



Enhancing Science Process Skills through Process-Oriented Guided Inquiry Learning (POGIL) in Fluid Dynamics

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Article Info	Abstract
Article history: Received: September 22, 2025 Accepted: December 8, 2025 Published: March 17, 2026	Science Process Skills (SPS) are essential competencies in science learning. However, observations indicate that the SPS of eleventh-grade students at a public high school in Banjarmasin remain relatively low, primarily due to the absence of systematic training in the learning process. Based on the results of a needs analysis, teachers require a learning approach that can effectively facilitate the development of students' SPS. This study aims to describe the effectiveness of the Process-Oriented Guided Inquiry Learning (POGIL) model in enhancing students' SPS in the context of fluid dynamics. The research employed a one-group pretest–posttest design. SPS training was implemented through practical activities utilizing both real and virtual laboratories. Data were collected using learning outcome tests (<i>Tes Hasil Belajar/ THB</i>) and SPS observation sheets completed by observers. The data were analyzed quantitatively using descriptive statistics. The results revealed that the n-gain value reached 0.79, indicating a high level of effectiveness, while students' SPS achievement was classified as very good. These findings demonstrate that the POGIL model is effective in enhancing the SPS of eleventh-grade students in learning fluid dynamics. The implications of this study suggest that the integration of POGIL in physics instruction, particularly in topics that involve experimental and analytical processes such as fluid dynamics, can serve as an effective strategy for developing students' inquiry skills and readiness for more advanced problem-solving tasks. This model may also provide a framework for teachers to design engaging and skill-oriented learning experiences across other science topics.
Keywords: Fluid dynamics POGIL Science process skills	
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INTRODUCTION

Science Process Skills (SPS) are fundamental competencies that must be developed throughout the educational process to enable students to acquire systematic and scientific ways of thinking, both in the classroom and in daily life include the ability to formulate questions, draw conclusions, analyze data, and communicate the results of scientific interactions, both individually and in groups ([Anggryani et al., 2024](#); [Nurfitriani et al., 2025](#)). SPS encompasses cognitive and psychomotor skills involved in problem-solving through scientific inquiry activities ([Salam & Miriam, 2016](#)). Students who actively participate in the learning process not only gain a deeper understanding of the subject matter but also enhance their self-confidence ([Safitri et al., 2024](#); [Sari et al., 2023](#)).

SPS covers both scientific processes and attitudes, and therefore, its training is ideally facilitated through laboratory activities. Laboratories serve as facilities for conducting experiments, investigations, and other scientific activities. Through physics laboratories, students can utilize tools and materials to develop systematic thinking patterns, gain meaningful learning experiences, and connect physics concepts with direct practice. Service laboratories, such as installation, conduct experiences, surveys, and other scientific activities. The use of laboratories by students plays an important role, that is, the benefit of science for students, and facing scientific fears as a career ([Astalini et al., 2020](#); [Nurdiansah et al., 2024](#)).

Initial observations conducted at a public high school in Banjarmasin City through interviews with physics teachers revealed that the commonly used learning approach was direct instruction combined with information-based discussions. This approach tends to be teacher-centered and focuses primarily on the theoretical understanding of scientific concepts. Consequently, essential SPS components—such as formulating hypotheses, identifying and defining variables, analyzing data, and drawing conclusions—are rarely practiced. Furthermore, the limited availability of laboratory equipment and materials, as well as the use of physics laboratories for other purposes, restricts students' access to practical activities.

In response to these issues, a learning model that can effectively train SPS is needed. One relevant approach is Process-Oriented Guided Inquiry Learning (POGIL), an inquiry-based learning method that emphasizes cooperative and metacognitive processes by combining guided inquiry with team collaboration. Through this model, students work collaboratively in groups to build cognitive understanding and develop critical thinking, problem-solving, and communication skills. POGIL focuses on understanding scientific concepts and processes to encourage deep thinking and problem-solving, both individually and collaboratively ([Samosir, 2022](#); [Sudartik et al., 2023](#)). The stages of this model include orientation, exploration, concept discovery, application, and evaluation ([Hanson, 2006](#)).

POGIL is grounded in constructivist learning theory, which asserts that students construct their own understanding through active learning experiences such as formulating concepts in their own words, processing information, drawing conclusions, and solving problems according to their stage of cognitive development ([Nainggolan & Daeli, 2021](#)). Theories of Piaget and Vygotsky also underpin this model. Piaget's theory emphasizes the importance of exploration and knowledge construction through discussion and problem-solving activities ([Salsabila & Muqowim, 2024](#); [Wahyuni et al., 2023](#)), whereas Vygotsky's theory highlights the role of social interaction in learning, such as group work, task sharing, discussion, and collective knowledge building ([Qiptiyah, 2024](#)).

The instructional materials selected for this study align with the *Merdeka Curriculum* for the odd semester, specifically the topic of fluid dynamics. SPS training was implemented through practical activities conducted in both real and virtual laboratories, supported by PhET simulations. The use of PhET has been proven to overcome equipment limitations and enable students to conduct interactive experiments using ([Sholikhah, 2021](#)). Moreover, PhET promotes student engagement in scientific activities, enhancing motivation and curiosity ([Drastisianti et al., 2024](#); [Muftid et al., 2021](#)). This aligns with the findings of Fertina ([2023](#)), which demonstrate that PhET simulations can enhance SPS, with n-gain values falling into the high category.

Several prior studies have confirmed the effectiveness of the POGIL approach in improving SPS. Fitriani ([2021](#)) reported a significant increase from an average pretest score of 44.2 to a posttest score of 82.2. Abram ([2022](#)) found that the experimental class achieved a posttest score of 83.5, higher than the control class's 72.5, indicating the positive impact of POGIL on learning outcomes. Rahmi ([2024](#)) reported that POGIL produced an n-gain of 0.73 (high category) and an average SPS achievement score of 3.63 (very good category).

The urgency of this study lies in the fact that SPS are not only essential for mastering scientific concepts but also serve as a foundation for developing 21st-century competencies such as critical thinking, problem-solving, collaboration, and communication. Without adequate training in SPS, students may struggle to connect theoretical knowledge with real-world applications, which is a key demand of the Merdeka Curriculum. Therefore, it is crucial to implement and evaluate an instructional model that effectively enhances SPS to ensure students are better prepared to face academic and everyday challenges

Based on this background, this study aims to describe the effectiveness of the POGIL model in developing students' science process skills in the topic of fluid dynamics. The novelty of this study lies in the integration of SPS training through real and virtual laboratories (PhET) within the context of the *Merdeka* Curriculum.

METHODS

This study employed a quantitative approach with a descriptive, pre-experimental design, specifically a one-group pre-test–post-test design. This design was selected because the research involved only one experimental class, due to the limited number of classes available during the study. The research was conducted in the odd semester of the 2024/2025 academic year, with 26 eleventh-grade students from a public high school in Banjarmasin City serving as the subjects, as presented in Table 1.

Table 1 Design one group pre-test post-test design

Pre-test	Dependent Variable	Post-test
O_1	X	O_2

Table 1 illustrates the symbolization of the one-group pre-test–post-test design, where O_1 represents the initial test administered before treatment, X represents the treatment in the form of Physics learning using the POGIL model, and O_2 represents the final test conducted after treatment ([Sugiyono, 2022](#)). The effectiveness of the treatment on students' abilities was analyzed using the normalized gain (n-gain) formula and categorized based on the criteria presented in Table 2.

Table 2 N-Gain categories

$\langle g \rangle$	Category
$\langle g \rangle > 0.7$	High
$0.3 \leq \langle g \rangle \leq 0.7$	Currently
$\langle g \rangle < 0.3$	Low

([Hake, 1998](#))

The learning materials in this study included the Principle of Continuity, Bernoulli's Law, and Applications of Bernoulli's Law. Measurement of students' science process skills (SPS) was conducted through observation of responses in the student worksheet, which were assessed according to SPS indicators with a maximum score of 4 for each indicator. Prior to the implementation, observers were provided with SPS observation sheets to evaluate six indicators: (1) formulating problems, (2) formulating hypotheses, (3) identifying variables, (4) conducting experiments, (5) analyzing data, and (6) drawing conclusions. The obtained scores were then categorized according to the criteria in Table 3 ([Suyidno et al., 2020](#)).

Table 3 SPS achievement categories

Interval Value	Category
$80 < \text{score} \leq 100$	Very good
$65 < \text{score} \leq 80$	Good
$55 < \text{score} \leq 65$	Pretty good
$40 < \text{score} \leq 55$	Less Good
$\text{Score} \leq 40$	Not good

RESULTS AND DISCUSSION

Implementation of the POGIL Model

The POGIL (Process-Oriented Guided Inquiry Learning) model comprises five key phases: orientation, exploration, concept formation, application, and closure. This model emphasizes concept-based learning and scientific processes to facilitate students' understanding of the material, enabling them to think critically and solve problems both individually and collaboratively ([Ahmad, 2025](#); [Sudartik et al., 2023](#)). In this study, the training of science process skills (SPS) was carried out over three meetings. The first meeting involved virtual laboratory activities using the PhET Simulation, while the second and third meetings were conducted through direct (real) laboratory experiments.

At each meeting, the POGIL model was implemented by facilitating exploration and concept formation activities. The learning process was conducted systematically and cooperatively, with students divided into small groups of four to five members. Each group implemented the role distribution suggested by [Hanson \(2006\)](#), namely: a group leader, a spokesperson, a note-taker, and a strategy analyst. This arrangement aimed to optimize group work and foster students' collaborative and metacognitive skills. Metacognitive development was promoted through reflection, debriefing, and final evaluation sessions, allowing students to become more aware of their own thinking processes.

Effectiveness of the POGIL Model

The effectiveness of learning was measured using a Learning Outcome Test (LOT) based on the intended learning outcomes for the fluid dynamics material. The LOT consisted of four essay questions with cognitive levels C3, C4, and C6. Essay-type questions were selected to give students the opportunity to express their understanding more openly. This choice is also in line with the nature of physics problems, which generally require students to perform a series of steps that lead them from the initial condition to the desired final condition ([Muftid et al., 2021](#); [Zulkifli & Mansyur, 2021](#)). Pre-test and post-test scores were analyzed using the normalized gain (*n-gain*) formula, with the results presented in Table 4.

Table 4 Results of calculating the effectiveness of the teaching module

Description	Score
Average Pre-test	5.29
Average Post-test	79.76
Average N-gain	0.79
Category	High

The results in Table 4 show a substantial improvement between the average pre-test and post-test scores, with a difference of 74.47 points. The low pre-test average was influenced by several factors, including: (1) the fluid dynamics material had not been previously taught, (2) students' reliance on teacher-provided example problems and difficulty in handling unfamiliar question types, and (3) the tendency of many students to only write the "known" and "asked" parts without completing the solute with [Hijriani & Hatibe \(2021\)](#), who argue that low problem-solving skills are often caused by minimal prior knowledge, limited exposure to similar problems, and low learning motivation.

After implementing the POGIL model, the average post-test score increased to 79.76, with an *N-gain* score of 0.79 (high category), indicating that the model was effective in improving learning outcomes. Figure 1 presents the improvement in average scores across all question items.



Figure 1 Graph of the average scores for each question item in the pre-test and post-test

Analysis of each test item revealed that questions 1 and 3 (C4 domain) showed the most significant improvement. Students demonstrated the ability to answer systematically, from formulating responses to drawing conclusions. Conversely, question 2 (C3 domain) had the smallest improvement, as some students still wrote only the data and formulas without completing the calculations accurately. This indicates a continued difficulty in recalling lengthy formulas and applying them correctly—a problem also noted by [Samani \(2021\)](#). To address this, mnemonic strategies and encouraging students to double-check their answers before submission, as suggested by [Arsy and Octarya \(2022\)](#), may be effective.

For question 4 (C6 domain), which required designing an experiment, most students successfully formulated problem statements, stated hypotheses, identified variables, and listed the necessary tools, materials, and procedures. This suggests that experimental design skills can be effectively developed through the POGIL model. This is because the POGIL model encourages students to be more active in the learning process, thereby reducing misconceptions and improving conceptual understanding, and there are key questions that make it easier for students to discover concepts. The POGIL learning model makes learning more effective, so if learning takes place effectively, it can be said that the learning is successful ([Abram et al., 2022](#); [Putri & Gazali, 2021](#); [Rahmawati & Sunarti, 2020](#)). These results are consistent with previous studies by [Fitriani \(2021\)](#), [Abram \(2022\)](#), [Rahmi \(2024\)](#), all of which reported significant improvements in both learning outcomes and SPS following the implementation of the POGIL model.

Achievement of Science Process Skills (SPS)

SPS performance was measured using observation sheets assessed by three observers. Six integrated process skills were evaluated: formulating problems, formulating hypotheses, identifying variables, conducting experiments, analyzing data, and drawing conclusions. Table 5 presents the average achievement scores for each indicator across the three meetings.

Table 5 Results of calculation of average SPS achievement

Indicator	Average SPS Achievement		
	Meeting 1	Meeting 2	Meeting 3
Formulating the Problem	94.44 (VG)	97.22 (VG)	100.00 (VG)
Formulating Hypotheses	84.72 (VG)	98.61 (VG)	100.00 (VG)
Identifying Variables	70.83 (G)	83.33 (VG)	97.22 (VG)
Conducting an Experiment	87.50 (VG)	95.83 (VG)	98.61 (VG)
Analyzing Data	81.94 (VG)	91.67 (VG)	94.44 (VG)
Drawing Conclusion	90.28 (VG)	93.06 (VG)	98.61 (VG)

Information: SB = Very Good, B = Good

The first indicator, formulating the problem, refers to students' ability to pose questions based on the background of the observed phenomena. In the first meeting, students appeared uncertain in determining the focus of their observations, as it was their first experience formulating a problem. However, by the second and third meetings, all groups

were able to formulate problems independently. Overall, the achievement for this indicator consistently fell into the very good category.

The second indicator, formulating a hypothesis, involves making a temporary assumption related to the problem formulation, expressed in the form of an “If..., then...” statement. The results indicate that students’ ability to formulate hypotheses improved throughout the learning process, with all meetings showing very good achievement.

The third indicator, identifying variables, pertains to distinguishing between manipulated, responding, and controlled variables according to the experimental context. During the first meeting, students had difficulty differentiating between the three types of variables due to their limited experience in conducting experiments, as evidenced by the tendency to list only one type of variable. Nevertheless, by the second and third meetings, substantial improvement was observed, with most groups accurately identifying all three variables. This indicator’s achievement increased from the good to the very good category.

The fourth indicator, conducting an experiment, includes selecting appropriate tools and materials as well as implementing experimental procedures. In the first meeting, which employed the PhET simulation, some students appeared confused and asked numerous questions, yet remained enthusiastic in carrying out the activities. In the second meeting, direct experimentation with physical equipment fostered greater enthusiasm and engagement. By the third meeting, students demonstrated improved skill and precision in executing the procedures. Overall, this indicator was categorized as very good.

The fifth indicator, analyzing data, requires students to process and interpret data in accordance with given instructions. In the first meeting, many students struggled to describe the data, often copying directly from the tables without providing meaningful interpretation—a challenge exacerbated by time constraints. However, in the second and third meetings, students became more adept at explaining and relating data to the problem under investigation. This indicator showed consistent improvement, remaining in the very good category.

The sixth indicator, drawing conclusions, evaluates students’ ability to summarize observational results, address the experimental objectives, and assess the alignment between findings and hypotheses. Overall, performance in this indicator was also categorized as very good.

In general, the average achievement across all SPS indicators was in the *very good* category, indicating that the implementation of the POGIL model in fluid dynamics is effective in developing students’ science process skills. This finding aligns with [Idul & Caro \(2022\)](#). [Muhammad \(2023\)](#), who reported that learning activities involving repeated practice can habituate students to SPS and improve conceptual understanding through practical work. POGIL fosters a learning environment in which students are actively engaged in mastering disciplinary content and developing essential skills by working in self-managed teams on guided inquiry activities. Furthermore, it supports the constructivist theory underpinning the POGIL model, which positions students as active participants in constructing knowledge through exploration and direct experience ([Sujanem et al., 2022](#)).

The POGIL model also demonstrates strong relevance to Vygotsky’s learning theory, which emphasizes that active student engagement is crucial for shaping learners into knowledge constructors [Muhammad \(2023\)](#). This is because the POGIL model encourages students to be directly involved in guided discovery through group work, by increasing interaction with group members and enhancing learning motivation. It also enables them to construct new knowledge and solve problems using their existing knowledge and allowing them to absorb knowledge well ([Hidayati, 2025](#); [Idul & Caro, 2022](#)). Thus, students do not merely receive information passively but actively build understanding through social interactions and guidance from teachers and peers. This approach is also consistent with Piaget’s perspective, which asserts that effective learning occurs when students participate in exploratory activities, discussions, and problem-solving that enable

them to construct knowledge independently (Agni, 2023). This is because in the POGIL model, students explore concepts, construct knowledge, and develop critical thinking skills through discussion and problem-solving with classmates. Active involvement in experimental activities also contributes to the formation of a deeper scientific understanding and increases students' curiosity (Alwanda et al., 2025; Iswanto, 2025). Thus, the POGIL model successfully integrates the principles of both theories, thereby fostering optimal improvement in students' science process skills.

CONCLUSION

The study demonstrates that implementing the Process-Oriented Guided Inquiry Learning (POGIL) model in fluid dynamics effectively enhances students' science process skills (SPS), as evidenced by a high n-gain value of 0.79 and the "very good" achievement of SPS indicators. These findings suggest that POGIL-based learning not only improves learning outcomes but also systematically and continuously trains SPS. The model's success in this context indicates its potential for broader application across other Physics topics and STEM disciplines, providing educators with a structured approach to fostering active engagement, critical thinking, and problem-solving abilities.

However, this study has a limitation, as students encountered difficulties in remembering long formulas and often did not recheck their answers, which affected accuracy in problem-solving. For future studies, it is recommended to employ mnemonic strategies or other methods to assist students in recalling physics formulas and to encourage the habit of reviewing their answers before submission.

The implications of this research are twofold. For schools, it provides information and innovation regarding the use of the POGIL model to foster students' science process skills. For future researchers, it offers reference material and additional insights for conducting further studies, particularly in the development of POGIL-based teaching modules to enhance science process skills.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

NAA developed, backgrounded, and wrote the research paper; AS and Q analyzed and validated the data.

AI DISCLOSURE STATEMENT

The author used ChatGPT and DeepL during the manuscript preparation process solely for translation and language refinement. After using these tools, the author carefully reviewed and revised the entire manuscript and assumes full responsibility for the content and accuracy of the work. All aspects of the research design, data collection, data analysis, and conclusion drawing were conducted entirely by the author without the assistance of artificial intelligence (AI).

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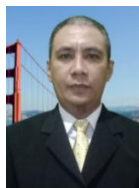
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