



Effectiveness of Problem and Design Process-Based Learning Model with STEAM Approach to Improve Students' Scientific Literacy in Science Learning in Rural and Urban Areas

Frendi Ihwan Syamsudin¹

ORCID: <https://orcid.org/0000-0002-5816-6981>

Sulistyo Saputro^{1*}

ORCID: <https://orcid.org/0000-0002-5613-9496>

Sarwanto Sarwanto¹

ORCID: <https://orcid.org/0000-0002-9602-5776>

Puguh Karyanto¹

ORCID: <https://orcid.org/0000-0002-5581-2538>

Azlan Kamari²

ORCID: <https://orcid.org/0000-0002-3167-0619>

¹ Doctoral Program in Natural Science Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia

² Department of Chemistry, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris, Malaysia

*Corresponding author email: sulistyo_s@staff.uns.ac.id

Abstract

Background: Despite global educational advancements, scientific literacy remains a significant challenge for Indonesian students. The persistence of this issue is often linked to conventional classroom practices that prioritise passive learning with limited or no connection to real-world natural phenomena.

Objective: This study aims to 1) examine the effect of applying the Problem and Design-Process Based Learning (PDP-BL) model with the STEAM approach on students' scientific literacy, and 2) evaluate its effectiveness in rural and urban areas.

Methodology: The research design employed was a quasi-experimental pre-test/post-test with two groups. Two matched groups, namely a rural experimental group (n = 35) and an urban experimental group (n = 33), received four weeks of PDP-BL instruction. In contrast, the

equivalent control groups did not receive PDP-BL instruction. Pre-tests and post-tests employed a validated 14-item instrument measuring curiosity, problem-solving, scientific inquiry, and involvement in decision-making. Item reliability and validity were confirmed using SMART-PLS. Data analysis comprised tests of normality, homogeneity, MANOVA, N-Gain, and effect size.

Results: The findings showed significant improvements in students' scientific literacy following the implementation of the PDP-BL model with a STEAM approach. In the rural school (School X), the experimental group achieved a post-test mean score of 87.06 (very high), compared with 60.88 (medium) in the control group, while in the urban school (School Y), the experimental group scored 79.53 (high) compared with 60.45 (medium) in the control group. N-Gain analysis indicated that the intervention was "quite effective" in both contexts (0.60 in School X and 0.57 in School Y), whereas the control groups were "ineffective" (0.26 and 0.31). MANOVA confirmed a statistically significant effect of the PDP-BL model with STEAM on scientific literacy ($p < 0.001$), and the effect size analysis demonstrated a substantial impact in both schools ($r = 0.93$). These results provided strong evidence that the PDP-BL model, combined with a STEAM approach, was highly effective in enhancing students' scientific literacy across both rural and urban areas.

Conclusion: It was concluded that the implementation of the PDP-BL model, combined with the STEAM approach, had a significant influence and was effective in improving students' scientific literacy in both rural and urban areas.

Unique contribution: This research presents a novel pedagogical framework by empirically validating the effectiveness of integrating the predict–discuss–prove (PDP) approach with the blended learning (BL) model, alongside the STEAM approach, to enhance scientific literacy in the Indonesian context. By demonstrating significant improvement through a focus on real environmental phenomena, this study addresses a critical gap in previous passive classroom practices and existing STEAM implementations, providing a new, empirically-tested model for science education reform in developing nations.

Key Recommendation: The PDP-BL model, combined with a STEAM approach, should be adopted to enhance students' scientific literacy through active, interdisciplinary, and practice-based learning.

Keywords : Problem and Design Process Based Learning models, STEAM approach, scientific literacy, science learning, rural and urban area

Introduction

Scientific literacy is a crucial 21st century skill that enables students to understand natural phenomena, respond scientifically to global issues, and contribute to key sectors, particularly education (Bybee, 2012; Dawson, 2024). It involves an understanding of scientific concepts as well as critical thinking skills, which also underpin effective decision-making in everyday life (Gyllenpalm, 2022; Syahgiah, 2023; Dawson, 2024). These competencies constitute the core dimensions of scientific literacy and are highly relevant to contemporary science education. However, according to the Programme for International Student Assessment (PISA), Indonesian students' scientific literacy scores have remained low, ranging from 395 in 2003 to 383 in 2022, with an overall decline observed between 2003 and 2012 and again between 2015 and 2022. Recent pre-test results in secondary schools similarly indicate low average scores, with 50.43 in rural areas and 48.59 in urban areas, confirming the persistent problem of weak scientific literacy in Indonesia.

One essential way to develop scientific literacy in science learning is through the exploration of natural phenomena. However, interviews revealed that 36% of teachers did not present phenomena, instead relying on internet sources without contextualization. Students reported that phenomena were primarily presented through photographs or videos, sometimes only shared in group chats. Observations indicated that students were frequently distracted, struggled to ask questions, and had difficulty interpreting phenomena. This limited and unstructured use of phenomena has diminished students' ability to identify problems, apply inquiry, and develop scientific reasoning, which are fundamental to literacy.

Scientific literacy also requires the ability to apply scientific methods in problem-solving. Observational data indicated that students experienced difficulties with essential skills such as observing phenomena, analysing data, designing experiments, and interpreting results. These findings underscore the low level of scientific literacy, particularly regarding the practical application of scientific methods.

Addressing these challenges requires innovative learning strategies that promote active engagement, interdisciplinary thinking, and problem-solving. One approach widely acknowledged for this purpose is STEM (Science, Technology, Engineering, and Mathematics). STEM represents an integrated problem-based approach designed to develop both scientific expertise and 21st-century skills (Abdullatif, 2021; Jabbar, 2024). The National Science Foundation has identified four key STEM learning elements: varied, deep learning; a focus on real environmental issues; integration of STEM components; and application of engineering design with critical analysis. To foster creative problem-solving, the arts component has been incorporated into STEAM, enhancing interdisciplinary learning and encouraging innovative solutions (Tsai, 2024).

In recent years, many countries, including South Korea, Japan, and Thailand, have implemented STEAM learning. In South Korea, STEAM has influenced both teachers and students; however, teachers have faced challenges, including extensive preparation, managing group activities, limited curriculum content, and inadequate facilities, despite mandates. Students' attitudes and problem-solving skills have remained moderate, indicating that STEAM has yet to improve scientific literacy significantly, but shows potential. The implementation of STEAM in Japan has enhanced science and engineering processes; however, the arts component has lacked a clear definition and practical integration, limiting its incorporation alongside environmental issues. Similarly, in Thailand, STEAM has encountered challenges, including low student involvement in problem formulation due to unrealistic phenomena and teachers' limited experience integrating design processes. These international findings suggest that STEAM has strong potential but requires contextual adaptations to address local problems and enhance scientific literacy.

To overcome these limitations, recent studies recommend integrating real environmental phenomena with design-based learning. Scientific literacy, particularly in the knowledge dimension, can be strengthened by presenting authentic problems derived from phenomena (Kotsis, 2024). A review by Syahgiah (2023) of 376 articles (2004–2022) found that problem-solving learning enhances scientific reasoning by starting with the observation of phenomena to

derive meaning, design solutions, and connect ideas to evidence. Scientific literacy skills are further developed through design-based learning and idea engineering, focusing on problem-solving procedures that lead to the creation of product prototypes (Lee, 2020; Jabbar, 2024). This process requires observing phenomena, formulating problems, designing procedures, collecting and analysing data, and drawing evidence-based conclusions (Dawson, 2024; Gormally, 2012).

Building on this foundation, the Problem and Design Process-Based Learning (PDP-BL) model integrates problem-solving and design-based learning within the STEAM framework. PDP-BL engages students in authentic projects that connect theory to practice, especially in environmental contexts. Students explore local phenomena and design innovative solutions such as reducing plastic waste and optimizing renewable energy, while simultaneously raising awareness through posters and vlog campaigns. This approach enhances scientific literacy while equips students to meet future industrial and global challenges.

Thus, the primary problem addressed in this research is the low level of scientific literacy among Indonesian students, as indicated by PISA results and pre-test findings. Unstructured presentation of natural phenomena, difficulties in applying scientific methods, and challenges in STEAM implementation underscore the need for a more effective model. Accordingly, this study employs the PDP-BL model, integrated with the STEAM approach, to enhance students' scientific literacy in high school science instruction on global warming. The PDP-BL syntax comprises 1) identifying problems and hypotheses, 2) designing conceptual solutions, 3) group investigation using design, 4) analysing and sharing, and 5) reflection. Students' scientific literacy is measured before and after the learning process using a pre-test and post-test instrument based on dimensions synthesised from Bybee (2010) and Gormally (2012) to evaluate the effectiveness of this integrated model.

The Objective Of The Study

This study aims to:

1. Determine the effect of implementing the PDP-BL model with the STEAM approach on students' scientific literacy in rural and urban areas concerning global warming.
2. Assess the effectiveness of integrating the PDP-BL model with the STEAM approach in enhancing students' scientific literacy.

H_{01} = Learning with the STEAM-based PDP-BL model has no significant effect on students' scientific literacy in rural and urban areas.

H_{02} = The STEAM-based PDP-BL model is not effective in improving students' scientific literacy.

Methodology

This study employs a quasi-experimental design with two pre-test/post-test groups to quantitatively examine the effect of the PDP-BL model, combined with the STEAM approach (independent variable), on students' scientific literacy (dependent variable). The experimental group receives the intervention following a pre-test, which is succeeded by a post-test to measure its impact. The control group serves to compare pre-test/post-test changes and isolate the effect intervention.

The framework of the quasi-experimental research design with two pre-test/post-test groups is presented in appendix 1. The intervention implemented in the experimental group was the Problem and Design Process-Based Learning (PDP-BL) model integrated with the STEAM approach. This model emphasises problem identification, collaborative design processes, integration of science, technology, engineering, arts, and mathematics, as well as the application of concepts in real-life contexts to foster students' scientific literacy. The intervention was conducted over a period of four weeks with comprising a total of eight sessions (two sessions per week, each lasting 90 minutes). Learning activities were delivered in a face-to-face classroom setting through a combination of project-based assignments, group discussions, guided experiments, and student presentations.

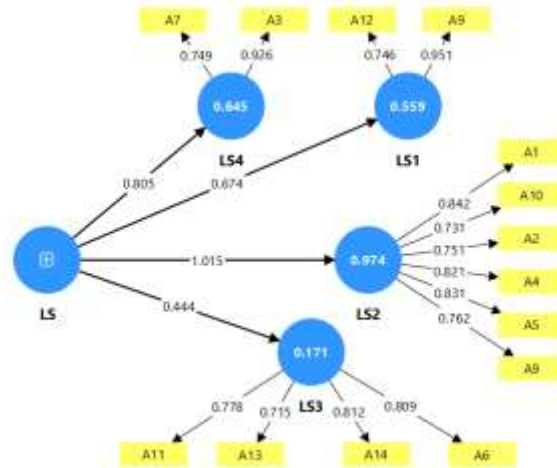
All learning materials, including lesson plans, worksheets, and assessment guidelines, were developed by the research team, which comprised experts in science education and pedagogy. The classroom teachers, who had received prior training from the researchers, were responsible for facilitating the intervention. Meanwhile, the control groups continued with conventional teaching methods based on the existing school curriculum without exposure to the PDP-BL with STEAM intervention.

The same pre-test instrument (O1) was used for both experimental and control groups. One week later, the experimental group underwent a four-week intervention (X), while the control group did not. One week after the intervention, both groups completed the post-test (O2) using the same instrument. Pre-test and post-test results were analysed to assess within-group changes and compare post-test means between groups in order to evaluate the effectiveness of the intervention.

The population comprises 6,450,747 grade X high school students in a province in Indonesia. Using random sampling, one rural school and one urban school were selected. The sample included 70 students from the rural school (X) and 66 students from the urban school (Y), divided equally into experimental groups (rural = 35, urban = 33) and control groups (rural = 35, urban = 33).

Data collection was conducted quantitatively. The research instrument used was the pre-test/post-test instrument of scientific literacy. The measurement dimensions of the pre-test/post-test instrument of scientific literacy are 1) curiosity, 2) problem-solving orientation, 3) scientific inquiry, and 4) involvement in decision-making. Based on the synthesis of these dimensions, the scientific literacy pre-test/post-test instrument items were compiled as shown in Appendix 2. The instrument was validated by seven professors, achieving a V-Aiken value of 0.81, indicating validity. Further analysis of the scientific literacy test items using SMART-PLS demonstrated convergent validity, with outer loading values for each indicator presented in Figure 1.

Figure 1. *Outer loading values representing the results of the indicator validity assessment*



Based on Figure 1, the outer loading values for each item of the science literacy test instrument exceed 0.7, indicating that all indicators are valid in terms of indicator validity. Furthermore, construct reliability measurements were conducted, with results presented in Appendix 3. All dimensions exhibit a Cronbach's alpha and composite reliability greater than 0.7, indicating reliable constructs according to Ghozali (2015). The AVE values for all dimensions exceed 0.5, meeting the convergent validity criteria outlined by Wong (2014), thereby confirming that all scientific literacy measurement dimensions are both valid and reliable.

The sample prerequisite test used the Shapiro-Wilk test for normality, with data considered normally distributed if the p-value exceeded 0.05. The independent-samples t-test was used to assess homogeneity; a p-value exceeding 0.05 indicated homogeneity (Ghozali, 2015). To measure the improvement in scientific literacy, the N-Gain test was applied to pre-test and post-test results, with categories based on Hake (1999) presented in Appendix 4. The effect of the PDP-BL was analysed using a MANOVA, with p-values < 0.05 indicating a significant effect. To compare the performance between the experimental and control groups, an effect size test was conducted, with categories based on Cohen's (1998) guidelines, as presented in Appendix 5.

Results

The average results of the scientific literacy pre-test are presented in Table 1.

Table 1. Average results of students' scientific literacy pre-test

School	Group	Average Score	LS Category
School X (rural area)	Control	44,56	Low
	Experiment	50,43	Low
School Y (urban area)	Control	37,66	Very low
	Experiment	48,59	Low

The results of the sample normality test, based on the pre-test values, are presented in Appendix 7. The results of the sample homogeneity test, based on the pre-test values, are presented in Appendix 8. Subsequently, learning was conducted using the PDP-BL model with the STEAM approach over four meetings. The average results of the scientific literacy post-test are presented in Table 2.

Table 2. *The average results of students' scientific literacy post-test*

School	Group	Average score	LS Category
School X (rural area)	Control	60,88	Medium
	Experiment	87,06	Very high
School X (urban area)	Control	60,45	Medium
	Experiment	79,53	High

Based on the results of the pre-test and post-test of scientific literacy, the N-Gain values are presented in Appendix 6. Subsequently, a MANOVA test was conducted to determine whether the implementation of the PDP-BL model with the STEAM approach affected the scientific literacy of students at School X and School Y, with the results presented in Appendix 9. Based on the results of the effect size test, derived from pre-test/post-test data, the differences between the control and the experimental groups are presented in Appendix 10.

Discussion

Based on the normality test results presented in Appendix 7, the pre-test data from School X (sig. = 0.131) and School Y (sig. = 0.147) were normally distributed (sig. > 0.05), meeting the requirements for parametric statistical tests in both rural and urban areas (Ghozali, 2015; Abdullatif, 2021). Similar findings were reported by Syahgiah (2023), who employed the Shapiro-Wilk test and obtained significance values above 0.05, indicating normal distribution.

Based on the homogeneity test in Appendix 8, the significance level is 0.978 (> 0.05), indicating that the pre-test data from School X and School Y were homogeneous, fulfilling the prerequisites for schools in both rural and urban areas. This aligns with Taherdoost (2021), who stated that sample homogeneity was necessary to prevent external variables from affecting research results. Similarly, Ghozali (2015) reported significant values greater than 0.05 in their homogeneity tests, indicating homogeneous samples. According to Dawson (2024), homogeneity allows researchers to determine whether differences in pre-test/post-test results are attributable to the treatment or variations in student characteristics.

The MANOVA results presented in Appendix 9 showed all p-values below 0.05, indicating a significant effect of the independent variable on scientific literacy at the 95% confidence level. Appendix 10 revealed a high effect size across schools, confirming significant differences between control and experimental groups. Thus, the PDP-BL model, combined with the STEAM approach, significantly improved scientific literacy in both rural (School X) and urban (School Y) settings. This aligns with Abdullatif (2021), who found that combining problem-solving with STEAM enhanced student engagement and real-life application. Jabbar (2024) reported that STEAM-based process design learning has a positive influence on 21st-century skills, including scientific literacy. Bybee (2013) emphasised that scientific literacy involves concept mastery and evidence-based decision-making, highlighting the relevance of STEAM in developing these skills.

Based on the N-Gain test results presented in Appendix 6, the experimental classes in Schools X and Y demonstrated effective improvement in scientific literacy through the PDP-BL model with the STEAM approach. This supports Lee (2020), who found that combining problem-solving and design-based learning enhances critical thinking and contextual problem-solving. Similarly,

Jabbar (2024) reported moderate N-Gain improvements using STEAM-based problem-solving, fostering a deeper understanding of scientific concepts.

The PDP-BL model, combined with the STEAM approach, was implemented in four group projects: posters (Worksheet 1), videos (Worksheet 2), vlogs (Worksheet 3), and tool prototypes (Worksheet 4). In worksheet 1, student groups from Schools X and Y created posters depicting local natural phenomena, as presented in Appendix 11.

Appendix 11 presents a poster by students from School X (rural) that depicts drought-related global warming phenomena, such as cracked soil, wilted trees, scarce water, bare ground, and hot weather, reflecting actual rural conditions. This aligns with Dawson (2024), who reported an increase in floods, droughts, and forest fires in rural Indonesia, disrupting agriculture and worsening food security (Bybee, 2012; Haleem, 2022). Cavicchi (2024) also emphasised that repeated droughts and crop failures severely impact food security.

Appendix 11 displays a poster created by students from Urban School Y, promoting proper waste disposal, the separation of organic and inorganic waste, and composting. This reflects urban practices that reduce methane emissions and support environmental quality. Effective waste management lowers landfill volume, greenhouse gas emissions, and the use of chemical fertilisers while improving soil fertility (Cavicchi, 2024; Jabbar, 2024). The poster aimed to raise awareness about proper waste disposal to protect air quality (Wong, 2014; Gyllenpalm, 2022).

The poster in Appendix 11 enhances students' scientific literacy in the curiosity dimension in both rural and urban schools by encouraging deeper exploration of global warming. Tsai (2024) states that exploring phenomena strengthens information processing, while Cavicchi (2024) links strong scientific literacy to high curiosity. This curiosity prompts students to question the content and environmental impacts shown in the posters, sparking inquiries into underlying processes (Antony, 2023; Timotheou, 2023).

In worksheets 2 and 3, students created videos and vlogs that demonstrated their ability to search for scientific journals, as evidenced by proper use of citations. This process required accurate information gathering (Tsai, 2024; Dawson, 2024), strengthening their scientific literacy in the curiosity dimension. Students also grasped key content concepts (Cavicchi, 2024), and some progressed to environmental campaigns, enhancing their understanding and ability to communicate scientific issues (Wong, 2014).

In learning worksheets 1, 2, and 3 at Rural School X, students struggled to create posters, videos, and vlogs due to limited access to laptops and the absence of a computer lab. These projects required technology for editing and presentation, which hindered their work. Laptops are essential for digital project-based learning and presentations (Haleem, 2022; Jabbar, 2024), and without them, students faced challenges in finding references and collaborating effectively (Abdullatif,

2021). However, they adapted by using mobile phones with suitable applications to complete their tasks.

At school, Y (urban) students faced challenges during the poster project, including a lack of focus on observing phenomena and a reluctance to ask questions, which hindered their ability to interpret and identify problems accurately. Some confuse causes with problems, leading to irrelevant formulations and hypotheses. In worksheets 2 and 3, several students struggled to analyse results due to weak theoretical understanding, resulting in minimal comprehension and illogical, unsupported analyses lacking scientific validity.

In Worksheet 4, students developed simple prototype tools as innovative solutions to mitigate global warming. These outputs, from both rural and urban schools, are presented in Appendix 12 and Appendix 13.

Appendices 12 and 13 show that students in both rural and urban areas were able to design simple smoke filters using cans, sponges, and gauze to reduce carbon monoxide emissions. This activity strengthened their scientific literacy in the problem-solving orientation dimension. It aligns with Lee (2020), who emphasised analysing major issues like global warming by identifying smaller, contributing problems such as carbon monoxide pollution.

The prototype designs varied between schools based on the availability of materials. Appendix 12 shows a simple model from Rural School X, using one can, one pen, and one sponge, while Appendix 13 presents a more complex urban design with multiple cans, pens, a sponge, and wire mesh. These differences reflect varying idea complexity and strengthen scientific literacy in the inquiry dimension. Dawson (2024) notes that such variations result from independent idea analysis and decision-making, thereby enhancing student engagement and project outcomes.

In worksheet 4, some groups designed detailed prototypes but used minimal materials due to limited equipment, indicating weak scientific investigation skills. These skills are essential for fostering analytical thinking, gathering information, formulating hypotheses, and drawing evidence-based conclusions (Kotsis, 2024). Without them, students struggle to think critically and evaluate information effectively (Syahgiah, 2023; Gyllenpalm, 2022). Linking findings to existing theories helps verify data and deepen understanding, enhancing the evaluation of results (Taherdoost, 2021; Tsai, 2024).

Conclusion

Based on the research findings, the PDP-BL model with the STEAM approach significantly improves students' scientific literacy in rural and urban areas, as evidenced by the normality and homogeneity of data and statistically significant MANOVA results with high effect sizes. The model has proven to be highly effective in enhancing scientific literacy, as shown by positive N-Gain scores and active student participation in various project-based activities that develop curiosity, inquiry, and problem-solving skills. Despite some challenges related to technology access and problem identification, the approach effectively fosters critical thinking and the ability

to apply scientific concepts, thereby demonstrating its suitability for improving scientific literacy across diverse school environments.

Recommendations

To ensure the effective implementation of the PDP-BL model through the STEAM approach, several recommendations are proposed. First, schools should provide teachers with training and orientation to develop a comprehensive understanding of the model's concepts, objectives, and procedures. Second, the selection of natural phenomena should correspond to the school's environmental and geographical context to enhance learning relevance. Third, implementation should consider the availability of facilities and infrastructure to support project-based and integrative learning in accordance with STEAM principles.

Funding. Mandatory Research (Contract Number: 194.2/UN27.22/PT.01.03/2024).

Acknowledgments

We would like to thank Universitas Sebelas Maret for providing funding to complete this article through Mandatory Research (Contract Number: 194.2/UN27.22/PT.01.03/2024)

References

- Abdullatif, A. M., & Gameil, A. A. (2021). The effect of digital technology integration on students' academic performance through project-based learning in an e-learning environment. *International Journal of Emerging Technologies in Learning (iJET)*, 16(11), 189–210. <https://doi.org/10.3991/ijet.v16i11.19421>
- Antony, S., & Ramnath, R. (2023). A Phenomenological Exploration of Students' Perceptions of AI Chatbots in Higher Education. *IAFOR Journal of Education*, 11(2), 7–38. <https://doi.org/10.22492/ije.11.2.01>
- Bybee, R. W. (2012). Scientific literacy in environmental and health education. In *Science / Environment / Health: Towards a Renewed Pedagogy for Science Education* (Vol. 9789048139491, pp. 49–67). Springer Netherlands. https://doi.org/10.1007/978-90-481-3949-1_4.
- Cavicchi, E. (2024). Curiosity Opens Relationships of the World and with Others: Narratives from Doing Teaching and Learning Through Curiosity. *Interchange*, 55(3), 261–301. <https://doi.org/10.1007/s10780-024-09529-8>
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Dawson, C., Julku, H., Pihlajamäki, M., Kaakinen, J. K., Schooler, J. W., & Simola, J. (2024). Evidence-based scientific thinking and decision-making in everyday life. *Cognitive Research: Principles and Implications*, 9(1), 1-37. <https://doi.org/10.1186/s41235-024-00578-2>
- Ghozali, I. (2015). Aplikasi Analisis Multivariate dengan Program IBM SPSS 23. Semarang: Badan Penerbit Universitas Diponegoro.
- Gormally, C., Brickman, P., & Lut, M. (2012). Developing a test of scientific literacy skills (TOSLS): Measuring undergraduates' evaluation of scientific information and arguments. *CBE Life Sciences Education*, 11(4), 364–377. <https://doi.org/10.1187/cbe.12-03-0026>

- Gyllenpalm, J., Rundgren, C. J., Lederman, J., & Lederman, N. (2022). Views About Scientific Inquiry: A Study of Students' Understanding of Scientific Inquiry in Grade 7 and 12 in Sweden. *Scandinavian Journal of Educational Research*, 66(2), 336–354. <https://doi.org/10.1080/00313831.2020.1869080>
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74. <https://doi.org/10.1119/1.18809>
- Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, 3, 275–285. <https://doi.org/10.1016/j.susoc.2022.05.004>
- Jabbar, R., & Halim, N. D. (2024). The effects of technology-integrated project-based learning on students' acquisition of programming abilities in computer science courses. *Journal of Electrical Systems*, 20(4), 1112-1116. <https://doi.org/10.21307/jes-2024-2155>
- Kotsis, K. T. (2024). Significance of Experiments in Inquiry-based Science Teaching. *European Journal of Education and Pedagogy*, 5(2), 86–92. <https://doi.org/10.24018/ejedu.2024.5.2.815>
- Lee, J. W., Daly, S. R., Huang-Saad, A., Rodriguez, G., & Seifert, C. M. (2020). Cognitive strategies in solution mapping: How engineering designers identify problems for technological solutions. *Design Studies*, 71, 1-33. <https://doi.org/10.1016/j.destud.2020.100967>
- Syahgiah, L., ZAN, A. M., & Asrizal, A. (2023). Effects of Inquiry Learning on Students' Science Process Skills and Critical Thinking: A Meta-Analysis. *Journal of Innovative Physics Teaching*, 1(1), 16–28. <https://doi.org/10.24036/jipt/vol1-iss1/9>
- Taherdoost, H. (2021). Data Collection Methods and Tools for Research; A Step-by-Step Guide to Choose Data Collection Technique for Academic and Business Research Projects. *International Journal of Academic Research in Management (IJARM)*, 10(1), 10-38. <https://hal.science/hal-03741847v1>
- Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Monés, A. M., & Ioannou, A. (2023). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, 28(6), 6695–6726. <https://doi.org/10.1007/s10639-022-11431-8>
- Tsai, Y. C. (2024). Empowering students through active learning in educational big data analytics. *Smart Learning Environments*, 11(14), 1-21. <https://doi.org/10.1186/s40561-024-00300-1>
- Wong, K. M. (2014). *The development and validation of an instrument for measuring civic scientific literacy*. *Disciplinary and Interdisciplinary Science Education Research*, 6(1), 1–12. <https://doi.org/10.1186/s43031-023-00092-3>

Appendix 1. Two-group pre-test/post-test quasi-experimental research design

Group	Implementation		
Experimental	O1 _a	X	O2 _a
Control	O1 _b		O2 _b

*O1_a and O1_b = pre-test; X = intervention ; O2_a and O2_b = post-test

Appendix 2. Pre-test and post-test questions for scientific literacy instruments

Dimensions	Item Number	Number of Items
Curiosity	8, 12	2
Problem-solving orientation	4, 5, 1, 2, 9, 10	6
Scientific inquiry	14, 6, 11, 13	4
Involvement in decision making	7, 3	2
Total Item		14

Appendix 3. Results of construct reliability measurement

Dimensions	Cronbach alpha	Composite reliability	Average variance extracted
Curiosity (LS1)	0,770	0,842	0,730
Problem-solving orientation (LS2)	0,880	0,909	0,625
Scientific inquiry (LS3)	0,805	0,861	0,608
Involvement in decision making (LS4)	0,714	0,828	0,709

Appendix 4. N-Gain value categories

No	Value	Criteria
1	$N - Gain > 0.7$	Effective
2	$0.3 \leq N - Gain < 0.7$	Quite effective
3	$0.0 \leq N - Gain < 0.3$	Ineffective

Appendix 5. Effect size value category

No	Value	Criteria
1	$0.8 \leq r \leq 2.0$	High
2	$0.2 \leq r \leq 0.8$	Medium
3	$0.0 \leq r \leq 0.2$	Low

Appendix 6. The results of the N-Gain Test of Students' Science Literacy Pre-test/Post-test Data

School	Group	Skor N-Gain (%)	N-Gain Category
School X (rural area)	Control	0,26	Ineffective
	Experiment	0,60	Quite effective

School X (urban area)	Control	0,31	Ineffective
	Experiment	0,57	Quite effective

Appendix 7. The sample normality prerequisite test results

School	Kolmogorov-Smimov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
School X (rural area)	.155	70	.038	.951	34	.131
School Y (urban area)	.116	66	.200	.950	32	.147

Appendix 8. The sample homogeneity test results

Levena Statistic	df1	df2	Sig.
.022	2	136	.978

Appendix 9. The MANOVA test results

Effect	Value	F	Hypothesis df	Error df	Sig.	Noncent Parameter	Observed Power ^d	
Intercept	Pillai's Trace	.987	1692.643 ^b	4.000	87.000	.000	6770.570	1.000
	Wilks	.013	1692.643 ^b	4.000	87.000	.000	6770.570	1.000
	Lambda							
	Hotelling's Trace	77.823	1692.643 ^b	4.000	87.000	.000	6770.570	1.000
	Roy's Largest	77.823	1692.643 ^b	4.000	87.000	.000	6770.570	1.000
School	Pillai's Trace	.325	4.263	8.000	176.000	.000	34.101	.994
	Wilks	.691	4.416 ^b	8.000	174.000	.000	35.329	.995
	Lambda							
	Hotelling's Trace	.425	4.567	8.000	172.000	.000	36.532	.997
	Roy's Largest	.363	7.980 ^c	4.000	88.000	.000	31.920	.997

Appendix 10. The effect size test results based on pre-test/post-test data on scientific literacy

School	r	Criteria
School X (rural area)	0,93	High
School Y (urban area)	0,93	High

Appendix 13. *Example of prototype design for students at School Y (urban area)*

