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Effect of the Self-Regulated Learning Model on High School Students' Physics Problem-Solving Ability

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Abstract: Physics education within the *Kurikulum Merdeka* emphasizes the development of students' problem-solving ability as an essential competency for addressing twenty-first-century challenges. However, physics teaching practices in many Indonesian schools continue to rely heavily on teacher-centered instructional approaches, limiting students' opportunities to develop systematic problem-solving ability. This study aimed to examine the effect of the Self-Regulated Learning (SRL) model on senior high school students' physics problem-solving ability. A quasi-experimental study employing a nonequivalent control group pretest–posttest design was conducted with 64 tenth-grade students at SMA Negeri 3 Singaraja, Indonesia. Students' problem-solving ability was measured using a validated essay test, and the data were analyzed using one-way Analysis of Covariance (ANCOVA) with pretest scores as covariates. Prior to the intervention, the SRL and conventional groups demonstrated comparable mean pretest scores of 36.67 (SD = 5.40) and 35.83 (SD = 4.81). After the intervention, students in the SRL group achieved a higher mean posttest score of 73.33 (SD = 5.32) than those in the conventional group, 69.17 (SD = 5.14). ANCOVA revealed a statistically significant effect of the learning model on students' problem-solving ability ($F = 17.067$, $p < 0.001$), with a large practical effect (partial $\eta^2 = 0.219$). Furthermore, the estimated marginal mean difference between the two groups was 5.095 points (95% CI [2.498, 7.691]), indicating a consistent advantage of the SRL model over conventional instruction. These findings demonstrate that SRL is substantially more effective in enhancing students' ability to understand problems, formulate solution strategies, implement appropriate procedures, and evaluate solutions. Therefore, the SRL model represents an effective student-centered instructional approach for strengthening physics problem-solving ability and supporting the implementation of the *Kurikulum Merdeka.*

Keywords: Conventional Learning; Physics Education; Problem-Solving Ability; Renewable Energy; Self-Regulated Learning.

Introduction

21st-century education is a learning process that integrates literacy skills, knowledge proficiency, attitudes, and technological mastery to produce a competent and globally competitive workforce [1]. In the *Kurikulum Merdeka,* the characteristics of learning are directed toward helping students understand their potential and talents through an approach that emphasizes critical thinking, creativity, collaboration, and communication [2]. Current instructional practices therefore, encourage student-centered learning environments in which learners actively construct their own understanding rather than just receiving information from teachers [3], [4].

Within science education, physics plays a fundamental role in strengthening students' logical reasoning and problem-solving skills [5]. Physics studies natural phenomena and their interactions, requiring an understanding of theoretical concepts as well as the skills to apply them in everyday life logically and analytically[6], [7]. Therefore, the *Kurikulum Merdeka* directs students to be able to analyze problems and formulate solutions based on scientific concepts as preparation to face future challenges[8].

Current classroom practices indicate that Indonesian students continue to face challenges in developing strong problem-solving abilities. According to the 2022 Programme for International Student Assessment (PISA), Indonesia was ranked 81st among 90 participating countries in the scientific problem-solving domain with a score of 383, considerably lower than the OECD average score of 485 [9], [10]. A similar pattern was also observed during preliminary observations conducted at SMA Negeri 3 Singaraja, which found that science learning, particularly on the topic of renewable energy, is still dominated by lecture methods and procedural exercises [11]. This approach has not been effective in actively engaging students, causing them to struggle in applying physics concepts to solve contextual problems [12], [13].

This low problem-solving ability is often caused by learning strategies that still focus on memorization and remain teacher-centered, rather than fostering creative thinking [13], [14]. Consequently, when faced with problem-solving questions, students encounter obstacles in identifying keywords, modeling the problems mathematically, and determining systematic resolution strategies [15], [16]. Therefore, an innovative learning model is needed that can foster independent learning and higher-

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order thinking skills, such as Self-Regulated Learning (SRL) [17].

SRL is an active learning process in which students establish goals, choose appropriate learning strategies, monitor their progress, and evaluate their learning outcomes [18], [19]. This approach allows students to overcome learning obstacles independently and systematically [20]. Previous studies have consistently demonstrated that implementing SRL improves students' metacognitive skills, academic achievement, and problem-solving performance across various disciplines, including mathematics, science, and physics [21], [22], [23].

Recent studies have further shown that SRL promotes students' self-monitoring, learning autonomy, and reflective thinking, enabling learners to solve increasingly complex problems more effectively. Furthermore, SRL supports students in selecting appropriate learning strategies, monitoring their learning progress, and evaluating their own performance, which are essential components of higher-order thinking skills required in 21st-century education [24], [25].

Although numerous studies have reported positive effects of SRL on students' learning achievement, metacognitive skills, and problem-solving ability, several important research gaps remain. Most previous studies have focused on mathematics, general science, or online learning environments, with limited attention given to physics learning at the senior high school level [21], [22], [26]. In addition, only a few studies have examined the effectiveness of SRL in the context of renewable energy learning, despite this topic requiring students to integrate conceptual understanding, scientific reasoning, and systematic problem-solving ability [23], [27], [28]. Furthermore, previous research has generally emphasized overall learning outcomes rather than providing a comprehensive evaluation of students' performance across each dimension of physics problem-solving ability. Few studies have also controlled for students' initial problem-solving ability using Analysis of Covariance (ANCOVA), resulting in limited empirical evidence regarding the actual effectiveness of SRL in improving students' physics problem-solving ability [22]. Therefore, further investigation is needed to provide more robust empirical evidence concerning the effectiveness of SRL in enhancing students' physics problem-solving ability within renewable energy instruction.

The present study attempts to address these limitations by investigating the effectiveness of the SRL model in improving students' physics problem-solving ability within renewable energy instruction. Renewable energy was selected because it provides authentic, interdisciplinary, and sustainability-oriented scientific problems that require students to integrate conceptual understanding, scientific reasoning, mathematical representation, and systematic problem-solving strategies [8], [28]. Moreover, this study evaluates students' performance across four dimensions of problem-solving ability, understanding the problem, planning a solution, implementing the solution, and evaluating the results while controlling students' initial problem-solving ability using ANCOVA. Therefore, this study provides more comprehensive empirical evidence regarding the effectiveness of SRL in physics learning and supports the implementation of student-centered learning in the *Kurikulum Merdeka* [8], [29].

Considering the learning issues identified at SMA Negeri 3 Singaraja and the increasing demands for global competencies, research investigates the influence of the SRL model on senior high school students' physics problem-solving ability, particularly in renewable energy topics. The findings of this study are expected to contribute to the growing body of evidence regarding the implementation of SRL in physics education while providing practical guidance for physics teachers in designing student-centered learning environments that foster independent learning and problem-solving ability in accordance with the objectives of the *Kurikulum Merdeka* [8], [29].

Research Methods

Research Design and Participants

This research adopted a quantitative quasi-experimental approach, employing a nonequivalent control group pretest–posttest design. The design was chosen to evaluate the effectiveness of the SRL model on students' physics problem-solving ability while statistically controlling differences in students' initial problem-solving ability using Analysis of Covariance (ANCOVA).

The research was carried out at SMA Negeri 3 Singaraja during the second semester of the 2025/2026 academic year. The target population comprised all tenth-grade students (N = 335). Two existing classes were randomly selected, with Class X D (n = 33) assigned to the experimental group and Class X B (n = 31) to the control group. Students in the experimental group were taught using the SRL model, while those in the control group received the conventional learning model [29].

Table 1. Non-equivalent pretest-posttest control group design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
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Control	O_3	X_2	O_4

Description:
O_1: Pretest of the experimental group
O_3: Pretest of the control group
O_2::Posttest of the experimental group
O_4: Posttest of the control group
X_1: Application of the SRL model treatment in the experiment class
X_2: Application of the conventional model treatment in the control class
----: Full randomization cannot be performed

Research Instrument

Students' physics problem-solving ability was measured using a validated essay test consisting of 10 items on renewable energy concepts. The instrument was developed based on Polya's problem-solving framework and assessed four indicators of problem-solving ability: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back [30].

Prior to implementation, the instrument was evaluated through expert judgment to establish content validity. Instrument reliability testing yielded a reliability coefficient of 0.761, indicating satisfactory internal consistency for measuring students' physics problem-solving ability. Student responses were scored using an analytical rubric developed for each indicator of problem-solving ability.

Research Procedure

The research was conducted in three main phases: preparation, implementation, and final evaluation. During the preparation phase, an initial classroom observation was undertaken to examine the existing learning environment and identify the research issues. Following this, the study population and sample were determined, instructional materials and research instruments were developed, lesson plans and student worksheets (LKPD) were prepared, and all instruments underwent expert validation prior to the study's implementation.

The implementation stage was conducted over five instructional meetings, each lasting 80 minutes. The first meeting was used to administer the pre-test in both groups to determine students' initial physics problem-solving ability. The following three meetings were devoted to the learning intervention, during which the experimental class received instruction using the SRL model, whereas the control class was taught using the conventional learning model. The fifth meeting was used to administer the posttest, administered with the same instrument, to measure students' physics problem-solving ability after the intervention.

The final stage involved scoring students' responses, processing research data, conducting statistical analyses, interpreting the findings, and drawing conclusions. During the intervention, learning in the experimental class followed the seven phases of the SRL model: analyze, plan, implement, comprehend, problem solving, evaluate, and modify [23], [31].

During the analyze phase, students identified relevant information from contextual renewable energy problems, determined learning objectives, and recognized the concepts required to solve the problems. In the plan phase, students selected appropriate physics principles, formulated mathematical models, and determined suitable solution strategies. During the implementation phase, students applied the selected strategies by solving problems collaboratively using Student Worksheets. In the comprehension phase, students monitored their conceptual understanding through discussions and teacher guidance, while identifying misconceptions encountered during problem-solving. During the problem-solving phase, students independently solved contextual problems in renewable energy by integrating conceptual understanding with mathematical reasoning. In the evaluation phase, students examined the accuracy of their solutions, reflected on errors, and compared alternative solution strategies. Finally, during the modify phase, students revised their problem-solving strategies based on reflection and teacher feedback before applying them to similar physics problems.

To ensure the consistency of the intervention, both groups were taught using identical learning objectives, teaching duration, assessment instruments, and learning materials. The difference between the two groups was limited to the instructional model employed, namely the SRL model in the experimental class and the conventional learning model in the control class. This procedure was intended to minimize threats to internal validity and ensure that differences in students' problem-solving ability could be attributed primarily to the implemented learning model.

Data Analysis

The research data were analyzed using SPSS software. Before conducting hypothesis testing, prerequisite assumption analyses were performed, including the Shapiro–Wilk normality test and Levene's test for homogeneity of variance. The hypothesis was subsequently examined using a one-way Analysis of Covariance (ANCOVA) at a 5% significance level ($\alpha = 0.05$). In this analysis, students' pretest results were treated as covariate variables to minimize the influence of initial group differences in their physics problem-solving abilities before determining the effectiveness of SRL relative to conventional learning method.

To evaluate the practical impact of the intervention, the effect size was estimated using partial eta squared (η^2_p), providing information on the magnitude of the treatment effect beyond statistical significance.

Results and Discussion

Following the intervention, both groups showed improvements in their post-test scores. However, students who learned using the SRL model demonstrated a greater increase in problem-solving ability than those who received the conventional model. The SRL group achieved a mean posttest score of 73.33 (SD = 5.32), whereas the conventional group obtained a mean score of 69.17 (SD = 5.14). These descriptive results indicate that students exposed to the SRL model tended to achieve better performance in physics problem solving than students taught through conventional learning.

Table 2. Results of descriptive statistics of students' physics problem-solving ability

Model	Pretest	Posttest
SRL	M = 36.33 SD = 5.40	M = 74.45 SD = 5.32
Conventional	M = 36.55 SD = 4.81	M = 69.27 SD = 5.14

Table 2 summarizes the descriptive statistics of students' physics problem-solving ability obtained before and after the instructional intervention. Prior to the intervention, both the SRL and conventional groups demonstrated comparable pre-test mean scores, indicating relatively similar initial levels of problem-solving ability. The SRL group obtained a mean pretest score of 36.67 (SD = 5.40), whereas the conventional group achieved a mean score of 35.83 (SD = 4.81).

Figure 1 compares the mean pretest and posttest scores of students across the two learning groups. The relatively small difference in the pretest means suggests that the two groups had comparable initial problem-solving ability before the intervention. In contrast, the posttest results reveal greater improvement in the SRL group than in the conventional group, providing preliminary evidence that the SRL model may enhance students' ability to solve physics problems.

The data was further analyzed across four specific problem-solving ability (PSA) dimensions: understanding the problem (PSA 1), devising a plan (PSA 2), carrying out the plan (PSA 3), and looking back/evaluating (PSA 4) [30]. The distribution of pretest and posttest scores across these dimensions is presented in Figures 2 and 3.

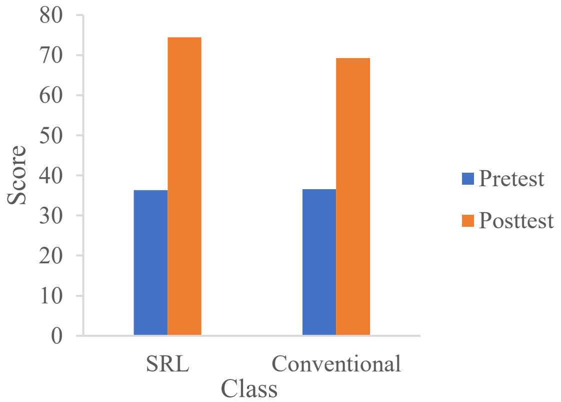

Figure 1. Mean pretest and posttest scores of students' overall physics problem-solving ability

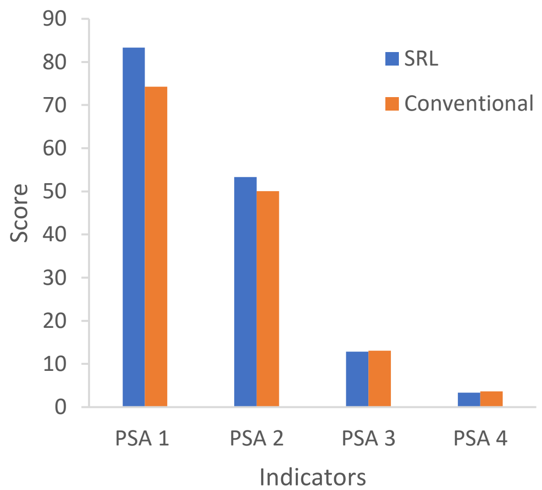

Figure 2. Comparison of pretest scores across the four dimensions of physics problem-solving ability.

Figure 2 shows that the experimental and control groups exhibited relatively similar achievement across all four problem-solving dimensions before the intervention. These results suggest that both the experimental and control groups began the intervention with comparable levels of physics problem-solving ability across all four assessed dimensions: understanding the problem, planning a solution, implementing the selected strategy, and evaluating the solution obtained.

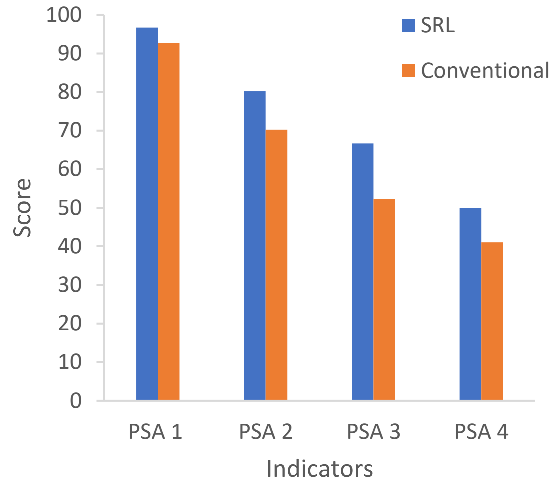

Figure 3. Comparison of posttest scores across the four dimensions of physics problem-solving ability.

Figure 3 demonstrates that the SRL model resulted in superior student performance across all dimensions of physics problem-solving ability compared with conventional instruction. The greatest difference was observed in the carrying out of the plan dimension (PSA 3), suggesting that the SRL model effectively supported students in implementing appropriate solution strategies. Considerable differences were also identified in the devising a plan (PSA 2) and looking back (PSA 4) dimensions, indicating that SRL not only facilitated students' planning and execution of problem-solving procedures but also enhanced their ability to evaluate the accuracy of their solutions. Although the difference in the understanding of the problem dimension (PSA 1) was comparatively smaller, students in the SRL group still demonstrated consistently higher achievement than those in the conventional group.

Overall, the descriptive findings indicate that students who participated in the SRL model consistently demonstrated higher performance across all dimensions of physics problem-solving ability than those who experienced conventional instruction. Although the descriptive results suggest differences between the two groups, further inferential statistical analyses were conducted to determine whether these differences were statistically significant.

Before performing the hypothesis test, several assumption tests were conducted to confirm that the data met the requirements for the subsequent ANCOVA analysis. These assumption tests included the normality test and the homogeneity of variance test.

Table 3. Results of the normality test for students' physics problem-solving ability

Dependent Variable	Learning Model	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	SRL	0.113	33	.200*	0.959	33	.240
	Konvensional	0.101	31	.200*	0.971	31	.551
Post-Test	SRL	0.092	33	.200*	0.964	33	.331
	Konvensional	0.083	31	.200*	0.975	31	.652

Table 3 summarises the normality test results for both the experimental and control groups based on the Kolmogorov–Smirnov and Shapiro–Wilk tests. The Kolmogorov–Smirnov test produced significance values of

0.200 for all datasets, whereas the Shapiro–Wilk test yielded significance values ranging from 0.240 to 0.652. Since all p-values were greater than the predetermined significance level ($\alpha = 0.05$), the data were considered normally distributed. These findings indicate that the pretest and posttest scores of both groups were normally distributed, thereby satisfying the normality assumption required for ANCOVA.

Table 4. Results of the homogeneity of variance test

Dependent Variable		Levene's Statistic	df1	df2	Sig.
Pre-test	Based on Mean	0.003	1	62	.953
	Based on Median	0.004	1	62	.953
	Based on Median and with adjusted df	0.004	1	62.000	.953
	Based on trimmed mean	0.003	1	62	.959
Post-test	Based on Mean	0.353	1	62	.555
	Based on Median	0.257	1	62	.614
	Based on Median and with adjusted df	0.257	1	61.218	.614
	Based on trimmed mean	0.294	1	62	.590

As presented in Table 4, Levene's test produced significance values of 0.953 for the pretest data and 0.555 for the posttest data. Because both values exceeded the established significance level ($\alpha = 0.05$), the assumption of homogeneity of variance was satisfied, indicating that the data were appropriate for subsequent ANCOVA analysis.

Following confirmation that all statistical assumptions were satisfied, the research hypothesis was examined using ANCOVA, with students' pretest scores as a covariate to account for differences in initial physics problem-solving ability.

Table 5. Tests of between-subjects effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	η^2_p
Corrected Model	563.621	2	281.810	11.286	.000	.270
Intercept	3938.757	1	3938.757	157.739	.000	.721
Pretest (Covariate)	148.715	1	148.715	5.956	.018	.089
Learning Model	426.175	1	426.175	17.067	.000	.219
Error	1523.176	61	24.970			
Total	332952.862	64				
Corrected Total	2086.797	63				

Table 5 presents the results of the ANCOVA analysis. The corrected model was statistically significant ($F = 11.286$, $p < 0.001$), indicating that the overall model adequately explained the variation in students' posttest scores. Furthermore, the pre-test score, which served as the covariate, significantly influenced students' post-test problem-solving ability ($F = 5.956$, $p = 0.018$). This finding indicates that students' initial problem-solving ability contributed significantly to their learning outcomes and, therefore, justified the inclusion of the covariate in the analysis.

More importantly, after controlling for students' initial problem-solving ability, the learning model had a statistically significant effect on students' physics problem-solving ability ($F = 17.067$, $p < 0.001$). These findings indicate that students who learned using the SRL model achieved significantly higher problem-solving ability than those who received conventional instruction.

The effect size analysis revealed a partial eta squared (η^2_p) value of 0.219, indicating that approximately 21.9% of the variance in students' posttest physics problem-solving ability was explained by the implemented learning model after controlling for the covariate. Based on the interpretation of partial eta squared commonly adopted in educational research, values of approximately 0.01, 0.06, and 0.14 indicate small, medium, and large effects, respectively [32]. Therefore, the obtained η^2_p value of 0.219 represents a large effect size, indicating that the SRL model had a substantial practical influence on students' physics problem-solving ability.

Table 6. Pairwise comparison of estimated marginal means between learning models

Sample		$\mu(I) - \mu(J)$	SE	*Sig.*	95% Confidence Interval for Difference^b	
					Lower Bound	Upper Bound
SRL	Konvensional	5.095^*	1.299	0.001	2.498	7.691
Konvensional	SRL	-5.095^*	1.299	0.001	-2.498	-7.691

Table 6 presents the pairwise comparison of the estimated marginal means after controlling for students' initial problem-solving ability. The comparison revealed that students in the SRL group achieved significantly higher adjusted post-test scores than those in the conventional learning group, with an estimated marginal mean difference of 5.095 points (SE = 1.299, $p < 0.001$). Furthermore, the 95% confidence interval ranged from 2.498 to 7.691, indicating that it did not include zero. This result confirms that the SRL model's superiority over conventional learning was statistically significant after controlling for differences in students' initial problem-solving ability.

Overall, both the ANCOVA and pairwise comparison analyses consistently demonstrated that students who learned through the SRL model achieved significantly higher physics problem-solving ability than those who received conventional instruction. These findings provide strong statistical evidence supporting the effectiveness of the SRL model in improving students' physics problem-solving ability.

This difference can be explained by the learning processes embedded in the SRL model, which provide students with structured opportunities to actively regulate their thinking during problem solving. The SRL model encourages students to analyze problems, develop solution strategies, monitor their understanding, evaluate their solutions, and modify their strategies through the phases of analyze, plan, implement, comprehend, problem solving, evaluate, and modify [23], [31]. This process is consistent with Zimmerman and Schunk [19], who describe self-regulated learning as an active and constructive process in which learners regulate their cognition, motivation, and behavior to achieve learning goals.

The effectiveness of SRL was also reflected in the four dimensions of physics problem-solving ability. Students in the SRL group achieved higher performance in understanding the problem (PSA 1), devising a plan (PSA 2), carrying out the plan (PSA 3), and looking back (PSA 4), with the largest difference observed in carrying out the plan (PSA 3), followed by devising a plan (PSA 2). This finding suggests that the structured activities in SRL helped students not only understand contextual renewable energy problems but also formulate and implement appropriate solution strategies. The evaluate and modify phases further encouraged students to review their answers, identify errors, and improve their solution strategies, which may explain the improvement observed in the looking back dimension (PSA 4).

The active involvement of students in the SRL learning process may further explain the experimental group's higher performance. Students were encouraged to construct solution strategies, monitor their understanding, and reflect on their performance rather than relying entirely on teacher explanations. This finding is consistent, SRL facilitates independent learning and higher-order thinking through continuous self-monitoring and self-evaluation [23]. The SRL contributes to students' metacognitive skills, problem-solving ability, and learning outcomes [21], [22], [24]. The SRL supports higher-order thinking by encouraging students to monitor and evaluate their own learning processes[25].

In contrast, students in the conventional group had fewer structured opportunities to independently regulate each stage of the problem-solving process. Although both groups demonstrated improvement after the intervention, the greater improvement observed in the SRL group indicates that learning activities involving planning, monitoring, evaluation, and modification can provide stronger support for solving contextual physics problems. Therefore, the higher problem-solving ability of students in the SRL group can be attributed to the integration of self-regulation, active problem solving, and reflection throughout the learning process.

Conclusion

The findings of this study demonstrate that the SRL model significantly improves senior high school students' physics problem-solving ability compared with conventional learning. After controlling for students' initial problem-solving ability through ANCOVA, the SRL model produced significantly higher posttest performance ($F = 17.067$, $p < 0.001$) with a large practical effect (partial $\eta^2 = 0.219$). The improvement was consistently observed across all four dimensions of physics problem-solving ability, indicating that the SRL model effectively supports students in understanding problems, planning solution strategies, implementing appropriate procedures, and evaluating the obtained solutions. Furthermore, this study extends previous research by providing empirical evidence for the effectiveness of the SRL model in renewable energy instruction and by evaluating students' performance across four dimensions of physics problem-solving ability, using ANCOVA to control for differences in initial ability. Therefore, the implementation of SRL can serve as an effective alternative instructional strategy for improving students' physics problem-solving ability in classroom practice and highlights the importance of teacher professional development in designing and facilitating student-centered learning environments.

Author’s Contribution

I.G.S.G. Merta: responsible for research design, data analysis, and completion of scientific article writing. P. Yasa: provided guidance and support throughout the research process, as well as reviewed the manuscript. P. Widiarini: contributed to the manuscript's writing and revision, enhancing its quality.

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