimplementasian Pembelajaran Mendalam (Deep Learning) Dalam Belajar Matematika: Studi Literatur. *Jurnal Kepemimpinan dan Pengurusan Sekolah*, 497–507. https://www.ejurnal.stkip-pessel.ac.id/index.php/kp/article/view/580

Hafizah, N., Widiati, I., Herlina, S., & Wahyuni, R. (2025). Analisis Kemampuan Pemecahan Masalah Matematis Siswa Berbasis Education for Sustainable Development (ESD) pada Materi Aritmetika Sosial Kelas VII SMP. *Jurnal Cendekia : Jurnal Pendidikan Matematika*, *9*(3), 1473–1483. https://doi.org/10.31004/cendekia.v9i3.4358

Hake, R. R. (1998). *Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses*. *66*(1), 66–74. https://www.researchgate.net/publication/228710512_Interactive-Engagement_Versus_Traditional_Methods_A_Six-Thousand-Student_Survey_of_Mechanics_Test_Data_for_Introductory_Physics_Courses

Hallarte, D. K., Camaongay, Q. M., Congson, J., Cuamag, S., Datosme, J., Laude, V. K. B., Milano, M. L., Gonzales, R., & Gonzales, G. (2024). Modeling self-regulation in learning mathematics through teacher-promoting interaction and parental support among STEM learners: The mediating role of intrinsic motivation. *Social Sciences & Humanities Open, 10*, 101077. https://www.sciencedirect.com/science/article/pii/S2590291124003322

Komariya, K., Farida, N., & Vahlia, I. (2018). Pengaruh Model Pembelajaran FSLC Terhadap Kemampuan Pemecahan Masalah Matematika Ditinjau Dari Motivasi Belajar Siswa. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *7*(1), 96-102. http://dx.doi.org/10.24127/ajpm.v7i1.1355

Ley, & Khofial Luthfi, A. (2024). Systematic Literature Review: Pengaruh Self-Regulated Learning Terhadap Kemampuan Pemecahan Masalah Matematika Siswa Berdasarkan Jenjang Pendidikan. *Jurnal Pendidikan Matematika*. https://doi.org/10.26618/jp.v11i2.15919

Manjaniawati, S., Yusritawati, I., Zaenal, R. M., & Kuningan, S. M. (2024). Efektivitas Penerapan Model Pembelajaran Pbl Berbantuan Alat Peraga Terhadap Kemampuan Pemecahan Masalah Matematis Siswa. *EMTEKA: Jurnal Pendidikan Matematika*, *5*, 378–391. https://doi.org/10.24127/emteka.v5i2.6595

Marton, F., & Saljo, R. (1976). On Qualitative Differences in Learning: I – Outcome and Process. *British Journal of Educational Psychology*, *46*(1), 4–11.

Ministry of Education, Culture, Research, and Technology. (2023). *Laporan Hasil Asesmen Nasional 2023.* Pusat Asesmen Pendidikan, Kemdikbudristek.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* NCTM.

Ningrum, A. P. S., Andayani, S., Vahlia, I., & Dewi, W. U. (2025). Analysis Of Problem Solving In Spldv Material Using Castel Stages Reviewed From Students'learning Styles. *EMTEKA: Jurnal Pendidikan Matematika*, 6(2), 1006-1018. https://doi.org/10.24127/emteka.v6i2.8803

OECD. (2023). *PISA 2022 results (volume I): The state of learning and equity in education.* OECD Publishing. https://doi.org/10.1787/53f23881-en

Piscayanti, K. S., Mujiyanto, J., Yuliasri, I., & Astuti, P. (2022). Deep Learning Approach Through Meaningful, Mindful, and Joyful Learning: A Library Research. *Electronic Journal of Education, Social Economics and Technology (EST)*, *3*(2), 288–297. https://jurnal.staialhidayahbogor.ac.id/index.php/est/article/view/553

Polya, G. (1973). How to Solve It: A New Aspect of Mathematical Method (2nd ed.). Princeton University Press.

Prihandhika, A., Aiyub, A., Suryadi, D., & Prabawanto, S. (2022). *Efektivitas model Missouri Mathematics Project terhadap kemampuan koneksi matematis dalam pembelajaran turunan*. JNPM (Jurnal Nasional Pendidikan Matematika), 6(3), 551–564. https://doi.org/10.33603/jnpm.v6i3.7073

Ramlah, Siswono, T. Y. E., & Lukito, A. (2024). Revealing the Uniqueness of Variations in Prospective Teachers' Metacognitive Activities in Solving Mathematical Problems Based on Gender. Infinity Journal of Mathematics Education, 13(2), 477–500. https://doi.org/10.22460/infinity.v13i2.p477-500

Raup, A., Ridwan, W., Khoeriyah, Y., Supiana, S., & Zaqiah, Q. Y. (2022). Deep Learning dan Penerapannya dalam Pembelajaran. *JIIP-Jurnal Ilmiah Ilmu Pendidikan*, *5*(9), 3258–3267. https://doi.org/10.54371/jiip.v5i9.805

Salsabila, S., & Asih, E. C. M. (2024). The effect of problem-based learning models on students' mathematical problem-solving ability: A meta-analysis. *Jurnal Pendidikan MIPA, 25*(2), 864–877.

Santiani, S. (2025). Analisis Literatur: Pendekatan Pembelajaran Deep Learning dalam Pendidikan. *Jurnal Ilmiah Nusantara*, *2*(3), 50–57. https://doi.org/10.61722/jinu.v2i3.4357

Santos-Trigo, M. (2024). Problem solving in mathematics education: Tracing its foundations and current research-practice trends. *ZDM–Mathematics Education, 56*, 211–222. https://doi.org/10.1007/s11858-024-01578-8

Schoenfeld, A. H. (1985). *Mathematical problem solving.* Academic Press.

Setiawan, D., Maulidina, A., & Sunaryo, Y. (2024). Implementasi Problem Based Learning Berbasis Teknologi Digital terhadap Kemampuan Pemecahan Masalah Matematis Siswa. *EQUALS: Jurnal Ilmiah Pendidikan Matematika*, *7*(2), 123–135. https://doi.org/10.46918/equals.v7i2.3045

Sriwahyuni, K., & Maryati, I. (2022). *Kemampuan Pemecahan Masalah Matematis Siswa pada Materi Statistika*. https://www.researchgate.net/publication/363260121_Kemampuan_Pemecahan_Masalah_Matematis_Siswa_pada_Materi_Statistika/fulltext/6313f6d8acd8

14437f0112ec/Kemampuan-Pemecahan-Masalah-Matematis-Siswa-pada-Materi-Statistika.pdf

Vahlia, I., Ramadhani, N., Loreza, N., & Febrilia, N. A. Analisis Kemampuan Pemecahan Masalah Dalam Menyelesaikan Soal Statistika. *Jurnal EMTEKA*, 3(1), 80-86. file:///C:/Users/hp/Downloads/1164-Article%20Text-3811-1-10-20220309%20(4).pdf

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Xie, K., Chen, Y., & Hwang, G. J. (2024). Toward self-regulated learning: Effects of different types of data-driven feedback on pupils' mathematics word problem-solving performance. *Frontiers in Psychology, 15*, 1356852. https://doi.org/10.3389/fpsyg.2024.1356852

Zimmerman, B. J. (1990). Self-Regulated Learning and Academic Achievement: An Overview. *Educational Psychologist*, 25(1), 3–17. https://www.tandfonline.com/doi/abs/10.1207/s15326985ep2501_2