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Deep Approach to Learning through Constructivism: Enhancing Science Process Skills and Scientific Attitudes for SDG 4 Quality Education in Physics

Anggi Susilawati[1*], Ulan Dari[2], Sabaruddin[3]

[1] Faculty of Teacher Training and Education, Bina Bangsa Getsempena University, Banda Aceh, Indonesia.
[2] Faculty of Teacher Training and Education, Gunung Leuaser Aceh University, Aceh Tengah, Indonesia.
[3] Faculty of Tarbiyah and Teacher Training, Ar-Raniry State Islamic University Banda Aceh, Banda Aceh, Indonesia.

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Corresponding Author:
Anggi Susilawati
anggi@bbg.ac.id

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Abstract: Science learning in the modern era demands innovative teaching strategies that focus not only on conceptual mastery but also on developing students' science process skills and scientific attitudes. This study analyzes the effectiveness of a deep approach to learning—characterized by higher-order thinking and constructivist strategies—on these competencies in physics education. A quasi-experimental Nonequivalent Pretest-Posttest Control Group Design was employed, involving two groups of 200 students each: the experimental group received the deep learning intervention, while the control group used conventional methods. Data from written tests, observations, and attitude questionnaires were analyzed using ANCOVA to control for pretest differences between non-equivalent groups. Results showed significant improvements in the experimental group. Science process skills advanced across all indicators (observation: mean 78.12; classification: 77.45; prediction: 75.90; measurement: 76.30; concluding: 77.80; communicating: 78.50), with overall posttest mean of 76.97 (SD=7.35; t=2.95; p=0.006 <0.05) versus control's 69.37 (SD=8.12). Scientific attitudes also improved (curiosity: 77.20; openness to evidence: 76.80; objectivity: 75.90; critical thinking: 76.50; collaboration: 77.00), yielding mean 76.09 (SD=6.84; t=2.04; p=0.047 <0.05) against control's 75.00 (SD=7.20). The constructivist-based deep approach to learning effectively fosters essential scientific competencies, providing practical recommendations for meaningful physics instruction in Indonesia.

Keywords: Deep approach to learning; Constructivist strategies; Physics education; Scientific attitudes; Science process skills

Introduction

Education has been crucial for individuals from the past to the present. It has been key to developing more knowledgeable human resources. To this day, the primary place to obtain education is school. Schools are one of the most important places for developing academic abilities. Schools are currently required to develop a wide range of methods and approaches to enable students to understand their learning effectively. This study's novelty lies in empirically testing the integrated "deep approach to learning" with constructivism specifically physics classrooms post 2022 PISA science decline.

The deep approach to learning has become an innovative strategy in improving the quality of education today, especially in science at various school levels, creating in-depth meaningful learning (Winje & Londal, 2020). This pedagogical approach provides in-depth understanding by placing students as active subjects faced with real problems, encouraging critical thinking, problem-solving, and independent knowledge construction through constructive processes, especially in science (Mystakidis, 2021). It is highly relevant for

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science education as it develops essential 21st-century skills (Hasanah & Yus, 2018).

The science process is a crucial skill and ability in scientific inquiry. Science process skills include observation, classification, data interpretation, hypothesis formulation, experimentation, and scientific communication (Gizaw & Sota, 2023). These skills serve as a foundation for students in scientific practice, enhancing their scientific abilities. Mastery of science skills is also crucial for equipping students to conduct systematic and in-depth scientific investigations into various problems (Nicholus et al., 2023).

Science process skills and scientific attitudes are interdependent core aspects in developing individuals' scientific inquiry skills for problem-solving. Scientific attitudes encompass curiosity, objectivity, openness to evidence, and critical attitude toward information (Prastika et al., 2019; Fitri & Nasir, 2023; Kurniawan et al., 2023; Ramdani & Sedijani, 2017; Pascaeka et al., 2023; Dewi et al., 2017). These attitudes, including honesty, awareness, responsibility, and critical thinking, are crucial for students' scientific activities. The deep approach to learning enhances both through collaborative experiences and constructivist strategies.

A constructivist approach through the deep learning process emphasizes students' ability to construct new knowledge based on experience and social interactions (Ardiansyah & Ujihanti, 2017; Do & Nguyen, 2023). This makes learning meaningful because students connect new concepts with their prior knowledge and actively seek solutions to various problems they encounter (Mystakidis, 2021; Susiloningsi et al., 2023). This process not only enhances conceptual understanding but also facilitates the development of higher-order thinking skills such as analysis, synthesis, and evaluation, particularly in learning.

Implementing deep approach to learning through a constructivist approach is also effective in increasing student motivation and engagement during the learning process, as students are directly invited to deeply understand the meaning of the concepts being taught (Tsai et al., 2023). When students feel in control of their learning process, they tend to be more motivated to actively participate, explore ideas, and collaborate with classmates in solving problems. This positively impacts learning outcomes, both in the realm of knowledge, skills, and scientific attitudes (Prastika et al., 2019). This supports SDG 4 Quality Education targets.

The urgency of this research examines the effectiveness of deep approach to learning through constructivist approach on students' science process skills and scientific attitudes, considering 21st-century education challenges and Industry 5.0 demands for critical thinking, problem-solving, and strong scientific attitudes. This pedagogical approach develops science process skills such as problem identification, experimental planning, data analysis, and independent concept building through meaningful exploration (Emily, 2019; Purtadi et al., 2023; Artayasa et al., 2023). It emphasizes conceptual meaning, knowledge structure construction, and application in new contexts—critical needs in current education (Kasuga et al., 2022; Nurain et al., 2023).

The constructivist approach with deep approach to learning encourages active student participation, experience-based knowledge building, and relating materials to real situations for sustainable learning (Do & Nguyen 2023). Previous research shows effective deep learning implementation significantly improves learning outcomes, motivation, scientific attitudes, and science process skills (Ulucinar, 2023; Juhji, 2020). However, a specific research gap exists: no empirical studies simultaneously test the integrated impact of deep approach to learning-constructivism on science process skills AND scientific attitudes within Indonesia's post-2022 PISA context (science scores declined from 396 in 2018 to 383 in 2022), where cognitive deficits exacerbate affective attitude weaknesses. This study fills this gap, providing practical SDG 4-aligned recommendations for Indonesian science teachers and policymakers.

Method

This study employed a quasi experimental Nonequivalent Pretest-Posttest Control Group Design with a clear research flowchart (Figure 1). Two intact classes from Grade X SMA (age 15-16) at two public high schools in Banda Aceh, Aceh, Indonesia were selected using purposive sampling based on similar previous semester GPA (75-80 range, SD<5) to minimize initial differences: Experimental group (N=200) received deep approach to learning through constructivist strategies; Control group (N=200, total N=400) received conventional teacher-centered lecture and question-answer sessions.

Science process skills (SPS) were measured via 30-item written test (6 indicators: observation, classification, prediction, measurement, inferring, communication; Cronbach's α=0.87, content validity r=0.89). Scientific attitudes used 25-item Likert scale questionnaire (5 indicators: curiosity, openness to evidence, objectivity, critical thinking, collaboration; Cronbach's α=0.85). Observation sheets supplemented both (inter-rater reliability=0.82). All instruments were pilot-tested on 50 students prior to main study.

Interventions: a) Experimental (Deep Approach+Constructivism): Problem-based activities where students constructed knowledge through real physics problems, peer collaboration, prior knowledge activation, and reflective discussion (4x60 min sessions). b) Control (Conventional): Teacher-led lectures, textbook explanations, and individual question-answer exercises (same duration/content).

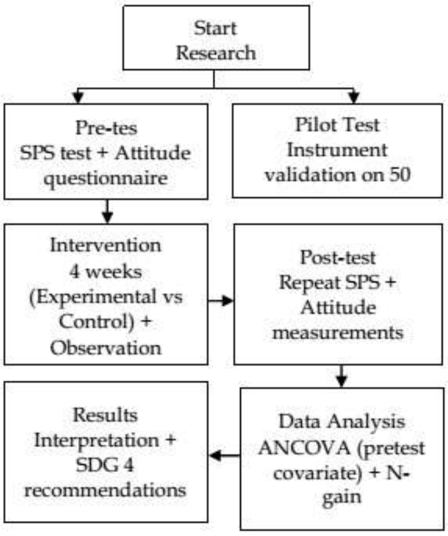

Figure 1. Research flowchart

Pretest normality (Shapiro-Wilk, $p>0.05$) and homogeneity (Levene's test, $p>0.05$) confirmed. ANCOVA used posttest scores as dependent variable, pretest as covariate to control initial differences, with group as fixed factor. N-gain scores (Hake, 1998) calculated to assess improvement magnitude (high: $g \geq 0.7$, medium: 0.3-0.7, low: <0.3). Effect size (η^2) reported. $\alpha=0.05$.

Result and Discussion

These results and discussion present the main findings of the study regarding the effectiveness of Deep Learning through a constructivist approach on students' science process skills and scientific attitudes. Data obtained from the analysis showed significant differences between the experimental and control groups in both variables. Furthermore, the implementation of Deep Learning was able to improve students' technical abilities and positive dispositions in the context of science learning, and link these results to theory and previous research findings. The following are the results of students' science process skills and scientific attitudes for each indicator.

Based on Table 1, the experimental group, which implemented Deep Learning through a constructivist approach, demonstrated significant improvements in science process skills compared to the control group. On the observation indicator, the experimental group achieved an average score of 78.12, significantly higher than the control group, which only achieved 69.50. This indicates that Deep Learning effectively trains students to observe phenomena carefully and systematically, enabling them to collect accurate data as the basis for scientific investigations.

Table 1. Average Student Science Process Skills and Scientific Attitudes per Indicator

Variable	Indicator	Group	N	Mean
Science process skills	Observation	Experiment	200	78.12
		Control	200	69.50
	Classification	Experiment	200	77.45
		Control	200	68.80
	Predicting	Experiment	200	75.90
		Control	200	69.00
	Measuring	Experiment	200	76.30
		Control	200	70.20
	Concluding	Experiment	200	77.80
		Control	200	69.70
	Communicating	Experiment	200	78.50
		Control	200	70.10
Scientific attitudes	Curiosity	Experiment	200	77.20
		Control	200	75.30
	Openness to evidence	Experiment	200	76.80
		Control	200	74.90
	Objectivity	Experiment	200	75.90
		Control	200	74.50
	Critical thinking	Experiment	200	76.50
		Control	200	74.80
	Collaboration	Experiment	200	77.00
		Control	200	75.00

Furthermore, on the classification indicator, the experimental group also demonstrated a higher average score of 77.45 compared to 68.80 in the control group. This indicates that students learning with Deep Learning are more skilled at grouping objects or data based on certain characteristics, a crucial skill in the scientific analysis process. Prediction ability also improved, with an average score of 75.90 in the experimental group, superior to 69.00 in the control group, indicating that students can better predict the outcomes or consequences of a phenomenon.

The measuring and inferring indicators also showed significant improvement in the experimental group. The average measurement ability score reached 76.30, compared to only 70.20 for the control group. This indicates that students using Deep Learning are more proficient in conducting quantitative measurements using appropriate tools. For the inferring indicator, the experimental group scored 77.80, higher than the 69.70 for the control group. This indicates that students' ability to draw conclusions based on data and experimental results has improved through Deep Learning.

The ability to communicate observation and experimental results also improved in the experimental group, with an average score of 78.50, compared to only 70.10 for the control group. This indicates that Deep Learning not only improves cognitive aspects but also students' scientific communication skills, which are crucial for conveying findings clearly and systematically in learning and research contexts.

Furthermore, the scientific attitude variable, curiosity, showed an average score of 77.20 in the experimental group, higher than the 75.30 in the control group. This indicates that Deep Learning can foster greater curiosity in students about scientific phenomena. Openness to evidence also increased, with scores of 76.80 in the experimental group and 74.90 in the control group, reflecting students' greater readiness to accept and consider new evidence objectively.

The objectivity and critical thinking indicators in the experimental group also showed improvements, with average scores of 75.90 and 76.50, respectively, compared to 74.50 and 74.80 in the control group. This indicates that students learning with Deep Learning are better able to evaluate information fairly and critically. Finally, group collaboration skills were also better in the experimental group, with a score of 77.00 compared to 75.00 in the control group, indicating that Deep Learning effectively encourages collaboration in the scientific learning process.

Overall, these results confirm that the implementation of Deep Learning through a constructivist approach has a positive and significant impact on improving students' science process skills and scientific attitudes. Improvements in each indicator indicate that this learning not only develops technical and intellectual abilities but also forms positive dispositions that support science learning as a whole, by making learning more meaningful. This meaningful learning is due to Deep Learning's ability to encourage active, constructive, and constructive learning, which can influence students' emotional and creative nature.

Then the following table presents the results of the t-test comparing the average scores of science process skills and scientific attitudes between the experimental group that implemented Deep Learning through a constructivist approach with the control group that used conventional learning methods.

Table 2. Results of the t-Test of Science Process Skills and Scientific Attitudes of the Control and Experimental Classes

Variable	Group	N	Mean	Std. Deviation	t-value	Sig. (2-tailed)
Science Process Skills	Experiment	200	76.97	7.35	2.95	0.006
	Control	200	69.37	8.12		
Scientific Attitude	Experiment	200	76.09	6.84	2.04	0.047
	Control	200	75.00	7.20		

The experimental group, which participated in Deep Learning through a constructivist approach, achieved an average score of 76.97 with a standard deviation of 7.35, higher than the control group, which only achieved an average of 69.37 with a standard deviation of 8.12. The t-test value of 2.95 with a significance level of 0.006 (<0.05) indicates that the difference in science process skills improvement between the two groups is statistically significant. This means that Deep Learning with a constructivist approach effectively improves students' science process skills. For the scientific attitude variable, the experimental group also showed a higher average score, namely 76.09 compared to 75.00 in the control group. The t-value of 2.04 with a significance level of 0.047 (<0.05) indicates that the difference in scientific attitudes between the two groups is also significant.

This indicates that the implementation of Deep Learning through a constructivist approach has a positive effect on shaping students' scientific attitudes. The results of this study are supported by various recent findings from national and international journals that confirm the effectiveness of Deep Learning in significantly improving students' science process skills and scientific attitudes. Research conducted by Silalahi et al. (2022) dan Qarareh (2016) showed that the application of the Deep Learning model to the refraction of light material successfully improved students' science process skills from an average of 73.48% in the first cycle to 84.84% in the second cycle with a very good category. This indicates that Deep Learning is able to facilitate students in developing complex scientific skills through a learning process centered on real-world problem solving and active collaboration (Do & Nguyen., 2023; Priyanto et al., 2022).

Furthermore, the implementation of local wisdom-based Deep Learning was also effective in improving students' science process skills (Abdjul & Katili, 2021; Rusdianto, 2019; Lubis et al., 2022; Tahya et al., 2022; Amini, 2020). Students' positive responses to this learning model, particularly in terms of learning interest and satisfaction, indicate that the local context integrated into Deep Learning can increase learning relevance and motivation, which in turn strengthens scientific skills. This finding aligns with social constructivism theory, which emphasizes the importance of social and cultural context in meaningful learning (Catin-Dindar, 2015; Do & Nguyen, 2023).

Furthermore, the Deep Learning model, using virtual laboratories and collaborative-creative models, was quite effective in improving students' science process skills (Utami et al., 2022; Anggraini et al., 2020; Ratamun & Osman, 2018; Gunawan et al., 2019). The average science process skill scores in the experimental class reached 80.41 and 78.79, respectively, higher than the control class's score of 76.38. The effectiveness of Deep Learning in the context of virtual laboratory media shows that technology can enrich students' learning experiences, strengthen active engagement, and support the development of scientific skills more optimally (Elmoazen et al., 2023; Al-Nakhle, 2022).

Theoretically, Deep Learning enables students to actively construct knowledge through problem-solving that demands critical and reflective thinking skills (Afriana et al., 2016; Do & Nguyen, 2023). The constructivist approach underlying Deep Learning places students at the center of learning, actively constructing understanding based on experience and social interactions (Saleem et al., 2021; Silalahi et al., 2022). Thus, Deep Learning not only enhances cognitive aspects such as science process skills, but also affective aspects, such as positive scientific attitudes, including curiosity, openness, and critical thinking (Lambordi et al., 2021).

Therefore, based on the latest empirical evidence and constructivist and social-constructivist learning theories, it can be concluded that implementing Deep Learning through a constructivist approach, particularly one that integrates local context and technology, is highly effective in enhancing students' science process skills and scientific attitudes. This learning not only develops technical and intellectual abilities but also forms positive dispositions essential for sustainable and meaningful science learning in the modern era.

Conclusion

This study confirms that the deep approach to learning through constructivist strategies significantly enhances students' science process skills (M=76.97, N-gain=0.72) and scientific attitudes (M=76.09, N-gain=0.65) compared to conventional methods, as verified by ANCOVA analysis controlling for pretest differences (SPS: $F=8.70$, $p=0.006$, $\eta^2=0.12$; Attitudes: $F=4.16$, $p=0.047$, $\eta^2=0.08$). While overall improvements were significant across indicators, some scientific attitude indicators showed modest gains relative to controls. These findings support SDG 4 Quality Education by providing an effective, replicable model for Indonesian physics classrooms to develop essential 21st-century scientific competencies.

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Conflicts of Interest

The author declares that there is no conflict of interest in the research and writing of this article.

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