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Improving Elementary School Students' Science Process Skills Through the PDEODE Instructional Model

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Improving Elementary School Students' Science Process Skills Through the PDEODE Instructional Model

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ABSTRACT

Basic science process skills (SPS) of fifth-grade students on the water cycle topic remain low due to the dominance of conventional, transmission-based instruction. This study aimed to examine the effect of the PDEODE learning model on improving these skills. A quantitative quasi-experimental approach with a nonequivalent control group design was employed, involving 51 fifth-grade students (26 experimental, 25 control) selected through purposive sampling at Public Elementary School 54 Salupikung, Palopo. Data were collected using a validated and reliable basic SPS test (15 short-answer items, CVI = 0.92, $\alpha = 0.84$) administered as pretest and posttest, and analyzed using descriptive statistics, N-gain calculation, prerequisite tests, and an independent sample t-test. The findings revealed that the experimental group achieved a significantly higher average N-gain (0.66) compared to the control group (0.32), with a highly significant statistical difference ($p = 0.000$) and a very large effect size (Cohen's $d = 2.98$), consistently outperforming the control group across all indicators, particularly in observing skills (N-gain 0.75), with 96.2% of experimental students achieving moderate to high improvement. Future research is recommended to incorporate retention tests, employ randomized controlled designs, and integrate PDEODE with project-based learning on contextual environmental themes.

Keywords: PDEODE Learning Model, Science Process Skills, Water Cycle, Elementary School

INTRODUCTION

Natural Science education in elementary schools aims to equip students with the ability to understand natural concepts while simultaneously developing Basic Science Process Skills (SPS) (Hani et al., 2024; Cole et al., 2024). Basic SPS encompass observation, classification, communication, prediction, inference, and measurement. These skills are essential as they enable students to learn actively, discover concepts independently, and connect theories with real-world phenomena (Mukaromah et al., 2023). In the Water Cycle topic for fifth grade, for instance, SPS are required so that students do not merely memorize terms such as evaporation, condensation, and precipitation, but are also able to observe changes in the state of water, predict the consequences if one stage is disrupted, and communicate the water cycle process through diagrams or written explanations. In other words, SPS serve as the foundation for comprehensive scientific understanding.

However, the reality in the field indicates that fifth-grade students' basic SPS on the Water Cycle topic remain considerably low. Based on preliminary observations conducted at Public Elementary School 54 Salupikung, involving 32 fifth-grade students who had studied the Water Cycle topic through conventional instruction, the following results were obtained: the average observation ability reached only 52% (students struggled to specify the details of changes occurring when water is heated); classification ability 48% (students could not accurately distinguish between evaporation and condensation processes); prediction ability 45% (students were unable to predict what would happen if the sun did not shine); communication ability 50% (students could not explain the water cycle in the correct sequence); and inference ability 43% (students could not conclude the causes of rainfall). Overall, the average basic SPS score was only 47.6 out of a scale of 100. These data indicate that

the instruction conducted thus far has not been optimal in training students' science process skills.

The low achievement of basic SPS did not occur by chance. The primary cause is the dominance of conventional learning models (lectures, note-taking, and textbook-based assignments) that are still employed in the classroom. In this model, students mostly listen to the teacher's explanations without being given opportunities to predict, observe directly, discuss findings, or revise their own explanations (Koomson et al., 2024). In fact, the characteristics of the Water Cycle topic, which is process-oriented, cyclical, and concrete, are highly suitable for learning through direct experience and reflective discussion. Therefore, a learning model that can specifically activate all components of students' basic SPS is needed.

One model with the potential to address this need is the PDEODE (Predict-Discuss-Explain-Observe-Discuss-Explain) learning model. Developed by Costu (2008), this model is an enhancement of the POE (Predict-Observe-Explain) model. The PDEODE syntax consists of six stages: (1) Predict – students make individual predictions; (2) Discuss – group discussion to align predictions; (3) Explain – groups explain the rationale for their predictions; (4) Observe – students conduct direct observation through experiments or demonstrations; (5) Discuss – a second discussion to compare observation results with initial predictions; (6) Explain – a revised final explanation. The advantage of PDEODE lies in its two discussion and two explanation phases, which create cognitive conflict and simultaneously train observation, prediction, communication, and inference skills.

Nevertheless, studies on the application of the PDEODE model at the elementary and secondary education levels have been relatively well developed, for instance in physics and biology subjects (Alviaturrohman et al., 2021; Hardianti & Permatasari, 2023; Halimah et al., 2019), as well as at the tertiary level (Coştu & Bayram, 2021; Özbulut & Uyulgan, 2025). However, upon closer examination, these studies still exhibit a number of fundamental limitations. First, most previous studies focused on only one or two aspects of process skills and have not measured the entire set of basic SPS indicators (observing, classifying, predicting, communicating, and concluding) simultaneously within a single coherent design. Second, from a methodological standpoint, several studies still employed one-group pretest-posttest designs without control groups and used less rigorous purposive sampling techniques, thereby weakening their ability to establish causal relationships and posing risks of internal bias. Third, the topics addressed in PDEODE research at the elementary education level generally remain abstract or have not been deeply connected to concrete and easily observable science topics, such as the Water Cycle in fifth grade, even though this topic is highly suitable as it aligns with students' concrete operational stage and allows for simple and safe experiments.

Considering these gaps, the actual research gap lies in the absence of a study that comprehensively examines the effect of the PDEODE model on improving all indicators of basic SPS among fifth-grade elementary school students on the Water Cycle topic. This gap is important to address, given that conceptually, the Predict, Observe, and Discuss stages in PDEODE are highly aligned with the practice of basic scientific skills, while the Water Cycle topic, which is processual and cyclical, enables students to experience cognitive conflict firsthand through direct observation. Consequently, this study aims to examine the effect of the PDEODE learning model on improving basic science process skills among fifth-grade students on the Water Cycle topic. Based on the aforementioned framework, the following research hypotheses are proposed:

H_1 : There is a significant difference in the improvement of basic science process skills between students who learn using the PDEODE model and students who learn using the conventional model on the Water Cycle topic.

H_0 : There is no significant difference in the improvement of basic science process skills between students who learn using the PDEODE model and students who learn using the conventional model on the Water Cycle topic.

METHODS OF RESEARCH

This study employed a quantitative approach with a quasi-experimental research type. The design selected was the Nonequivalent Control Group Design, as the researcher could not perform full randomization of students since the classes had already been naturally formed within the school. In this design, there were two groups: the experimental group and the control group. Both groups were given a pretest before the treatment and a posttest after the treatment, without random assignment. The experimental group received instruction using the PDEODE (Predict-Discuss-Explain-Observe-Discuss-Explain) model, while the control group received instruction using the conventional model (lectures, question-and-answer sessions, and textbook-based assignments). Thus, the difference in the improvement of basic science process skills between the two groups could be measured more accurately.

The population of this study was all fifth-grade students at Public Elementary School 54 Salupikung, Palopo in Indonesia, in the even semester of the 2025/2026 academic year, which consisted of two parallel classes, namely Class V-A and Class V-B. The sample was selected using purposive sampling, with the consideration that both classes had relatively similar initial characteristics based on the class teacher's recommendation and previous daily science test scores that did not show significant differences. Class V-A was selected as the experimental group with 26 students (14 male, 12 female), while Class V-B served as the control group with 25 students (13 male, 12 female). Therefore, the total sample in this study was 51 students.

This study involved two types of variables. The independent variable was the learning model, which was distinguished into two: the PDEODE model for the experimental group and the conventional model for the control group. The dependent variable was the improvement in students' basic science process skills on the Water Cycle topic, which was measured through the difference between posttest and pretest scores (gain scores) or using N-gain (normalized gain) to categorize the level of improvement.

The instrument used was a Basic Science Process Skills test in the form of limited short-answer questions developed based on the basic SPS indicators investigated, comprising: (1) observing, (2) classifying, (3) predicting, (4) communicating, and (5) concluding. Each indicator was represented by three items, resulting in a total of 15 items. Prior to use, the instrument underwent a content validity process by two experts: one lecturer in Science Education and one experienced fifth-grade teacher at Public Elementary School 54 Salupikung. The validation results indicated that all items were declared valid with a CVI (Content Validity Index) of 0.92. Subsequently, the instrument was piloted with 20 fifth-grade students at another elementary school with similar characteristics (Public Elementary School 55 Salupikung). Based on the trial, the item validity test using Pearson product-moment correlation showed that out of 15 items, 13 were declared valid (r calculated $>$ r table = 0.444) and 2 items were revised. The instrument's reliability was calculated using Cronbach's Alpha formula and yielded a value of $\alpha = 0.84$, which indicates that the instrument has high reliability (highly suitable for use). In addition to the test, this study also employed an observation sheet for the implementation of the PDEODE model to ensure that the teacher delivered the learning syntax according to the plan.

The research procedure was carried out in five sequential stages. The first stage (preparation) began with an analysis of the Learning Outcomes for the Water Cycle topic in

Phase C (fifth grade), which were then elaborated into Learning Objectives and the Learning Objective Flow. Subsequently, the researcher developed teaching modules for three sessions for the experimental group (with PDEODE syntax) and three sessions for the control group (with the conventional model based on interactive lectures and assignments). Each teaching module was equipped with appropriate Student Worksheets, as well as assessment instruments (pretest and posttest) based on basic SPS. The second stage (pretest) was conducted in the first week, where both groups were given the basic SPS pretest for 60 minutes to measure initial abilities prior to the treatment. The third stage (treatment) lasted for three weeks with three sessions (each 2 x 35 minutes). In the experimental group, instruction followed the PDEODE syntax integrated into the Kurikulum Merdeka teaching modules: (1) Predict – each student wrote individual predictions about the water cycle process in their project book or worksheet; (2) Discuss – discussion in small groups (4-5 students) to align predictions, with process differentiation for students who required it; (3) Explain – group representatives explained the rationale for their predictions in front of the class, with the teacher providing reinforcement; (4) Observe – students conducted direct observation through simple demonstrations (heating water in a closed container, observing condensation, and rain simulation) in accordance with the Student Worksheets oriented toward the Pancasila Student Profile (Critical Reasoning and Mutual Cooperation); (5) Discuss – a second discussion in groups to compare observation results with initial predictions, noting any cognitive conflicts; (6) Explain – a final individual or group explanation that had been revised based on observational findings, written as conclusions in the Student Worksheets. Meanwhile, in the control group, the teacher used the conventional model also guided by the Kurikulum Merdeka teaching modules, but without the PDEODE syntax: activities centered on interactive lectures, question-and-answer sessions, reading texts from student books, completing practice questions, and constructing simple concept maps without prediction stages, direct observation, or reflective discussion. During the treatment, observation of the PDEODE model implementation was conducted by the partner teacher (the fifth-grade teacher) using a checklist, and the results showed that all syntax was implemented properly (average percentage 94%), thereby maintaining the internal validity of the study. The fourth stage (posttest) was conducted in the fourth week, where both groups were given the same basic SPS test as the pretest (with the item order randomized) to measure final abilities after the treatment. The fifth stage (data analysis) was performed after all data were collected, including the calculation of pretest scores, posttest scores, and N-gain.

Data analysis techniques were performed statistically using SPSS version 26 software. The first step was descriptive statistics to calculate the mean, standard deviation, minimum, and maximum values of the pretest, posttest, and N-gain for both groups. Subsequently, prerequisite tests were conducted prior to hypothesis testing, namely the normality test using Shapiro-Wilk (since the sample size was < 50 per group) and the homogeneity of variance test using Levene's test on the N-gain data. The normality test results indicated that the N-gain data for both groups were normally distributed ($p > 0.05$), and the homogeneity test also showed that the variances were homogeneous ($p > 0.05$). Therefore, the hypothesis testing employed the parametric Independent Sample t-test with a significance level of $\alpha = 0.05$. The testing criterion was that if the significance value (2-tailed) was < 0.05, then H_1 was accepted (there was a significant difference). In addition, to determine the category of basic SPS improvement in each group, N-gain calculations were performed using Hake's formula, then categorized as high ($g > 0.7$), moderate ($0.3 \leq g \leq 0.7$), or low ($g < 0.3$). This study was conducted from March to May 2026 at Public Elementary School 54 Salupikung, Palopo, located on Jalan Poros Salupikung, Wara Selatan District.

RESULTS AND DISCUSSION

RESULTS

Initial Data Description (Pretest)

Prior to the treatment, both groups completed a pretest to measure their initial basic science process skills on the Water Cycle topic. The descriptive statistics of the pretest are presented in Table 1.

Table 1 Descriptive Statistics of Pretest Basic SPS

Group	N	Mean	SD	Min	Max
Experimental (PDEODE)	26	48.12	5.67	38	58
Control (Conventional)	25	47.96	5.72	37	57

The mean pretest score of the experimental group (48.12) was nearly identical to that of the control group (47.96), with a difference of only 0.16 points. The standard deviations of both groups were also relatively similar (5.67 vs. 5.72), indicating comparable variability. The minimum and maximum values were also closely aligned. To determine whether this difference was significant, an independent sample t-test was conducted on the pretest data. The results showed a calculated t-value of 0.102, $df = 49$, and a significance value (2-tailed) of 0.919 ($p > 0.05$). This confirms that there was no significant difference in the initial basic SPS abilities between the two groups. In other words, the initial conditions of students in the experimental and control groups were equivalent, such that any differences observed in the posttest can be attributed to the treatment administered.

Final Data Description (Posttest)

Following the three-session treatment, both groups were administered a posttest using the same instrument. The descriptive statistics of the posttest are presented in Table 2.

Table 2 Descriptive Statistics of Posttest Basic SPS

Group	N	Mean	SD	Min	Max
Experimental (PDEODE)	26	82,35	6,28	70	92
Control (Conventional)	25	64,72	6,91	52	78

The mean posttest score of the experimental group (82.35) substantially exceeded that of the control group (64.72), with a highly meaningful difference of 17.63 points. More importantly, the improvement from pretest to posttest in the experimental group reached 34.23 points, while the control group improved by only 16.76 points. Thus, the PDEODE group experienced nearly twice the improvement compared to the conventional group. The standard deviation of the experimental group (6.28) was smaller than that of the control group (6.91), indicating that learning outcomes in the PDEODE group were more homogeneous (all students tended to improve uniformly), whereas the control group exhibited greater variation. The minimum posttest score of the experimental group (70) was also higher than the maximum pretest score of the control group (57), demonstrating that even the lowest-performing student in the experimental group successfully surpassed the initial ability of the highest-performing student in the control group.

Improvement of Basic Science Process Skills (N-Gain)

To determine the category of basic SPS improvement more objectively, N-gain calculations were performed using Hake's formula. A summary of the N-gain for both groups is presented in Table 3.

Table 3 Descriptive Statistics of Basic SPS N-gain

Group	N	Mean N-gain	SD	Kategori
Experimental (PDEODE)	26	0,66	0,12	Sedang
Control (Conventional)	25	0,32	0,11	Sedang

The mean N-gain of the experimental group (0.66) falls into the moderate category, yet it is very close to the high threshold (0.7). This means that, on average, students closed approximately 66% of the gap between their initial scores and the ideal score. Conversely, the control group achieved an N-gain of only 0.32 (also in the moderate category but at the lower boundary). This difference of 0.34 points is highly substantial on the N-gain scale. Furthermore, the standard deviation of the experimental group (0.12) was slightly larger than that of the control group (0.11), indicating that although the average was higher, the variation in improvement among students in the experimental group was somewhat more diverse; some students achieved very high improvement while others remained at moderate levels.

To examine the distribution of improvement in greater detail, Table 4 presents the frequency distribution of N-gain categories.

Table 4 Distribution of N-gain Categories

Category	Experimental Group (n=26)	Control Group (n=25)
High ($g > 0,7$)	8 students (30,8%)	2 students (8,0%)
Moderate ($0,3 \leq g \leq 0,7$)	17 students (65,4%)	14 students (56,0%)
Low ($g < 0,3$)	1 students (3,8%)	9 students (36,0%)

In the experimental group, 96.2% of students fell into the moderate to high improvement categories, with nearly one-third (30.8%) achieving high improvement. In contrast, only 64.0% of students in the control group achieved moderate to high improvement, and more than one-third (36.0%) remained in the low category (showing almost no meaningful improvement). This finding reinforces that PDEODE is not only effective on average but also equitable: only one out of 26 students showed low improvement, whereas in conventional instruction, nine out of 25 students showed almost no development in their basic SPS.

Analysis per Basic Science Process Skill Indicator

To understand the specific contribution of PDEODE to each aspect of SPS, an analysis per indicator was conducted. The five indicators measured (observing, classifying, predicting, communicating, and concluding) each had a maximum score of 12. Table 5 and Figure 1 presents the mean pretest, posttest, and N-gain scores for each indicator.

Table 5 Mean Pretest, Posttest, and N-gain Scores per Basic SPS Indicator

SPS Indicator	Group	Pretest	Posttest	N-gain	Category
Observing	Experimental (PDEODE)	6,24 (52%)	10,56 (88%)	0,75	High
	Control (Conventional)	6,20 (52%)	8,40 (70%)	0,29	Low
Classifying	Experimental (PDEODE)	5,76 (48%)	9,84 (82%)	0,65	Moderate
	Control (Conventional)	5,72 (48%)	7,92 (66%)	0,32	Moderate
Predicting	Experimental (PDEODE)	5,40 (45%)	9,36 (78%)	0,60	Moderate
	Control (Conventional)	5,36 (45%)	7,20 (60%)	0,26	Moderate
Communicating	Experimental (PDEODE)	6,24 (52%)	10,08 (84%)	0,67	Moderate
	Control (Conventional)	6,00 (50%)	8,16 (68%)	0,34	Moderate
Concluding	Experimental (PDEODE)	5,16 (43%)	9,48 (79%)	0,63	Moderate
	Control (Conventional)	5,16 (43%)	7,20 (60%)	0,26	Low
Total Raw Score (Max: 60)	Experimental	28,80	49,32	-	-
	Control	28,44	38,88	-	-
Total Score (0-100)	Experimental	48,00	82,20	0,66	Moderate
	Control	47,40	64,80	0,32	Moderate

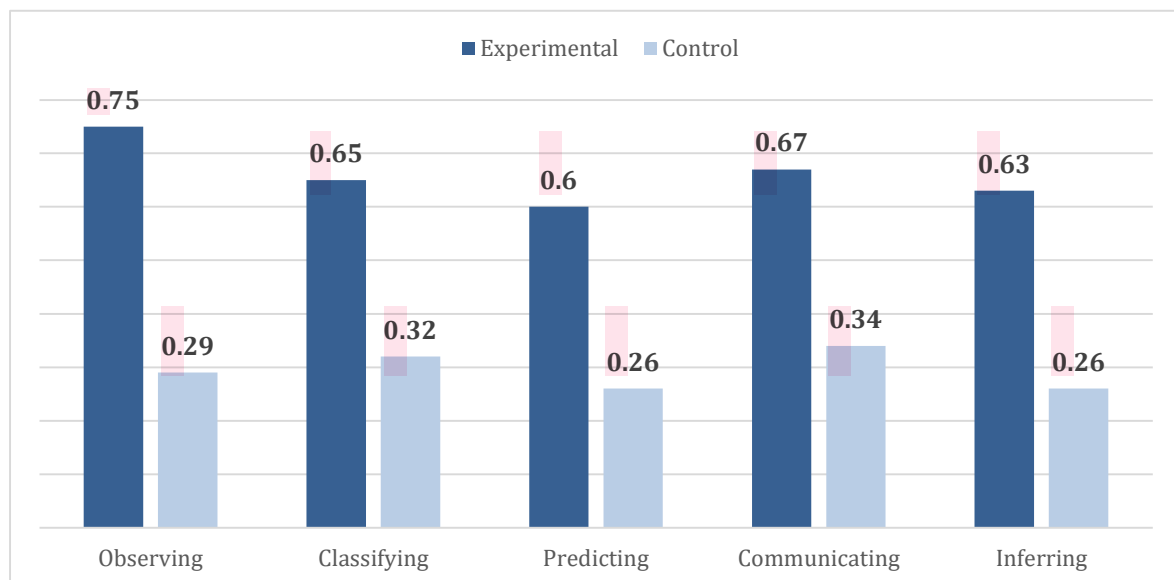


Figure 1 Comparison of Students' Average n-Gain in Science Process Skills

Table 5 demonstrates that the PDEODE learning model consistently outperformed the conventional model across all five basic science process skill indicators. The mean N-gain of the experimental group (0.66) fell into the moderate-high category, while the control group

(0.32) fell into the moderate-low category. This difference did not occur by chance but rather reflects the effectiveness of each PDEODE stage in training specific skills. The following is an analysis per indicator.

20 The observing indicator exhibited the most striking difference. The experimental group achieved an N-gain of 0.75 (high category), while the control group achieved only 0.29 (low). 3 On the pretest, both groups were equivalent (52%). However, after the treatment, the experimental group surged to 88%, whereas the control group only reached 70%. The scientific meaning of this is that the Observe stage in PDEODE, which involves direct demonstrations (heating water, observing condensation, rain simulation), provides a complete sensory experience that cannot be replaced by images or texts. Direct observation allows students to capture details of temperature changes, timing, and sequences of events, something impossible to obtain from conventional instruction that relies solely on verbal descriptions. The 36 percentage point increase in the experimental group (52% to 88%) constitutes empirical evidence that direct experience significantly improves the accuracy and depth of student observation. Meanwhile, the control group's improvement of only 18 points (52% to 70%) largely stemmed from repeated exposure to texts and images, without direct sensory experience.

The predicting indicator also demonstrated significant superiority of PDEODE (N-gain 0.60 vs. 0.26). The experimental group increased from 45% to 78%, while the control group only reached 60%. The scientific meaning is that the Predict stage in PDEODE requires every student to make an individual conjecture grounded in reasoning before knowing the facts. This activity trains hypothetical-deductive thinking, an ability that falls within Piaget's formal operational stage. In the control group, prediction was not trained in a structured manner; the teacher directly explained concepts so that students never tested their own reasoning. The N-gain difference of 0.34 points (0.60 vs. 0.26) indicates that structured prediction prior to observation is the key to developing forecasting ability in science. Furthermore, the very small improvement in the control group (45% to 60%) suggests that without prediction practice, this ability barely develops even after the material has been studied.

The concluding (inference) indicator showed a similar pattern: experimental N-gain 0.63 (moderate), control 0.26 (low). The experimental group's improvement from 43% to 79% contrasted sharply with the control group, which only reached 60%. The scientific meaning is that the ability to conclude in science does not automatically develop simply by listening to lectures. In PDEODE, the second Explain stage forces students to revise their initial explanations based on observational evidence. This process creates cognitive conflict, as when initial predictions do not match observation results, students must integrate new information and construct coherent conclusions. In contrast, in conventional instruction, conclusions are always provided by the teacher, causing students to lose the opportunity to practice independent inference. These data reinforce the theory that structured cognitive conflict improves the quality of scientific inference.

The communicating indicator was the only indicator in the control group that reached the moderate category (N-gain 0.34), though it still lagged behind the experimental group (0.67). The experimental group increased from 52% to 84%, while the control group increased from 50% to 68%. The scientific meaning is that although ordinary question-and-answer sessions in conventional instruction can slightly improve oral communication, PDEODE, with its two Discuss and two Explain stages, provides far more intensive scientific communication practice. In the first discussion, students learn to convey predictions and listen to alternatives. In the second discussion after observation, they learn to compare, critique, and revise statements. The 32 percentage point increase in the experimental group (52% to 84%) shows

that scientific communication requires a reflective discussion structure, not merely ordinary question-and-answer. The control group's improvement of only 18 points (50% to 68%) confirms that without structured discussion, communication improvement is limited to the ability to recall information rather than explain reasoning.

The classifying indicator also demonstrated the superiority of PDEODE (N-gain 0.65 vs. 0.32). The experimental group increased from 48% to 82%, while the control group increased from 48% to 66%. The scientific meaning is that classification in the water cycle topic involves the ability to distinguish evaporation, condensation, precipitation, and infiltration. In PDEODE, initial discussions often elicit misconceptions, for instance students consider condensation the same as precipitation. However, after direct observation, students visually distinguish these processes: evaporation is seen as water vapor rising, condensation as droplets on cold surfaces, and precipitation as falling water. The confrontation between initial predictions, which are often misclassified, and observational evidence causes restructuring of classification schemas. Meanwhile, conventional instruction relies solely on rote memorization of definitions, which is easily forgotten and does not fundamentally change students' thinking schemas. The control group's improvement (48% to 66%) was still in the low-moderate range and most likely reflects the effect of material repetition rather than conceptual change.

The pattern emerging from Table 5 is highly consistent: PDEODE provides higher improvement on all indicators, with the largest differences occurring in indicators requiring direct experience (observing) and hypothetical reasoning (predicting and concluding). These findings reinforce the argument that the PDEODE model not only improves total scores but also develops each component of science process skills in a balanced manner. In contrast, the conventional model provides only minimal impact on procedural indicators (communicating and classifying) while failing to develop higher-order skills such as predicting and concluding. Furthermore, the fact that the control group still showed small improvements on the communicating and classifying indicators (N-gain 0.34 and 0.32) indicates that the conventional model is not entirely without benefit, but its effectiveness is highly limited to aspects that do not require deep cognitive restructuring.

Prerequisite Test Results

Prior to hypothesis testing, normality tests (Shapiro-Wilk) and homogeneity of variance tests (Levene's test) were conducted on the N-gain data. The results are presented in Tables 6 and 7.

Table 6 Normality Test Results for N-gain Data (Shapiro-Wilk)

Group	Statistic	df	Significance
Experimental	0.952	26	0.256
Control	0.944	25	0.182

The significance values for the experimental group (0.256) and the control group (0.182) were both > 0.05 . Thus, the null hypothesis of normality was accepted, meaning that the N-gain data for both groups were normally distributed. This satisfies the requirement for using parametric tests.

Table 7 Homogeneity of Variance Test Results (Levene's Test)

F	df1	df2	Significance
1.347	1	49	0.251

The significance value (0.251) > 0.05 , indicating that the variances between the two groups were homogeneous. With both prerequisites satisfied (normal and homogeneous), the

hypothesis testing could proceed with the Independent Sample t-test.

Hypothesis Test Results (Independent Sample t-test)

The t-test was conducted to compare the mean N-gain between the experimental and control groups. The results are presented in Table 8.

Table 8 Independent Sample t-test Results for N-gain

Variable	t-value	df	Significance (2-tailed)
SPS N-gain	10,584	49	0,000

The calculated t-value was 10.584 with a significance value of 0.000 (far below $\alpha = 0.05$). Consequently, H_1 was accepted and H_0 was rejected. This means that there was a significant difference in the improvement of basic science process skills between students who learned using the PDEODE model and students who learned using the conventional model on the Water Cycle topic. This difference was very strong, as indicated by Cohen's d effect size of 2.98 ($d > 0.8$ is considered a large effect category). In practical terms, this means that the PDEODE model exerts a very large impact on students' basic SPS.

DISCUSSION

The findings of this study provide robust empirical evidence that the PDEODE model does not merely improve test scores, but rather transforms how elementary school students process and reason about scientific phenomena. The difference in average N-gain, which reached twice the magnitude (0.66 compared to 0.32), along with a highly significant statistical test and a large effect size (Cohen's $d = 2.98$), demonstrates that the instructional intervention exerts a substantive impact, not merely a chance effect or the result of individual variation alone. This superiority of PDEODE should be interpreted as a reflection of how each stage of its syntax works synergistically to create learning conditions that activate all components of science process skills simultaneously, a condition that is difficult to realize within conventional, transmission-based instruction.

If examined through the lens of Piaget's theory of cognitive development, these findings are particularly compelling, given that the research subjects (fifth-grade students, aged 10–11 years) are in a transitional period between the concrete operational stage and the formal operational stage (Zarkasyi et al., 2023). At this stage, children begin to demonstrate hypothetical-deductive thinking abilities, yet they remain highly dependent on concrete experiences as anchors for their reasoning. The PDEODE syntax emerges as an ideal bridge: the Observe stage provides concrete experience (concrete operational), while the Predict and the second Explain stages demand abstract reasoning and hypothesis revision (formal operational). This is precisely what distinguishes it from conventional instruction, which relies solely on verbal symbols and static images. As emphasized by Driver et al. (2000), scientific literacy among elementary-age children is not constructed through memorizing definitions, but rather through the process of testing one's own ideas against evidence, a process that is systematically structured within the PDEODE framework.

The most striking difference occurred in the observing indicator, where the experimental group achieved an N-gain of 0.75 (high category), whereas the control group only attained 0.29 (low). The leap from 52% to 88% in the experimental group indicates that direct observation through tangible demonstrations, such as heating water in a closed container, observing condensation, and conducting rain simulations, provided multisensory information that cannot be replicated by texts or illustrations. Within the framework of Kolb's (1984)

26 experiential learning theory, concrete experience serves as the foundation for reflection and conceptual abstraction. Students did not merely watch water boil; they also felt the steam, observed changes in water volume, and recorded the time required for droplets to form on the lid of the container. These details are precisely what enrich their mental schemas regarding evaporation and condensation. In contrast, control group students, who only observed illustrations in textbooks, tended to form static and oversimplified mental representations, such that when faced with essay questions requiring a systematic description of processes, they struggled to generate an accurate causal sequence.

19 Regarding the predicting and concluding indicators, both of which are classified as higher-order reasoning skills, they exhibited parallel improvement patterns (N-gain of 0.60 and 0.63 respectively for the experimental group, compared to 0.26 for the control group on both indicators). Prediction skills are not automatically possessed by elementary school children; they require deliberate practice in "what if" thinking. The Predict stage in PDEODE compels every student to formulate their own conjecture along with its justification, prior to any social intervention. As explained by White & Gunstone (1992), this activity functions as a truthful elicitor of initial conceptions, free from peer or teacher influence. When a previously held prediction contradicts observation results, a cognitive conflict occurs, which Piaget referred to as disequilibrium. The second Discuss and second Explain stages then serve as vehicles for reaching a new equilibrium, where students revise their initial explanations based on empirical evidence. This revision process specifically trains concluding skills, as students must integrate new information, discard unsubstantiated assumptions, and formulate coherent generalizations. Meanwhile, in the control class, conclusions were always provided by the teacher at the end of the lecture, leaving students to receive only the finished product without ever experiencing the process of knowledge production. This explains why the improvement on the concluding indicator in the control group was negligible (from 43% to 60%, with an N-gain of 0.26).

As for the classifying and communicating indicators, both groups demonstrated a moderate improvement category, though the gap remained substantial (0.65 vs. 0.32 for classification, and 0.67 vs. 0.34 for communication). A plausible explanation is that classification activities (distinguishing evaporation, condensation, and precipitation) and communication activities (explaining in the correct sequence) do indeed receive a larger portion of practice in conventional instruction through repetition, rote memorization of definitions, concept mapping, and oral question-and-answer sessions. However, this improvement reflects surface learning, where students memorize terminology and sequences without understanding why the order must be as such. Conversely, in the experimental group, dual discussions created space for students not merely to state classifications, but also to articulate the reasons why a particular event is grouped into a specific process. The first discussion encouraged students to articulate predictions and listen to alternatives, aligning with Podolskiy's (2012) Zone of Proximal Development theory, in which peer social interaction enables children to surpass their individual level of understanding. The second discussion, conducted after observation, encouraged students to compare, critique, and revise statements, resulting in richer and more reasoned scientific communication. This methodological discrepancy explains why, although both groups were classified as "moderate," the experimental group reached the upper threshold (0.67), while the control group only attained the lower threshold (0.34).

The systemic failure of the conventional model in developing basic science process skills is not solely attributable to the lecture method itself, but also to the unaccommodated cognitive structure it entails. In a transmission-based model, students are treated as passive

recipients who receive information packages. This information is processed in short-term memory; however, because there is no opportunity to confront it with experience or test it through discussion, it either quickly decays or becomes embedded as fragile rote knowledge. In information processing theory, this phenomenon is termed shallow encoding, which is encoding that does not involve elaboration of meaning. By contrast, PDEODE compels students through repeated prediction-observation-explanation cycles, which create deep semantic encoding because each new piece of information is always linked to initial predictions and observational evidence. This is why improvement occurred not only in total scores, but also was evenly distributed: 96.2% of students in the experimental group achieved moderate to high improvement, whereas more than one third of control group students (36%) remained in the low category.

From the perspective of implementing the Kurikulum Merdeka, these findings hold strong practical relevance. The Kurikulum Merdeka emphasizes student-centered learning approaches, the strengthening of the Pancasila Student Profile (particularly the dimensions of Critical Reasoning and Mutual Cooperation), as well as learning differentiation. The PDEODE syntax naturally accommodates all three demands: the Discuss stage trains Mutual Cooperation through group work and deliberation; the Predict and second Explain stages train Critical Reasoning through hypothesis testing and evidence-based inference; while the iterative process within PDEODE provides space for teachers to implement process differentiation, for instance by providing additional scaffolding for students who struggle to formulate predictions. These findings also reinforce the results of [Ekawati \(2018\)](#), [Basmala et al. \(2025\)](#) and [Maharani et al. \(2026\)](#), which demonstrated the effectiveness of PDEODE at the junior high school level, while simultaneously extending its scope to the elementary level with concrete and cyclical material. In other words, PDEODE is not a model exclusive to higher grade levels; rather, it is adaptive to students' cognitive developmental stages, provided that the selected material aligns with their everyday experiences.

This study has several limitations that must be acknowledged. First, the use of purposive sampling without randomization introduces the potential for selection bias, although the pretest equivalence test indicated that both groups were comparable. Second, the treatment duration was only three sessions (totaling 3.5 hours), which is relatively short for measuring long-term changes in process skills; it is possible that the observed effects represent short-term or novelty effects that may diminish over time. Third, the instrument only measured lower-level basic science process skills (observation, classification, prediction, communication, and inference) and has not yet covered integrated skills such as designing experiments, interpreting data, or posing investigative questions. Fourth, because observations were carried out through teacher demonstrations, it remains uncertain whether every student was genuinely and motorically engaged in the experimental process, or merely served as passive observers during the demonstration.

For future research, the inclusion of retention tests, for instance two weeks after the intervention, is recommended to assess the stability of science process skill improvement. A randomized controlled trial design involving a more diverse range of schools would enhance external validity. Exploring moderating variables, such as learning styles (visual, auditory, kinesthetic) and prior ability, could also reveal whether PDEODE is more beneficial for particular groups of students. Equally important, a direct comparative study between PDEODE and guided inquiry or problem-based learning models would assist teachers and policymakers in determining which model is most efficient for specific contexts and subject matter. Finally, integrating PDEODE with project-based learning under the Pancasila Student Profile theme of environmental conservation, for instance a project investigating the water cycle in the school's

surrounding environment, could serve as an engaging and contextual instructional development for elementary school teachers.

CONCLUSIONS

This study aimed to examine the effect of the PDEODE learning model on improving basic science process skills among fifth-grade elementary school students on the water cycle topic. The results demonstrated that the PDEODE model exerted a significant and substantial effect, with the experimental group achieving a considerably higher average N-gain (0.66) compared to the control group (0.32), along with a statistically significant t-test ($p = 0.000$) and a very large effect size (Cohen's $d = 2.98$). This superiority was consistently observed across all basic science process skills indicators, particularly in observing skills (N-gain 0.75), confirming that the PDEODE syntax effectively activates multiple scientific skill components simultaneously through concrete experiences and structured cognitive conflict, thereby successfully filling the research gap at the elementary school level. Nevertheless, this study has several limitations, including the use of purposive sampling without randomization, a relatively short treatment duration (three sessions), an instrument that only measured lower-level basic science process skills, and observation activities that relied on teacher demonstrations, which may have constrained active student engagement. For future research, it is recommended to incorporate retention tests to assess the stability of improvements, employ a randomized controlled trial design with a broader school coverage, explore moderating variables such as learning styles, and integrate PDEODE with project-based learning models on environmental conservation themes to enhance contextual relevance.

REFERENCES