

Effectiveness of Utilizing PhET Simulation Application Oriented Self-Regulated Learning to Improve Students' Metacognition Ability

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ARTICLE INFO	ABSTRACT
Keywords: Metacognition; PhET Simulation; Self-Regulated Learning;	This study aims to evaluate the effectiveness of the use of PhET Simulation oriented self-regulated learning (SRL) to improve the metacognition skills of junior high school students in science learning. The background of the research is the low metacognitive skills of students and the unoptimal use of technology reflectively. The research method used was quantitative with non-equivalent control group design and purposive sampling technique. The subjects consisted of VIII grade students in two schools. The research instruments included observation sheets and metacognition ability tests based on planning, monitoring, and evaluation indicators. The results showed that the experimental class experienced a significant improvement compared to the control class, with a higher N-Gain value and t-test significance <0.001. The Cohen's d effect size value of 1.590 indicates a large practical effect. This finding indicates that the integration of PhET Simulation and SRL is effective in increasing thinking awareness and learning independence. This study recommends the application of similar strategies in learning to develop higher order thinking skills.
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INTRODUCTION

Advances in digital technology have brought about a major transformation in the world of education, particularly in Science learning at the junior secondary level.¹ This development not only impacts the method of material delivery, but also expands the scope of learning resources that students can access anytime and anywhere. Technology allows the presentation of abstract concepts in a visual, interactive, and applicative manner, thus potentially increasing students' understanding in more depth. One form of technology implementation that is growing rapidly is the use of computer simulations in learning. Simulations allow students to interact directly with scientific concepts through virtual experiments that resemble real laboratory experiences. However, not all uses of this technology have an optimal impact, as student engagement is often passive and only focused on visual displays without any reflection or directed learning strategies.

The main challenge in applying technology in the classroom is how to make it a tool that truly empowers students' thinking processes, not just entertainment or visual aids. Changes in the form of learning media should also be accompanied by a transformation in pedagogical strategies that emphasize cognitive engagement and strengthening higher-order thinking skills.² Teachers play an important role in this process, as they are the ones who guide students to use technology as a means of exploration and problem solving, not as an instant tool to get answers. In this case, the presence of technology such as computer simulations needs to be combined with learning approaches that prioritize reflection, self-regulation, and evaluation of the learning process itself.

In many cases, students utilize technology only as a momentary aid without developing meaningful understanding. They tend to copy information from the internet or follow instructions mechanically without going through a deep thinking process.³ As a result, the learning process becomes superficial and does not contribute to the development of long-term learning skills. This points to the importance of an approach

¹ Abid Haleem et al., "Understanding the Role of Digital Technologies in Education: A Review," *Sustainable Operations and Computers* 3 (2022), <https://doi.org/10.1016/j.susoc.2022.05.004>.

² Eka Nurillahwaty, "Peran Teknologi Dalam Dunia Pendidikan," *Jurnal Keislaman Dan Ilmu Pendidikan* 3, no. 1 (2021): 123–33, <https://ejournal.stitpn.ac.id/index.php/islamika>.

³ Rahma Azzahrah Putri et al., "Pengaruh Gaya Belajar Terhadap Pembelajaran Siswa Sekolah Dasar," *Cerdika: Jurnal Ilmiah Indonesia* 1, no. 2 (2021), <https://doi.org/10.59141/cerdika.v1i2.26>; Clara Fatimah et al., "Peningkatan Minat Belajar Siswa Melalui Pendekatan Matematika Realistik Pada Pembelajaran Berbasis Daring," *Mathema Journal* 3, no. 2 (2021).

that not only introduces technology, but also guides students to use it reflectively and strategically. In this context, metacognition becomes highly relevant. Metacognition is the ability of individuals to realize, control, and evaluate their own thinking processes.⁴ With this ability, students can plan learning strategies, monitor their effectiveness, and make adjustments to achieve better understanding.

Metacognitive skills are very important, especially in science learning which requires understanding of complex and abstract concepts. Students who have metacognitive skills tend to be better able to direct their learning process, evaluate their own understanding, and apply strategies that are appropriate to the learning situation at hand.⁵ Therefore, the development of metacognition needs to be an integral part of learning design, especially at the junior secondary education level. Unfortunately, in practice, this skill is still often neglected and has not become the main focus in the daily learning process. This becomes even more relevant when the education system demands that students become independent learners who are able to adapt to constantly evolving information.

One approach that supports the systematic development of metacognition is self-regulated learning (SRL). This approach emphasizes students' active involvement in planning, monitoring, and evaluating their own learning process.⁶ SRL not only encourages learning independence, but also trains students to think about their thinking process (metacognitive awareness), which is needed in facing increasingly complex academic challenges. Through SRL, students learn to take responsibility for their own learning success, and are able to adapt learning strategies based on experience and reflection. This concept also places students as active subjects in learning, in contrast to traditional approaches that emphasize the role of the teacher as the center of information.

⁴ Eleni Mitsea, Athanasios Drigas, and Panagiotis Mantas, "Soft Skills & Metacognition as Inclusion Amplifiers in the 21st Century," *International Journal of Online and Biomedical Engineering* 17, no. 4 (2021), <https://doi.org/10.3991/ijoe.v17i04.20567>.

⁵ Ida Ayu Wiwin Anindya, Mahrus Mahrus, and Gito Hadiprayitno, "Hubungan Kemampuan Metakognisi Siswa Dengan Hasil Belajar Ipa Melalui Penerapan Model Pembelajaran Berbasis Masalah Di Smp Negeri 2 Kuripan," *Jurnal Pendidikan Biologi* 10, no. 2 (2019), <https://doi.org/10.17977/um052v10i2p66-73>; Geni Sri Elita et al., "Pengaruh Pembelajaran Problem Based Learning Dengan Pendekatan Metakognisi Terhadap Kemampuan Pemecahan Masalah Matematis," *Mosharafa: Jurnal Pendidikan Matematika* 8, no. 3 (2019): 447–58, <https://doi.org/10.31980/mosharafa.v8i3.580>; Matthew G Rhodes, "Metacognition," *Teaching of Psychology* 46, no. 2 (2019): 168–75.

⁶ Yusufu Gambo and Muhammad Zeeshan Shakir, "Review on Self-Regulated Learning in Smart Learning Environment," *Smart Learning Environments*, 2021, <https://doi.org/10.1186/s40561-021-00157-8>.

In the context of science learning, SRL is very relevant because it helps students develop critical and reflective thinking skills needed in understanding the scientific process. The principles of SRL are also in line with the constructivist approach that emphasizes the active role of students in constructing knowledge through interaction with the learning environment.⁷ SRL has been shown to increase students' motivation, self-efficacy, and learning awareness.⁸ Its application becomes more effective if supported by interactive and adaptive learning media, such as PhET Simulation.

PhET Simulation is a science-based interactive simulation application developed by the University of Colorado Boulder. It provides a virtual learning environment that allows students to explore scientific phenomena through manipulation of variables and direct observation of results.⁹ With its visually appealing and interactive design, PhET provides a learning experience that resembles real laboratory experiments, but with less flexibility and risk. In addition to increasing student engagement, PhET also provides space for the gradual and independent development of scientific skills.¹⁰ This is in line with the demands of the independent curriculum that emphasizes contextual, discovery-based learning and differentiation of learning processes.

However, the initial findings obtained by researchers show that the metacognition skills of junior high school students in learning science are still relatively low. The average metacognition score only reached 70 out of a maximum scale, with dominant weaknesses in the planning and evaluation aspects. The interview results also revealed that most students were not accustomed to designing learning strategies, did not reflect on learning outcomes, and relied more on instant information from outside without deep processing of meaning. This condition shows that the utilization of media such as PhET will not be optimal if it is not integrated with learning approaches that explicitly develop thinking awareness and self-regulation.

⁷ Dale H Schunk and Barry J Zimmerman, *Self-Regulation of Learning and Performance: Issues and Educational Applications* (Taylor & Francis, 2023).

⁸ Henry Khat and Silke Vogel, "A Self-Regulated Learning Management System: Enhancing Performance, Motivation and Reflection in Learning," *Journal of University Teaching and Learning Practice* 19, no. 2 (2022), <https://doi.org/10.53761/1.19.2.4>.

⁹ Issa I Salame and Jana Makki, "Examining the Use of PhET Simulations on Students' Attitudes and Learning in General Chemistry II," *Interdisciplinary Journal of Environmental and Science Education* 17, no. 4 (2021), <https://doi.org/10.21601/ijese/10966>.

¹⁰ Suci Prihatiningtyas, "Efektivitas Pembelajaran Fisika Berbasis Simulasi PhET Dan Kitoptik Dengan Model Pembelajaran langsung Untuk Menuntaskan Hasil Belajar Siswa," *EDUSCOPE: Jurnal Pendidikan, Pembelajaran, Dan Teknologi* 3, no. 2 (2018): 16–22.

Thus, there is an urgent need to develop a learning model that combines the advantages of simulation media with an integrated SRL approach. The combination of the two is believed to be able to encourage deeper cognitive engagement and form sustainable reflective learning habits.¹¹ Various studies show that PhET Simulation is effective in improving conceptual understanding, but not many studies have directly assessed how this media can improve metacognitive abilities, especially when integrated with the Self-Regulated Learning (SRL) approach. Most previous studies have focused on cognitive learning outcomes rather than on thinking awareness such as planning, monitoring, and evaluation. This gap is even more apparent at the junior high school level, as the cognitive development characteristics of eighth graders require learning strategies that encourage self-regulation and reflection, but this has not been supported by sufficient empirical evidence.

Although many studies have shown the effectiveness of PhET Simulation in improving conceptual understanding, very few have evaluated how this media can contribute to strengthening metacognition when combined with the SRL approach.¹² In fact, the development of metacognition skills is an important demand in the 21st century curriculum, especially to equip students to face increasingly complex and rapidly changing learning challenges. Taking this into account, it is necessary to conduct an empirical study that explicitly assesses the integration of both in the context of science learning in secondary schools.

This study aims to answer these challenges by empirically exploring the effectiveness of the use of PhET Simulation applications oriented towards self-regulated learning on improving students' metacognition skills. Direct integration between PhET Simulation and SRL strategies at the junior high school level, as well as specific measurement of metacognition through indicators of planning, monitoring, and evaluation. In addition, this study quasi-experimentally compares the effectiveness of this approach with conventional learning, thereby providing new empirical contributions to

¹¹ Lalu Sumardi, Arif Rohman, and Dwi Wahyudiati, "Does the Teaching and Learning Process in Primary Schools Correspond to the Characteristics of the 21st Century Learning?," *International Journal of Instruction* 13, no. 3 (2020), <https://doi.org/10.29333/iji.2020.13325a>.

¹² A B Dimas Ghimby, "Pengaruh Self Regulated Learning Terhadap Kemampuan Berpikir Kritis Dan Hasil Belajar," *JOEL: Journal of Educational and Language Research* 1, no. 12 (2022): 2091–2104; Rozi Saputra, Susilawati Susilawati, and Ni Nyoman Sri Putu Verawati, "Pengaruh Penggunaan Media Simulasi Phet (Physics Education Technology) Terhadap Hasil Belajar Fisika," *Jurnal Pijar Mipa* 15, no. 2 (2020), <https://doi.org/10.29303/jpm.v15i2.1459>.

the development of metacognitive literacy in junior high school students. This focus is expected to contribute to the development of a more relevant, reflective and technology-based science learning model. The results of this research are expected to be a reference for teachers and curriculum developers in designing learning that supports the development of higher order thinking skills and fosters students' learning independence.

RESEARCH METHOD

This study uses a quantitative approach with a quasi-experimental method, aiming to examine the effect of using the PhET Simulation application oriented to self-regulated learning on improving the metacognition skills of junior high school students in science learning. Quasi experimental in educational research is used when full control and randomization of subjects are difficult to determine, such as in intact groups of students in one class.¹³ The research design used was a non-equivalent control group design, which involved two groups: one experimental group and one control group. Both groups used the same learning model, namely discovery learning. However, the experimental group received PhET Simulation-based learning with the SRL approach, while the control group only received conventional learning commonly used in schools.

This research was conducted at SMP Negeri 1 Jetis, Ponorogo Regency, with the research subjects being class VIII students. The sample consisted of two classes of 31 students each, so that a total of 62 students were involved. The sampling technique used purposive sampling by considering the equality of academic ability between experimental and control classes based on report card scores and initial study results.¹⁴

The instruments used in this study include: Metacognition ability test and observation sheet. The test is in the form of multiple choice questions that measure three indicators of metacognition ability: planning, monitoring, and evaluation. This test was given in the form of pretest and posttest to compare the improvement before and after treatment. In addition, the observation sheet was used to record the implementation of learning and student activities while using the PhET Simulation application, especially in terms of the application of SRL strategies.

The research implementation was divided into three main stages: pretest, treatment,

¹³ Matthew L. Maciejewski, "Quasi-Experimental Design," *Biostatistics and Epidemiology* 4, no. 1 (2020), <https://doi.org/10.1080/24709360.2018.1477468>.

¹⁴ Bagus Sumargo, *Teknik Sampling* (Unj press, 2020).

and posttest. The pretest was given to measure students' initial metacognition ability. After that, the experimental group received treatment in the form of learning with PhET Simulation which was arranged based on SRL strategies for two meetings, each lasting 2 x 40 minutes. The treatment was designed to encourage students to go through the stages of SRL: planning (setting learning goals and strategies), implementation (accessing and exploring the simulation), control (adjusting learning strategies when experiencing difficulties), and evaluation (analyzing the results of virtual experiments and learning reflection). Meanwhile, the control group underwent learning with lecture, discussion, and question and answer methods as usually applied by teachers.

The quasi-experimental research design according to¹⁵ can be described in Table 1.

Table 1. Quasi-Experimental Research Design

Class	Pretest	Treatment	Posttest
Experiment	O ₁	X	O ₃
Control	O ₂	-	O ₄

Description:

- O₁ : Giving experimental class pretest
- O₂ : Giving control class pretest
- O₃ : Giving experimental class posttest
- O₄ : Giving control class posttest
- X : Giving self-regulated learning-oriented PhET simulation treatment
- : Not treatment given

The data collected were analyzed quantitatively with descriptive and inferential statistics. Independent samples t-test was used to test the difference in scores between the experimental and control groups. To determine the effectiveness of the treatment, N-Gain analysis was used to measure the increase in metacognition scores.¹⁶ The N-Gain value obtained was then classified into effectiveness categories to help interpret the level of improvement that occurred after the treatment. The effectiveness classification criteria based on the N-Gain value are presented in Table 2.

¹⁵ Isnawan (2020)
¹⁶ Moh Irma Sukarelawan, Toni Kus Indratno, and S M Ayu, "N-Gain vs Stacking," *Yogyakarta: Suryacahaya*, 2024.

Table 2. Criteria for Determining the Level of Effectiveness N-Gain Score

Percentage (%)	Interpretation
< 40	Not Effective
40 – 55	Less Effective
56 – 75	Moderately Effective
> 76	Effective

In addition, the effect size calculation was carried out using Cohen's *d* formula to see the effect of the treatment on improving students' metacognitive abilities.¹⁷ The value obtained from this test is used to show how much impact the treatment has practically in the learning context. The interpretation of Cohen's *d* value refers to the categories commonly used in educational research, as shown in Table 3.

Table 3. Cohen's *d* Effect Size Interpretation Criteria

Range	Criteria
$d < 0.2$	Small
$0.2 < d < 0.8$	Medium
$d > 0.8$	Large

All research procedures followed the rules of academic ethics, including seeking approval from the school, maintaining the confidentiality of students' identities, and ensuring that all participation in the research was voluntary and did not harm any party.

The steps of this research are visualized in a flowchart in Figure 1.

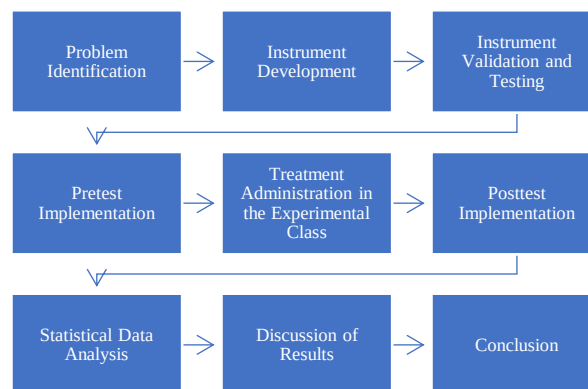


Figure 1. Research Process

¹⁷ Andrey Lovakov and Elena R. Agadullina, "Empirically Derived Guidelines for Effect Size Interpretation in Social Psychology," *European Journal of Social Psychology* 51, no. 3 (2021), <https://doi.org/10.1002/ejsp.2752>.

RESULT AND DISCUSSION

This study aims to evaluate the effectiveness of utilizing PhET Simulation oriented to self-regulated learning (SRL) in improving the metacognition skills of junior high school students. Data were collected through various instruments, including student activity observation sheets, assessment of the implementation of SRL strategies, and metacognition ability tests which include pretests and posttests that measure aspects of metacognition.

Table 4. Recapitulation of Implementation of PhET Simulation Utilization

No.	Applicability Indicators	Average Score	Percentage (%)	Category
1.	Student Activity	3.9	96.9%	Very Good
2.	Student Comprehension	3.5	87.5%	Very Good
3.	Student Skills	3.8	95.8%	Very Good

Based on Table 4, the utilization of self-regulated learning-oriented PhET Simulation application is in the excellent category, indicating that this media is effective in science learning. Students are actively involved in exploring the application features, discussing, and showing high enthusiasm for technology-based learning. The use of this simulation is also proven to improve understanding of the concept of waves, with students able to identify concepts, explain relationships between variables, and provide examples of applications in everyday life. Students' skills in managing variables in the PhET simulation, interpreting experimental results, and completing simulation tasks in a timely manner also showed good results. This reflects that they are able to manage virtual experiments independently and effectively, and not only understand the theory, but are also able to apply it in practical situations.



Figure 2. PhET Simulation Utilization Activity

The results of this study indicate that both teachers and students have the ability to adapt to simulation-based methods in supporting the learning process that is oriented towards exploration and problem solving. This adaptability reflects their readiness to integrate innovative approaches into teaching and learning activities. In addition, the high level of implementation indicates that the implementation of PhET simulation-based methods can be optimally applied in the learning environment. It also indicates that the use of technology as part of educational innovation has been well received and can be integrated effectively to improve the quality of learning.

Table 5. Recapitulation of Students' SRL and Metacognition Activities

No.	Implementation Indicators	Average Score	Percentage (%)	Category
1.	Planning	3.5	87.5%	Very Good
2.	Monitoring	3	75%	Good
3.	Control	3.5	87.5%	Very Good
4.	Evaluation	3.5	87.5%	Very Good

Based on Table 5, students show high activity in exploring the PhET Simulation application, discussing with friends, and showing independence in learning, which supports the optimal application of self-regulated learning. Students design steps before starting the simulation, formulate initial hypotheses, and plan exploration of available variables. This strategy helps them explore the simulation more purposefully and build concept understanding systematically. In addition, observation of concept understanding is done independently. Awareness of errors and the ability to correct understanding show that students can assess their own learning development based on the results of exploration during the simulation.

The adjustment of learning strategies can be seen from the ability of students to change variables when facing difficulties in the simulation. The courage to try new approaches and flexibility in adapting learning methods reflect high independence and build critical and adaptive thinking skills. Reflection on learning outcomes also helps students evaluate the effectiveness of the strategies used, understand their strengths and weaknesses, and encourage the improvement of learning techniques in the future. This high student activity shows initiative in controlling the learning process independently, and indicates that the PhET simulation provides strong support in understanding abstract

concepts interactively and exploratively.

Measurement of the effectiveness of the utilization of PhET Simulation application oriented to self-regulated learning on students' metacognition skills is carried out using a test instrument in the form of 12 multiple choice questions that have gone through validity and reliability tests. This test was carried out in two stages, namely pretest and posttest, with a score of 1 for correct answers and 0 for wrong or unanswered answers. The pretest and posttest data from the control class and experimental class showed a variation in scores. In the control class, the minimum and maximum scores of the pretest were 17 and 75, while the posttest reached 25 and 92. On the other hand, in the experimental class, the pretest had minimum and maximum values of 25 and 75, while the posttest increased to 58 and 100.

Table 6. Recapitulation of Pretest-Posttest Values of Control and Experiment Class

Students					
	Student Count	Min	Max	Mean	Std. Deviation
Pre_Control	31	17	75	43.00	14.401
Post_Control	31	25	92	56.42	17.382
Pre_Experiment	31	25	75	49.23	13.848
Post_Experiment	31	58	100	79.26	10.517

The average difference between the two classes showed a more significant increase in the experimental class. The control class recorded an average pretest of 43.01 and posttest of 56.45, while the experimental class increased from 49.19 to 79.30. The maximum posttest score of the experimental class reached 100, higher than the control class which only reached 92. Analysis of the standard deviation also showed more stable results in the experimental class, with values of 13.837 in the pretest and 10.513 in the posttest, compared to the control class which had standard deviations of 14.449 and 17.308 respectively. Based on these results, it can be concluded that the use of self-regulated learning-oriented PhET Simulation application contributes positively to the improvement of students' metacognition abilities more significantly than learning without simulation.

To ensure the feasibility of statistical analysis, a normality test was conducted on the pretest and posttest data in the control and experimental classes using the Shapiro-

Wilk test. The test results showed that all significance values in each group > 0.05 , both for pretest and posttest. Thus, the data from both classes were declared normally distributed and met the basic assumptions for further analysis using parametric tests. The results of the normality test are shown in Table 7.

Table 7. Results of Pretest-Posttest Normality Test

Tests of Normality							
		Kolmogorov-Smirnov			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Result	Pre_Control	0.120	31	0.200	0.954	31	0.201
	Post_Control	0.162	31	0.036	0.949	31	0.149
	Pre_Experiment	0.183	31	0.010	0.946	31	0.123
	Post_Experiment	0.167	31	0.027	0.941	31	0.091

Furthermore, the homogeneity test was conducted to test the similarity of variance between groups. Based on the results of testing with Levene's Test, a significance value of 0.088 ($p > 0.05$) was obtained, which indicated that the data had a homogeneous variance. This means that both control and experimental classes have a similar level of data diversity and come from the same population, so they are suitable for comparison. A summary of the homogeneity test results is presented in Table 8.

Table 8. Results of Pretest-Posttest Homogeneity Test

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Result	Based on Mean	2.236	3	120	0.088
	Based on Median	2.100	3	120	0.104
	Based on Median and with adjusted df	2.100	3	110.487	0.104
	Based on trimmed mean	2.230	3	120	0.088

An independent t-test was then used to test the difference in posttest results between the experimental and control classes. The test results showed a significance value of < 0.001 ($p < 0.05$), which means there is a statistically significant difference between the

two classes. These results indicate that the use of PhET Simulation oriented self-regulated learning has a real impact on improving students' metacognition skills. Details of the t-test results can be seen in Table 9.

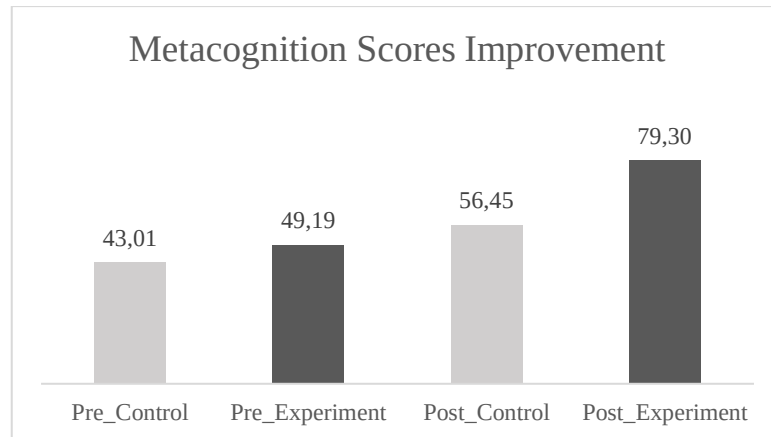
Table 9. Results of Independent Sample Test

Independent Sample Test										
		Levene's Test Equality of Variances		t-test for Equality of Means						
				95% Confidence Interval of the Difference						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Result	Equal variances assumed	6.446	0.014	-6.259	60	<.001	-22.839	3.649	30.137	15.540
	Equal variances not assumed			-6.259	49.369	<.001	-22.839	3.649	30.170	15.508

To measure the effectiveness of the treatment, the N-Gain test was conducted on the pretest and posttest results. The experimental class obtained an average N-Gain of 60.63%, which is in the moderately effective category. Meanwhile, the control class only obtained an average N-Gain of 26.13%, which is in the ineffective category. These results indicate that students in the experimental class experienced a higher increase in metacognition skills than students in the control class. The results of the N-Gain calculation are shown in Table 10.

Table 10. Results of N-Gain Score Test Calculation

Class	Student Count	Minimum	Maximum	Mean (%)
Control	31	0.00	68.00	26.1316
Experiment	31	37.31	100.00	60.6268

**Figure 3.** Metacognition Scores Improvement

To complement the effectiveness analysis, an effect size calculation was conducted using Cohen's d test. The results showed a value of 1.590, which is categorized as a very large effect. This value not only shows that the treatment has a significant effect, but also indicates that the impact of utilizing self-regulated learning-oriented PhET Simulation applications on improving metacognition skills is practically strong. Details of the effect size calculation are presented in Table 11.

Table 11. Results of Effect Size Calculation

Independent Samples Effect Sizes					
			Point Estimate	95% Confidence Interval	
				Lower	Upper
Result	Cohen's d	14.365	1.590	1.012	2.158
	Hedges' correction	14.548	1.570	0.999	2.131
	Glass's delta	17.382	1.314	0.708	1.904

The findings of this study indicate that the use of PhET Simulation oriented self-

regulated learning (SRL) not only provides a statistically significant effect on improving students' metacognition skills, but also has a practical impact in the process of learning science. The results indicated that the implementation of SRL-oriented PhET Simulation-based learning was in the excellent category. The active involvement of students during the learning process shows that this simulation media successfully creates an interactive learning environment and supports conceptual understanding concretely. These findings are consistent with those of Drastisianti et al., who stated that PhET can improve higher-order thinking skills, although their study did not assess metacognitive aspects.¹⁸ Students' ability to manage variables, interpret results, and complete exploratory tasks shows that a technology-based approach can optimize the learning process.

SRL-based learning provides space for students to organize their learning strategies independently.¹⁹ In this context, PhET Simulation supports such independence by providing an environment that allows free, yet purposeful exploration. In addition, the visual representation and direct manipulation of abstract concepts in the simulation strengthens students' cognitive engagement.²⁰ Theoretically, this is in line with the concept of zone of proximal development (ZPD) which states that students' understanding can increase optimally if supported by appropriate tools.²¹ Thus, PhET Simulation can be considered as a medium that can bridge the gap between potential and actual achievement of students.

The high level of student activity during learning indicates the application of SRL strategies that include planning, monitoring, control, and evaluation. Students are able to design exploration steps, formulate initial hypotheses, and set learning goals independently.²² This shows that students are not only passively involved, but also take the initiative in directing their learning process. In the monitoring stage, students actively

¹⁸ Drastisianti et al. (2024)

¹⁹ Tim Hartelt and Helge Martens, "Self-Regulatory and Metacognitive Instruction Regarding Student Conceptions: Influence on Students' Self-Efficacy and Cognitive Load," *Frontiers in Psychology* 15 (2024): 1450947.

²⁰ Philip H Winne and Roger Azevedo, "Metacognition and Self-Regulated Learning," in *The Cambridge Handbook of the Learning Sciences*, ed. R Keith Sawyer, 3rd ed., Cambridge Handbooks in Psychology (Cambridge: Cambridge University Press, 2022), 93–113, <https://doi.org/DOI:10.1017/9781108888295.007>.

²¹ Laela Nur Afifah and Eli Masnawati, "Peran Teknologi Dalam Pembelajaran Dan Perkembangan Kognitif Anak Usia Sekolah," *EduCurio: Education Curiosity* 2, no. 3 (2024): 616–21.

²² Arief Budhiman et al., "Implementasi Media Pembelajaran IPA Berbasis Adobe Flash CS6 Untuk Meningkatkan Kemampuan Metakognisi Siswa SMP," *UPEJ Unnes Physics Education Journal* 10, no. 3 (2021).

assess the effectiveness of the strategies used and show awareness of their own progress. Ghimby proved that SRL affects critical thinking skills,²³ but has not yet combined it with simulation media. This awareness is a reflection of metacognitive skills that develop along with involvement in simulation.

Furthermore, students also show good control through adjusting learning strategies when facing difficulties.²⁴ This flexibility shows independence in thinking and cognitive resilience in facing learning challenges. The evaluation stage strengthens students' self-regulation, where they are able to reflect on the effectiveness of the learning approach, recognize the weaknesses of the strategies used, and plan improvements for the future.²⁵ This shows the formation of reflective thinking skills which are the core of metacognition. From the perspective of social cognitive theory, students' active involvement in controlling the learning process also increases their motivation and self-efficacy,²⁶ which in turn strengthens critical thinking and problem solving skills.

The quantitative findings previously described showed a significant increase in students' metacognition ability in the experimental class compared to the control class. The t-test and N-Gain results show that the simulation-based learning approach with SRL integration encourages students to develop thinking awareness and evaluative ability of their learning strategies. This shows the effectiveness of the approach in shaping deeper and sustainable learning abilities. In the framework of constructivism, this improvement is the result of an active learning experience, where students build their own knowledge through direct interaction with learning materials.²⁷ Simulation allows students to experiment with various variables and evaluate the results without high risk, which strongly supports independent scientific exploration.

²³ Ghimby, "Pengaruh Self Regulated Learning Terhadap Kemampuan Berpikir Kritis Dan Hasil Belajar."

²⁴ Hartelt and Martens, "Self-Regulatory and Metacognitive Instruction Regarding Student Conceptions: Influence on Students' Self-Efficacy and Cognitive Load."

²⁵ Wahyu Lestari, Fatinatus Selvia, and Rohmatul Layliyyah, "Pendekatan Open-Ended Terhadap Kemampuan Metakognitif Siswa," *At-Ta'lim: Jurnal Pendidikan* 5, no. 2 (2019), <https://doi.org/10.36835/attalim.v5i2.263>.

²⁶ Mulyanto Mulyanto, Hasan Maksum, and Eko Indrawan, "Kontribusi Disiplin Belajar, Efikasi Diri Dan Iklim Sekolah Terhadap Hasil Belajar Simulasi Dan Komunikasi Digital Siswa," *Jurnal Imiah Pendidikan Dan Pembelajaran* 5, no. 1 (2021), <https://doi.org/10.23887/jipp.v5i1.31491>.

²⁷ Riyanti Riyanti et al., "Konstruktivisme Dalam Pembelajaran IPA Abad 21," *Prosiding Seminar Nasional Pascasarjana*, 2021.

Furthermore, metacognitive skills develop through the process of organizing, monitoring, and evaluating learning strategies that are continuously carried out.²⁸ The learning environment provided by PhET Simulation provides this opportunity explicitly. This process helps students learn from mistakes, build reflective and analytical thinking skills, and develop more effective ways of learning for future academic challenges. The improvement of metacognition skills in this study is inseparable from the use of learning media that can make students maximize their abilities.²⁹ Thus, this study fills the gap in previous research by presenting a combination of SRL + PhET and focusing on measuring metacognition at the junior high school level.

CONCLUSION

Based on the results of the analysis and discussion, this study shows that the use of PhET Simulation oriented self-regulated learning (SRL) is proven effective in improving students' metacognition skills in science learning. The application of this approach encourages students to be more independent in organizing learning strategies, increasing awareness of the thinking process, and developing reflective and evaluative abilities towards their own understanding. The results of statistical testing, both descriptive and inferential, showed a significant increase in students' metacognition skills in the experimental class compared to the control class. This effectiveness is also supported by the active involvement of students during learning, which reflects the successful integration of interactive simulation media with learning approaches that emphasize self-regulation. Based on these findings, it is suggested that the use of SRL-oriented PhET Simulation can be applied more widely in science learning and other subjects that require the development of higher order thinking skills. Further research can examine its effect on other variables such as learning motivation, long-term learning outcomes, or its application in the context of project-based learning.

²⁸ Erianti et al. (2020)

²⁹ (Khasanah & Hadi, 2024)

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