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The Effectiveness of Project Online Collaboration Laboratory in Improving Science Process and Critical Thinking Skills

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Abstract: This paper aims to determine the effectiveness of the implementation of the Project-based Collaboration (POC_Lab) online practicum model in improving students' Science Process Skills (SPS) and Critical Thinking Skills (CTS). This study uses a quasi-experimental method with a one-group pre-test and post-test design. The sample in this study was 50 students who had taken Basic Physics I and II courses. The research sample took part in the collaborative practicum with an online mode to complete physics project products in small groups. Students collaborated to apply fluid concepts to submarine and hydram pump products. Data were collected using KPS and CTS Test Questions, each with 4 essay questions given before and after the treatment. N_gain was used to determine the increase in students' KPS and ultimately determine the effectiveness of POC_Lab on students' KPS and CTS. The results showed that implementing POC Lab in project-based learning improved students' KPS and CTS. High effectiveness was seen in the increase in N-Gain in various aspects, especially in reasoning, argument analysis, hypotheses, and applying concepts.

Keywords: science process skills, critical thinking skills, project-based physics practicum, collaborative online practicum.

▪ INTRODUCTION

Science education is an essential foundation in the development of science and technology. One of the main goals of science education is to improve science process skills (SPS), which include the ability to observe, classify, predict, interpret data, and formulate and test hypotheses (Çakiroğlu et al., 2020; Firmansyah & Suhandi, 2021). These skills are not only essential for students in science but also crucial for developing critical thinking and problem-solving skills in everyday life (Maison et al., 2022). In science education, labs are one of the most effective methods to hone these skills. However, the COVID-19 pandemic and the shift to online learning have brought new challenges to implementing online labs (Arantika et al., 2019).

Another challenge is felt in distance learning, which is now being implemented in universities. Implementing physics practicums in distance learning at the Teacher Training Institute involves partner campus laboratories that are spread according to the student's domicile. In reality, the distribution of students in the remote, frontier, and outermost areas results in the inefficient implementation of practicums, requiring students to access partner campus laboratories at certain distances and other accommodation costs (Arkorful & Abaidoo, 2015; Moosvi et al., 2019).

There are characteristics of Distance Learning that facilitate students' learning independently, collaborating asynchronously and synchronously through e-learning, and following online tutorials as distance learning assistance (Alsayer, 2023). Especially in practical courses, effectiveness depends on the availability of practical facilities and

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infrastructure and ease of collaboration in practical stages, which impact physics concepts, skills, and attitudes (Firmansyah, Suhandi, Setiawan, & ..., 2022b; Ifeoma, 2016; Marjanah et al., 2021).

The implementation of the practicum reportedly confirmed several obstacles relevant to distance learning. Students often face accessibility constraints when conducting practical work, mainly because they have to work in specific partner laboratories far from where they live (Assbeihat, 2016; Malik et al., 2018). Furthermore, distance learning often results in a lack of interaction between students, lecturers/other participants, which can affect students' overall learning experience. This also impacts collaboration between students in practicums, which is becoming difficult due to the limitations of the platforms used and the lack of infrastructure to support such cooperation (Bond-Barnard et al., 2018; Ojediran et al., 2014; Wahyuni et al., 2021). Ultimately, a less interactive and collaborative lab experience can impact the overall quality of student learning, affecting understanding of the concepts being taught (Anwar, 2019).

Physical laboratory-based practicums, a tradition in science education, have become difficult to adapt to an online environment. However, advances in information technology have enabled the development of new practicum models, one of which is the Project Online Collaboration Laboratory (POC_Lab). This model combines collaborative and project-based approaches with online practicum implementation, which aims to improve students' science process skills by utilizing virtual technology, simulations, and online collaboration platforms (Saputra, Firmansyah et al., 2023). In addition, the project-based approach has been shown to provide space for students to engage in complex problem-solving and a more meaningful learning experience (Sadeghi, 2019).

Science process skills are a set of abilities that are essential in modern science learning. These skills include cognitive and psychomotor aspects that support students in identifying problems, designing experiments, collecting and analyzing data, and drawing conclusions based on empirical evidence (Septyowaty et al., 2023). Many studies have shown that science process skills can be improved through practical activities, where students are challenged to understand natural phenomena directly through experiments (Strat et al., 2024). However, limited laboratory infrastructure, especially in online learning situations, can be a significant obstacle to effectively implementing practicums (Masril et al., 2024).

Collaborative learning has long been recognized as an effective pedagogical method for improving learning outcomes across various disciplines, including science (Le et al., 2018). Collaboration allows students to share knowledge, experiences, and skills and work together to solve complex problems (Hussein, 2021). Students can better understand science concepts through collaboration and improve their critical thinking skills (CTS). A project-based approach can also increase students' motivation to learn because it gives them more control over their learning process (Almulla, 2020). In the context of science learning, collaboration can enrich students' practical experiences, enabling them to exchange ideas and actively contribute to joint research projects (Lin & Wang, 2024).

One of the significant challenges in online science education is integrating authentic laboratory experiences into a virtual format. Traditional laboratory experiences allow students to conduct physical experiments, essential to understanding scientific phenomena firsthand (Alnaser & Forawi, 2024). Nonetheless, in an online environment, the limitations of physical tools and direct interaction with experimental materials present new challenges. However, advancements in virtual laboratory simulation technologies, online data analysis tools, and online collaboration platforms have created new opportunities for conducting science practicums online (May et al., 2023).

The project-based approach to science learning has several advantages, especially in improving critical thinking, science process skills, and students' learning motivation. Project-based practicums allow students to be actively involved in solving problems, formulating hypotheses, and designing their experiments (Haryati et al., 2024). In online practicums, this approach allows students to collaborate with their peers in project teams through online discussions, joint data collection, or collaborative data analysis (Osmond-Johnson & Fuhrmann, 2022).

Furthermore, simulation technology in online practicums effectively supports the development of science process skills. Simulations provide students with realistic laboratory experiences without being in a physical laboratory while allowing them to repeat experiments and observe different variables in different situations (Lakka et al., 2023; Mashami et al., 2023). Simulations also allow students to access data that is difficult to obtain under conventional laboratory conditions, thereby expanding their understanding of complex scientific phenomena. Thus, integrating project-based approaches and online simulations in POC_Lab offers significant opportunities to improve the quality of science learning, particularly in honing students' science process skills.

One solution that is starting to be implemented is POC_Lab, which uses digital technology to simulate laboratory activities and allows students to work collaboratively on science projects. Through POC_Lab, students can conduct virtual experiments, share data, and discuss results with their peers online while still following the scientific steps required in science process skills (Firmansyah, Suhandi, Setiawan, & ..., 2022a; Saputra, Firmansyah, et al., 2023; Suarez et al., 2017). Several studies have shown that simulation-based labs and online collaborative projects can provide comparable results to traditional labs in improving science process skills and conceptual understanding (May et al., 2023).

Online collaboration in the context of online practicums offers an interactive and dynamic learning experience. POC_Lab encourages students to work in groups, share responsibilities, and communicate effectively to achieve project goals. This allows for the development of social and collaborative skills that are essential in scientific practice. Students involved in online collaboration showed significant improvements in science process skills, especially in critical thinking, data analysis, and scientific communication (Kurniawan et al., 2023).

In addition, online collaboration allows students to work with colleagues from diverse backgrounds, enriching their perspectives and approaches to solving scientific problems. In a digitally integrated environment, students can access global resources, discuss with field experts, and get valuable feedback from various parties (Haleem et al., 2022). Thus, POC_Lab not only functions as a science learning medium but also as a platform that facilitates the development of communication and collaboration skills needed in an increasingly globally connected world of work.

Research on the effectiveness of collaborative project-based online labs in improving science process skills is still in its early stages, but existing results show great potential. Simulation-based and collaborative project-based practical approaches can improve students' understanding of fundamental physics concepts and enhance their ability to design and conduct experiments (Kamalov et al., 2023). POC_Lab can help students develop science process skills that are more structured and systematic than traditional practicums.

With the increasing demand for flexible education and access to digital technology, POC_Lab can effectively solve the challenges of science learning in the digital era. The main advantage of POC_Lab is its ability to integrate collaborative, project-based learning and virtual simulations into one platform that allows students to engage actively in interactive and innovative science learning. Along with technological developments, this model is expected to continue to develop and contribute significantly to improving the quality of science education in the future. Therefore, this study aims to investigate the possibility of success or failure of using virtual workspace in project-based physics practicums to improve students' science process skills and critical thinking skills.

▪ METHOD

Participants

The population in this study was comprised of students enrolled in practical courses within science study programs at the university or college level. The sample consisted of 50 students who had completed Basic Physics I and II courses. To ensure the validity of the results, this study employed purposive sampling, where participants were selected based on specific criteria relevant to the research objectives. The requirements included students who participated in Basic Physics I & II practicums and had adequate access to the technological devices necessary for conducting POC_Lab.

Research Design and Procedures

This study employs a quasi-experimental approach with a pre-test and post-test design, comparing experimental and control groups to determine if significant differences in science process skills and critical thinking skills emerge after the POC_Lab intervention. A quasi-experimental design was chosen due to its flexibility in educational settings, where random assignment of subjects can be challenging. The pre-test and post-test design allowed researchers to assess the development of student skills before and after the POC_Lab intervention, comparing the results with those of a control group that did not receive the intervention.

The experimental group participated in the POC_Lab, applying the concepts of Archimedes' Principle through a submarine project. In contrast, the control group followed a project-based practicum focused on the Hydram Pump Project without using POC_Lab. Science process and critical thinking skills were measured using validated standardized test instruments administered before and after the practicum. Figure 1 illustrates the submarine product, while Figure 2 depicts the Hydram Pump product. Both products resulted from student collaboration in project-based lab stages, with and without the integration of POC_Lab.

Instrument

Data collection will be conducted using cognitive test instruments such as science process skills (SPS) and critical thinking skills (CTS) tests consisting of 4 questions each. Table 1 shows one of the SPS and CTS questions used.

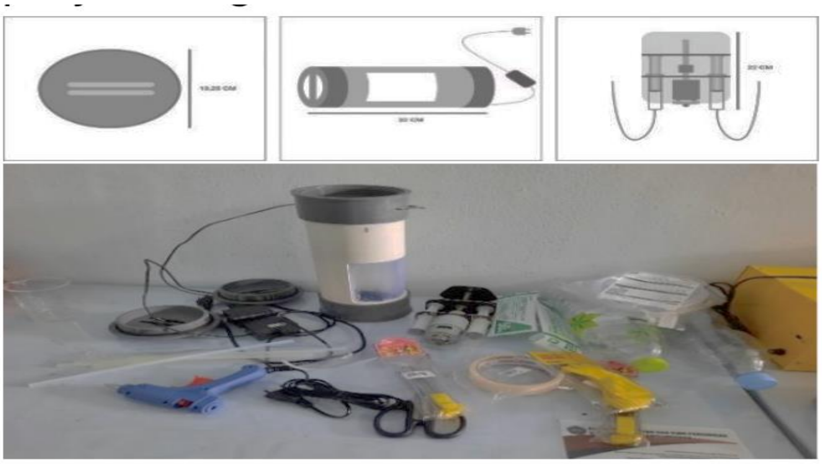


Figure 1. Submarine product

Figure 2. The path of hydram pump product

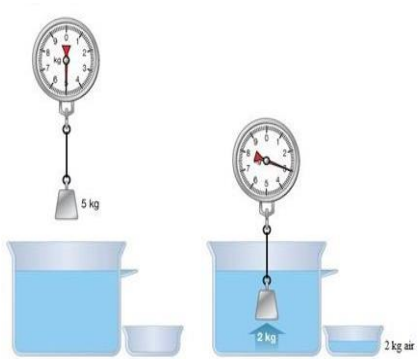
Test of Science Process Skills

This Test measures students' science process skills before and after the intervention. The Science Process Skills Test (TSP) consists of four essay questions, each targeting a specific aspect of science process skills, including observation, formulating experimental hypotheses, data interpretation, and concept application. This Test has been used in previous studies and has demonstrated good validity and reliability (Firmansyah & Suhandi, 2021).

Critical Thinking Skills Test

This Test will measure students' critical thinking skills and assess their reasoning, hypothesis testing, argument analysis, and probability and uncertainty analysis abilities. This study assesses each essential aspect of thinking skills (CTS) with one essay question. This instrument has been developed based on content validity and has been tested for use in project-based practicum activities (Firmansyah et al., 2021; Firmansyah, Suhandi, Setiawan, & ..., 2022b; Tiruneh, De Cock, et al., 2018).

Table 1. Sample of instrument test

Instruments	Question
SPS - Concept application	Amin and his group were tasked with measuring the volume of wooden chess pieces, as shown in the following picture.  Give your arguments to help Amin and his group complete the task using Archimedes' concept!
CTS - Reasoning	As shown in the picture below, Romi experimented by dipping an object into a liquid.  Based on the experiment conducted by Romi, is the weight of an object in a liquid lighter than that of an object in the air? Explain your answer.

Data Analysis

The data obtained from the pre-test and post-test will be analyzed quantitatively using relevant statistical methods. The normality test determines whether the pre-test and post-test data are typically distributed. Furthermore, the homogeneity test is used to see whether the experimental and control groups have homogeneous variances or whether the pre-test results' variability is similar.

Equivalence Test (Pre-Test) is conducted to determine whether the pre-test scores between the control and experimental groups are equivalent or not significantly different before treatment is given. Suppose all data are typically distributed and homogeneous, and the groups are statistically comparable. In that case, the N-gain Test can be conducted to calculate the increased process and critical thinking skills. Data on the rise in science processes and critical thinking skills are analyzed using the concept of normalized gain (<g>). Normalized gain is a measure of the effectiveness of a treatment, in this case, the POC_Lab practicum model. This measure of effectiveness is seen from the increase in the average gain value (Hake, 1998; Nissen et al., 2018) of both classes before and after the practicum is carried out.

Interpretation of mean N-gain <g> describes the criteria for the difference in impact before and after the application of the POC_Lab practical model, can use the requirements as shown in Table 2 (Hake, 1998)

Table 2. Mean N-Gain criteria

Limitation	Criteria
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

The effectiveness of applying the POC-Lab practicum model in improving science process and critical thinking skills can be seen from the percentage of students in each category <g> improving science process and critical thinking skills. Table 3. shows the effectiveness of the POC_Lab practicum.

Table 3. Effectiveness of using the POC-Lab practical model

Number of Students (N) who achieved a high $< g >$ increase %	Classification of Effectiveness
$75 < N \leq 100$	High
$50 < N \leq 75$	Medium
$N \leq 50$	Low

▪ RESULT AND DISSCUSSION

Fluid Practicum Based on POC Lab

The POC Lab-based fluid practicum integrates collaborative, project-based learning through a virtual workspace. This innovative approach allows students to explore fluid dynamics concepts, such as Archimedes' principle and Bernoulli's law, while working on practical projects like submarine and hydram pump designs. The POC Lab platform facilitates seamless online collaboration, where students engage in pre-lab, lab, and post-lab stages, enhancing their conceptual understanding and collaborative skills.

POC_Lab utilizes virtual workspaces that guide students through the pre-lab, lab, and post-lab stages. It is implemented and integrated into an online practicum system, enabling students to collaborate remotely and complete project-based practicum tasks. Students are divided into small groups to practice fluid dynamics concepts during implementation. It begins with establishing effective communication, tracing data and project requirements, and completing conceptual exploration before moving on to project design and execution. Figure 3 illustrates the implemented POC_Lab model.

POC_Lab is designed as a cloud-based digital workspace and information management system to enhance productivity and improve group work efficiency. In addition to fostering greater student engagement in practicum activities and promoting effective peer communication, it enables online collaboration meetings to discuss project designs and address other essential matters for project completion. Furthermore, POC_Lab helps students maintain organization by managing data, practical documents, and proof of project completion, all of which can be archived within the system. Figure 4 shows the interface of the virtual practical activity before students begin the project, as further explained in Figure 5.

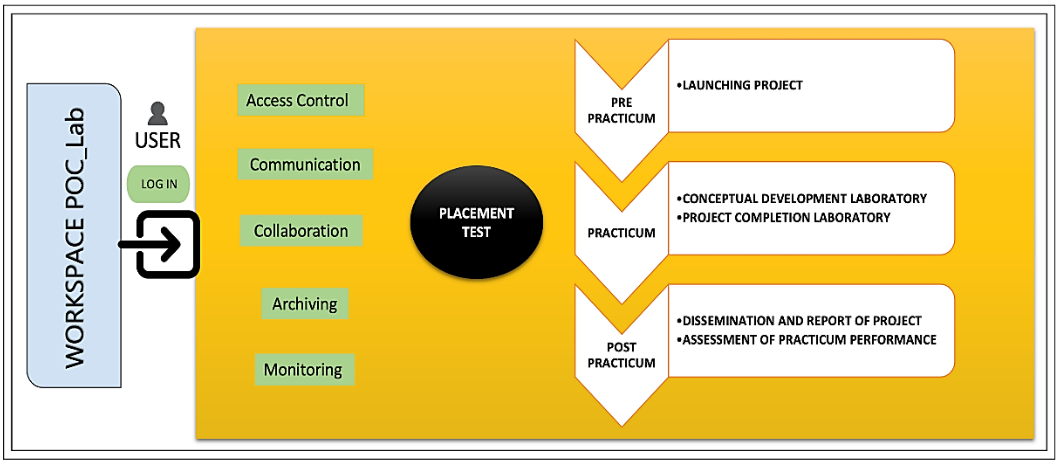


Figure 3. POC_Lab model in practicum

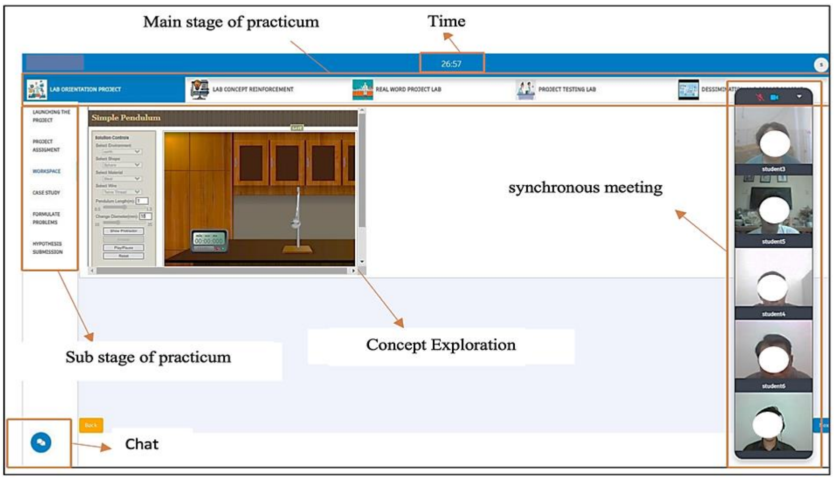


Figure 4. Interface POC_Lab

A placement test was administered to determine the student's initial cognitive level on fluid concepts. The placement test consisted of 4 questions assessing Science Process Skills (SPS) and 4 assessing Critical Thinking Skills (CTS). The results of the placement test were not only used to assess students' initial abilities but also to determine small group assignments for the subsequent stages. The next stage involved students participating in the project launching, where they began working in groups based on their placement test results. At this stage, students study and understand the project assignments, which are targeted to produce two practicum products: a hydram pump and a submarine. Next, students begin formulating problems and answering project-related questions to guide them in identifying the relationships between variables in the products they will create. The expected outcome is that students will discover several physics sub-concepts that can be applied to the completion of the submarine and hydram pump projects.

Next, students begin reinforcing concepts and sub-concepts through exploratory activities. POC_Lab facilitates students in following the inquiry stages by collaborating in small groups. A virtual laboratory also supports Exploring concepts, allowing students to re-test their experiments if necessary. Additionally, key features in POC_Lab can be optimized at this stage, such as enabling communication and collaboration through messaging channels within small groups and among peers. Students can also archive essential documents related to the practicum for more comprehensive evaluation. At this stage, instructors and lab supervisors can monitor student performance using analytical features, which track their activity throughout the practicum.

Figure 5. Project concept exploration and design activities

In the next stage, after students have formulated relevant conclusions to be applied to the submarine or hydram pump project, they complete the project based on the concept exploration from the previous phase. Students begin designing the project using the prepared worksheets. They then determine the tools and materials needed for the project. In practice, the necessary tools and materials are provided, and students select the appropriate ones for their planned project. Small groups collaborate to establish a commitment within the group, divide job responsibilities, assign roles to each member, and move forward to the product testing stage.

The final stage involves revising the test results to prepare for project dissemination and report preparation. The report and dissemination are carried out through recorded videos and YouTube broadcasts, allowing other groups to provide arguments and feedback on the product report and its dissemination. Ultimately, student activities and performance in the practicum can be assessed and monitored using the analytical features available in the system.

Implementing the POC_Lab in dynamic fluid learning represents an innovative approach integrating project-based physics learning with cloud-based technology, enabling online student collaboration. In this practicum, students are divided into small groups to design and complete real-world projects, such as building mini-submarines and hydram pumps. These projects deepen students' understanding of dynamic fluid concepts, including Bernoulli's principle, fluid flow, and hydrostatic pressure. Using digital workspaces in POC_Lab allows students to communicate effectively, track data, and comprehend project requirements collaboratively. This is consistent with the findings of Zhang & Ma (223), who noted that project-based learning enhanced by digital technology can increase student engagement in group discussions and help them design innovative solutions.

The collaborative process begins with concept exploration, where students must grasp the fundamental principles of fluid dynamics before conducting virtual experiments. After mastering the basic concepts, students design and develop solutions for their projects. One of the primary advantages of POC_Lab is its ability to enhance the organization of practicum data. Students can systematically store experimental results, project reports, and evidence of project completion within the platform. POC_Lab also facilitates online collaborative meetings, allowing students to discuss project designs and problem-solving strategies. According to Gonzales et al. (2023), cooperative learning through online platforms has improved students' time and resource management skills during the practicum process. The results of POC_Lab implementation demonstrate that students could produce tangible products, such as mini submarines and hydram pumps, which prove their understanding of dynamic fluid concepts. These products not only showcase their ability to apply theoretical knowledge but also their capacity to solve project-based problems collaboratively

This study conducted normality and homogeneity of variance tests to ensure that the pre-test and post-test data met the basic assumptions required for parametric statistical analysis. The normality test checks whether the data is typically distributed, an essential requirement when using the t-test or ANOVA analysis. On the other hand, the homogeneity test checks whether the variance between the two groups, namely the pre-test and post-test, is uniform. Failure to meet these assumptions may affect the statistical results' validity and require more appropriate non-parametric analysis methods.

A normality test was conducted using the Shapiro-Wilk test on pre-test and post-test data. The test results showed that pre-test data had a W value = 0.99149 with a p-value = 0.9955, and post-test data had a W value = 0.94051 with a p-value = 0.07738. The p-value of both groups is more significant than 0.05, which indicates that the data is usually distributed. Therefore, it can be concluded that the pre-test and post-test data meet the assumption of normality, which allows the use of parametric statistical analysis methods.

Levene's Test was used to test the homogeneity of variance between the pre-test and post-test data. The test result showed an F value = 0.0085 with a p-value = 0.9268 greater than 0.05. This indicates no significant difference in variance between the two groups. Thus, the assumption of homogeneity of variance is met, which means that the variance between the pre-test and post-test can be considered homogeneous. Figure 6 explains the results of the normality and homogeneity tests using the RStudio Model Analysis.

The results of the normality and homogeneity tests show that the pre-test and post-test data are typically distributed and have homogeneous variance (see Table 4). Therefore, parametric analysis can be used validly in this study. Furthermore, N-Gain analysis will be used to measure the effectiveness of the treatment in improving student skills.

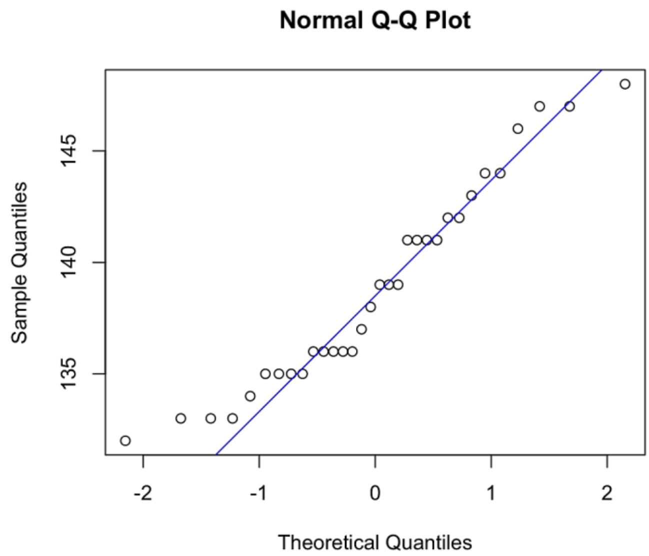


Figure 6. normal Q-Q plot

Table 4. Results of normality and homogeneity tests

Statistical Test	Statistical Value	p-value	Conclusion
Shapiro-Wilk (Pre-test)	W = 0.99149	0.9955	Data is normally distributed
Shapiro-Wilk (Posttest)	W = 0.94051	0.07738	Data is normally distributed
Levene's Test	F = 0.0085	0.9268	Homogeneous variance

The Impact of POC_Lab on Science Process Skills

The pre-test equivalence test showed no significant difference between the experimental and control groups in science process skills and critical thinking skills. This indicates that both groups had equivalent initial conditions before reintervention. Table 5 provides information on improving students' science process skills in each aspect, with a moderate category and an effectiveness score of 68 - 79%.

Table 5. N-Gain and effectiveness classification of SPS

SPS	High N_gain (%)	Effectiveness Classification
Observation	68	Medium
Interpretation	71	Medium
Hypothesis	76	High
Applying Concepts	79	High

Figure 7 also illustrates the effectiveness of POC_Lab on SPS. All aspects are above the threshold of 50%. Applying physics concepts through established projects gets the highest percentage of effectiveness value, which is 79%.

Science Process Skills (SPS) are crucial in science education, encompassing the abilities of observation, hypothesis formulation, data interpretation, and concept application. Implementing POC_Lab has been shown to improve students' science process skills positively. Pre- and post-assessments of SPS were conducted to measure

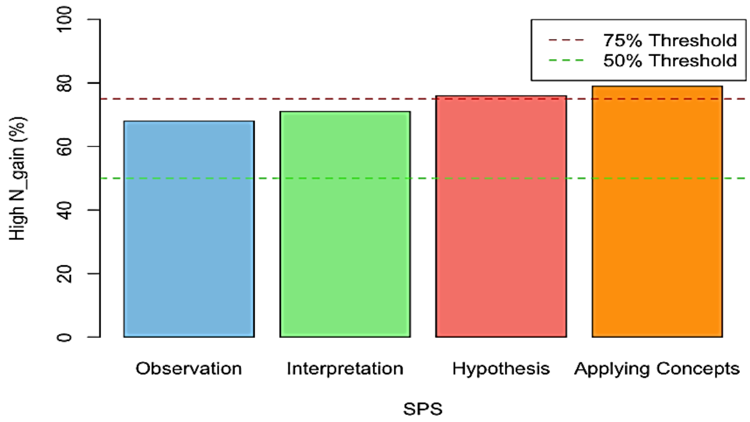


Figure 7. Threshold SPS

the extent of improvement in students' abilities in observation, experimentation, and data processing. At the observation stage, students could identify dynamic fluid phenomena within the context of the projects they were working on. Using POC_Lab as a platform for managing experimental data made it easier for students to observe changes occurring during the experiments, such as the effects of fluid pressure on water flow in the hydram pump. This is supported by the study of Matovu et al. (2023), which demonstrated that using digital technology in science learning can enhance students' observational skills by providing more precise and structured visualizations. Regarding hypothesis formulation and data interpretation, students in POC_Lab could generate hypotheses based on their observations and critically analyze experimental data (Bereczki & Kárpáti, 2021).

They evaluated the results of their experiments to determine whether the hypotheses they had formulated aligned with the actual outcomes. According to Firmansyah et al. (2021), integrated with digital technology, project-based learning can improve students' ability to interpret data more accurately, as they can monitor and access experimental data in real time. The application of dynamic fluid concepts in the projects also showed significant improvement. Students could apply the physics principles they had learned to real-world project designs, such as managing fluid flow in the hydram pump and the principle of buoyancy in the mini-submarine. This is consistent with the findings of Guo et al. (2020a) , who stated that students' science process skills improve significantly through project-based learning that emphasizes the application of theoretical concepts in real-world contexts

The Impact of POC_Lab on Critical Thinking Skills

Furthermore, improving critical thinking skills increases the N_Gain results after participating in a project-based practicum. These results are presented in Table 6.

Table 6. N-Gain and effectiveness classification of CTS

CTS	High N_gain (%)	Effectiveness Classification
Reasoning	83	High
Thinking as hypothesis testing	78	High

Argument analysis	87	High
Probability and Uncertainty Analysis	80	High

Based on Table 6, the critical thinking skills were improved in the implementation of POC_Lab and the completion of the project. The improvement and effectiveness scores are between 83% and 87% in the high category. Figure 8 explains the effectiveness of POC_Lab in terms of its threshold.

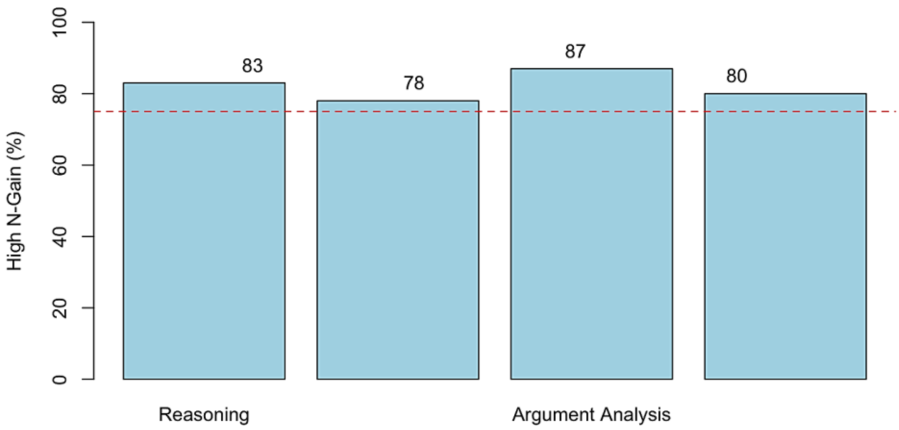


Figure 8. Effectiveness classification of CTS

The higher increase in science process skills in the experimental group compared to the control group indicates that project-based POC_Lab can effectively improve these skills. POC_Lab facilitates student collaboration in designing, implementing, and analyzing experimental results, providing hands-on experience that strengthens their scientific abilities. In addition, applying fluid concepts through the submarine and the hydram pump project allows students to understand the relationship between theory and practice, which is the basis for improving science process skills.

Critical Thinking Skills (CTS) are essential for solving complex problems, including those encountered in dynamic fluid practicum projects. The implementation of POC_Lab provides students with the opportunity to develop their critical thinking abilities, particularly in logical reasoning and argument analysis. One key aspect of CTS fostered through POC_Lab is hypothesis testing. Students are encouraged to think critically when formulating hypotheses about how fluid dynamics concepts can be applied to their projects. They then test these hypotheses through virtual experiments conducted on the POC_Lab platform. This aligns with Tiruneh, Gu et al. (2018), who reported that project-based learning can enhance students' critical thinking skills, especially in hypothesis testing and problem-solving. Argument analysis is another vital skill developed through group discussions in POC_Lab. Students engage in discussions that require them to consider different perspectives, analyze arguments presented by their peers, and devise logical strategies for project completion. According to a recent study by

De Klerk et al. (2024), collaborative discussions on online platforms can improve students' ability to evaluate arguments and critically solve problems.

Furthermore, probability and uncertainty analysis is essential to CTS development in POC_Lab. Students must consider uncertain variables, such as fluid pressure fluctuations in the hydram pump or buoyancy variations in the mini-submarine. They learn to analyze risks and uncertainties that may affect the outcomes of their projects. Aránguiz et al. (2020) note that risk and uncertainty analysis is a critical element of developing critical thinking skills in project-based learning contexts

The results of this study are in line with a survey conducted, where a project-based approach in practicums was shown to improve students' critical thinking skills (Firmansyah et al., 2022; Haryanto et al., 2019; Saputra, Suhandi, et al., 2023). POC_Lab forces students to be actively involved in the analysis, evaluation, and decision-making process based on the data they collect during the practicum. This is crucial in developing critical thinking skills, as they must independently and collaboratively formulate hypotheses, test theories, and draw valid conclusions (Jumhur et al., 2024).

The findings of this study indicate that implementing a project-based Online Collaboration Lab (POC Lab) Practicum significantly impacts students' critical thinking skills (CTS) and science process skills (SPS). Based on the N-Gain analysis, the results show that the improvement in these skills is in the high to moderate category, indicating the excellent effectiveness of this learning method.

The findings from Table 5 show that aspects of science process skills (SPS), such as observation, interpretation, hypothesis, and applying concepts, experienced significant improvements after project-based intervention through POC Lab. The N-Gain improvements in hypothesis and applying concepts were in the high category, with N-Gain percentages of 76% and 79%, respectively. This shows that project-based practicum can facilitate the development of these skills more effectively than the traditional approach.

According to research by Guo et al. (2020), project-based learning effectively develops science process skills by encouraging students to participate actively in the authentic scientific investigation process. Students are involved in activities requiring exploration, reasoning, and applying scientific concepts, aligning with this study's findings. For example, students engaged in physics-based projects must design experiments, collect data, and use physics concepts in authentic contexts, which ultimately improves their skills in making hypotheses and applying scientific concepts.

In addition, Marnewick (2023) also showed that the Project-based practicum approach allows students to develop observation and interpretation skills through more opportunities to interact directly with scientific phenomena. These findings are consistent with their findings, where this study's observation and interpretation aspects experienced quite good improvements, reaching 68% and 71%. The findings in Table 4 show that all aspects of critical thinking skills experienced significant improvements. In the high category, n-Gain in reasoning and argument analysis reached 83% and 87%, respectively. This improvement shows that project-based practicums allow students to develop in-depth critical thinking skills, especially regarding analysis, logical reasoning, and hypothesis testing.

This finding aligns with Sri Asmorowati et al.'s (2021) research, which shows that critical thinking skills can be developed through learning that provides intellectual challenges, such as formulating and testing hypotheses in scientific practicums. In the context of this research, students were involved in projects that required them to formulate hypotheses, analyze arguments, and evaluate evidence in real situations, which ultimately strengthened their critical thinking skills. Furthermore, the high increase in the probability and uncertainty analysis aspect (80%) indicates that students also become more proficient in assessing and evaluating the possible outcomes of an experiment, especially in situations full of uncertainty. This finding is supported by (Tiruneh, De Cock, et al., 2018), who stated that a student-centred project-based learning approach could improve critical analysis skills and the ability to handle complex situations full of uncertainty.

Based on the results of N-Gain and the effectiveness classification presented in this study, it can be concluded that POC Lab effectively improves students' science process skills and critical thinking skills. This practicum's effectiveness is seen not only from the high category in most aspects but also from the alignment with the results of previous studies that emphasize the importance of active and project-based learning approaches to develop high-level thinking skills. According to Yu (2024), project-based learning allows students to build their knowledge collaboratively, deepen their understanding of the subject matter, and develop critical thinking skills. In addition, this learning facilitates contextual learning, where students must relate the concepts learned to real problems faced in the project. The high effectiveness of POC Lab in this study is in line with these findings, especially in improving students' reasoning and argument analysis skills.

The findings of this study have several important implications for the development of curriculum and learning methods in higher education, especially in the context of science and physics education. The use of POC Lab integrating a project-based approach has been effective in improving students' critical thinking and science process skills. Therefore, it is recommended that this approach be adopted more widely in science learning in higher education. Furthermore, since POC Lab can be implemented online, this method is relevant in today's rapidly evolving distance learning environment. Using technology in project-based learning can facilitate student collaboration and help them develop 21st-century skills, such as critical thinking, problem-solving, and collaboration.

▪ CONCLUSION

Based on this study's findings, implementing POC Lab in project-based learning improves students' critical thinking and science process skills. High effectiveness is seen in the increase in N-Gain in various aspects, especially in reasoning, argument analysis, hypothesis, and applying concepts. These results are consistent with existing literature, which shows that project-based learning provides opportunities for students to develop higher-order thinking skills through hands-on and collaborative experiences.

This study demonstrates that the implementation of the Practical Online Collaborative Lab (POC_Lab) in dynamic fluid learning has a significant positive impact on enhancing students' Science Process Skills (SPS) and Critical Thinking Skills (CTS). Through a project-based approach supported by cloud-based collaborative technology, students developed a deeper understanding of physics concepts, such as Bernoulli's principle and buoyancy, while working in groups to complete real-world projects like building mini-submarines and hydram pumps. These findings underscore the importance of integrating technology into education to enhance student engagement, collaboration, and conceptual understanding in project-based learning contexts.

This research has significant educational implications, particularly in technology-enhanced learning and online collaboration. The use of POC_Lab shows excellent potential in improving critical thinking and science process skills, which are essential for preparing students to tackle real-world scientific challenges. However, the study also has limitations, such as the potential for students to rely heavily on technology without fully grasping the underlying theoretical concepts. Additionally, the generalizability of the findings may be limited to the specific context of science and technology education, highlighting the need for further research to evaluate the effectiveness of POC_Lab across different disciplines and broader populations.

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