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Transforming Laboratory Learning through Project-Oriented Laboratories: Challenges, Opportunities, and Recommendations for Science Education

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Abstract. Project-oriented laboratories (POLs) and project-based laboratories (PBLs) approaches have become important innovations in science education, providing more relevant learning experiences through real-world based projects. This study aims to evaluate the potential of POLs implementation in supporting science education integrated with sustainable development goals (SDGs) issues, particularly to develop creative ideas in solving environmental problems. In addition, this study also aims to identify the main challenges faced in the implementation of POLs and provide practical recommendations to optimize this approach. Through a systematic literature review based on Prisma 2020 guidelines, 34 articles from 1993 to 2024 were analyzed. The results showed that POLs are effective in improving students' technical, collaboration, and problem-solving skills. However, the integration of POLs with SDGs issues is still limited. Although some projects, such as the development of renewable energy systems, support SDG 7 (clean and affordable energy), most projects have not been strategically geared towards solving other global challenges, such as climate change mitigation (SDG 13) or waste management (SDG 12). The research identified key challenges in the implementation of POLs, including the need for technological infrastructure, intensive training for educators, and funding support. To maximize their impact, it is recommended that POLs actively integrate SDGs themes into project design and promote cross-disciplinary collaboration. This research confirms that POLs have great potential to support science education that not only results in academic achievement, but also tangible contributions to global sustainability.
Keywords: Project-oriented laboratory, project-based laboratory, sustainable development goals, science education, global sustainability.

Introduction

Laboratories are a core component of science education, playing a vital role in connecting theory with practice through hands-on experiments. However, traditional laboratories often focus solely on predetermined outcomes, emphasizing rote memorization of procedures over scientific exploration. As an alternative, project-oriented

laboratories (POLs) have emerged as an innovative approach centered on real-world projects. By emphasizing inquiry-based learning, POLs allow students to develop critical thinking, problem-solving, and collaboration skills (Movahedzadeh et al., 2012). The importance of POLs can also be seen in their relevance to global challenges such as those listed in the sustainable development goals (SDGs). Projects in POLs can be geared towards addressing environmental issues, such as climate change mitigation (SDGs 13), natural resource conservation (SDGs 15), or waste management (SDGs 12). Thus, POLs not only prepares students to understand science concepts, but also empowers them to come up with creative solutions to real problems facing the global community.

While POLs offer a lot of potential, implementing this approach in science education still faces various challenges. Project-based labs often require additional resources, such as technological infrastructure, teacher training and flexible curriculum frameworks. In addition, the lack of integration of global issues such as SDGs in POLs projects deprives students of the opportunity to relate their learning to real-world challenges, such as pollution, clean water crisis, or energy sustainability (Fadli et al., 2024). One common solution is to develop project-based curricula that are more responsive to global challenges. For example, an SDGs-based inquiry approach can be integrated into POLs, where students are empowered to design and implement projects relevant to environmental issues. In addition to enhancing learning, this approach also promotes awareness of the importance of science's contribution to achieving sustainable development goals (Robinson, 2013). A number of recent studies have also emphasized the importance of integrating sustainability education into active learning models such as POLs, in response to the increasing urgency of global environmental issues (Lavado-Anguera et al., 2024; Setiyaningsih, 2024).

Several studies have demonstrated the benefits of POLs in enhancing students' understanding and developing practical skills. For example, Farnham & Dube, (2015) reported how a project-based biochemistry laboratory enabled students to develop practical skills before engaging in original research. Another study by Lencastre et al., (2017) showed that the integration of inquiry methods in POLs can improve students' understanding of modern techniques such as molecular biology. In addition, Fadli et al., (2024) demonstrated the effectiveness of a project-based virtual laboratory in strengthening constructivist and conceptual thinking skills. The integration of these technologies is crucial, especially in regions with limited access to physical laboratories. However, most of these studies focus only on academic or cognitive outcomes, and not many have explicitly examined how POLs can be directly linked to the SDGs to shape scientific literacy as well as environmental and social responsibility (Jones et al., 2024; Kleespies & Dierkes, 2022).

While the literature supports the effectiveness of POLs in enhancing inquiry-based learning, research specifically highlighting their relevance to the SDGs is limited. Most studies emphasize the development of technical skills, but rarely explore how POLs can be utilized as a medium to foster creative solutions to global problems. This gap has been identified in recent continuing education literature, which encourages the emergence of educational models that actively engage students in solving real environmental challenges in line with the SDGs (Laurett et al., 2022). This provides an opportunity for this research to explore how POLs can be geared towards supporting the achievement of the SDGs through science-based projects.

This study aims to evaluate the potential of POLs in supporting science education integrated with SDGs issues, particularly in developing creative ideas relevant to solving environmental problems. In addition, this study also aims to identify the main challenges faced in the application of POLs and provide practical recommendations to optimize this approach. The novelty of this study lies in the explicit focus on linking project-oriented laboratories not only as a means of learning, but also as a vehicle for real action towards achieving sustainable development goals, which is still rarely described in previous studies (Espino-Díaz et al., 2025; Jones et al., 2024; Kleespies & Dierkes, 2022; Laurett et al., 2022; Lavado-Anguera et al., 2024).

This research is directed to answer the following questions: (1) What is the potential of implementing POLs in supporting practical learning in the field of science education that is integrated with SDGs issues? (2) What are the main challenges faced in the implementation of POLs in the context of science education? (3) How can POLs implementation schemes be proposed to optimize their contribution to project-based science learning and global issues?

Method

A systematic literature review approach was used to achieve the research objectives and provide an in-depth understanding of the opportunities for the application of POLs in the field of science education. The study followed the latest preferred reporting items for systematic reviews (Prisma) 2020 guidelines (Page et al., 2021), which emphasize the importance of transparency, replicability, and scientific rigor in systematic reviews. A protocol was designed to clarify the research questions and detail the selected sources of information, search methods, inclusion and exclusion criteria, and the data extraction and analysis process.

The systematic literature review in this study included a thorough search of articles published between 1993 and 2024 in the scopus database. The database was chosen due to its globally recognized impact metrics, as well as its broad coverage of various fields and disciplines (Pranckutė, 2021; Singh et al., 2021). The search strategy used key concepts relevant to the research focus (e.g., project oriented, laboratory, and project based laboratory) and research question, utilizing boolean operators (AND, OR) and parentheses to effectively construct the search string (Kalogiannakis et al., 2021). After initial testing and customization according to the syntax requirements of each database, the final search string was compiled (Table 1).

Table 1. Information source and search strategy.

Information Source	Search String and Parameters
Scopus (https://www.scopus.com/)	TITLE-ABS ({project oriented}) AND TITLE-ABS (laboratory) = 39 article TITLE-ABS ({project oriented}) AND TITLE-ABS (laboratory) AND PUBYEAR > 1992 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar")) = 32 article
Scopus (https://www.scopus.com/)	TITLE-ABS ({project based}) AND TITLE-ABS (laboratory) = 290 article TITLE-ABS ({project based}) AND TITLE-ABS (laboratory) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SRCTYPE , "p") OR LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (OA , "all")) = 68 article

This study only included research articles published in academic journals and proceedings. During the search process, additional filters were applied to each database according to the inclusion and exclusion criteria described in the next section, including document type (articles, proceedings) as well as publication language (English). To maintain thorough coverage, some journals were intentionally excluded at the search strategy formulation stage (Vojíř & Rusek, 2019). The final database-wide search was completed on December 20, 2024.

To ensure that only studies relevant to our research topic were selected from the database, specific inclusion and exclusion criteria were set. Inclusion criteria (IC), IC1: Journal articles and proceedings of conferences; IC2: The study is written in English; IC3: The study is not listed in another database; IC4: This research was conducted in a higher education setting; IC5: This research is related to the field of science and technology; IC6:

Full text of the study is available or open access; and IC7: This study covers the implementation of project-oriented laboratories or project-based laboratories.

Exclusion criteria (ExC), ExC1: Book chapter, book, conference review, editorial, note, short survey, erratum, retracted, letter, report, and data paper; ExC2: The study is not written in English; ExC3: The study is listed in another database; ExC4: The study was not conducted in a higher education setting; ExC5: This study is not related to project-oriented or project-based laboratory courses; ExC6: The full text of this study is not available; and ExC7: This research does not address project-oriented or project-based laboratory courses for science and technology students.

The systematic literature review was conducted in five stages following the Prisma 2020 guidelines (Page et al., 2021). In the first stage, an initial literature search was conducted in electronic databases, namely Scopus with the keywords "project oriented laboratory" (n = 39), and the keyword "project based laboratory" (n = 290). Applying the inclusion (IC1, IC2) and exclusion (ExC1, ExC2) criteria, 228 papers were eliminated-either through database automation tools or manual review-for not meeting document type or language requirements. Furthermore, based on additional inclusion and exclusion criteria (IC3, ExC3), 15 duplicate papers were identified and removed using microsoft excel.

In the second stage, inclusion (IC4, IC5) and exclusion (ExC4, ExC5) criteria were applied by examining the titles and abstracts of the 85 papers. If the abstracts were not informative enough or unclear, the entire content of the paper was reviewed. A total of 36 articles were declared ineligible because they were outside the context of project-oriented or project-based laboratory courses and were not relevant to the field of science and technology. In addition, 10 papers without full text access were also excluded from further analysis (IC6, ExC6). In the fourth stage, a total of 39 papers were evaluated in depth to ensure their eligibility based on the inclusion (IC7) and exclusion (ExC7) criteria. Finally, in the fifth stage, the full texts of the remaining 30 papers were thoroughly reviewed to assess their relevance to the criteria and questions of this study. This process is summarized in the Prisma flowchart (Figure 1).

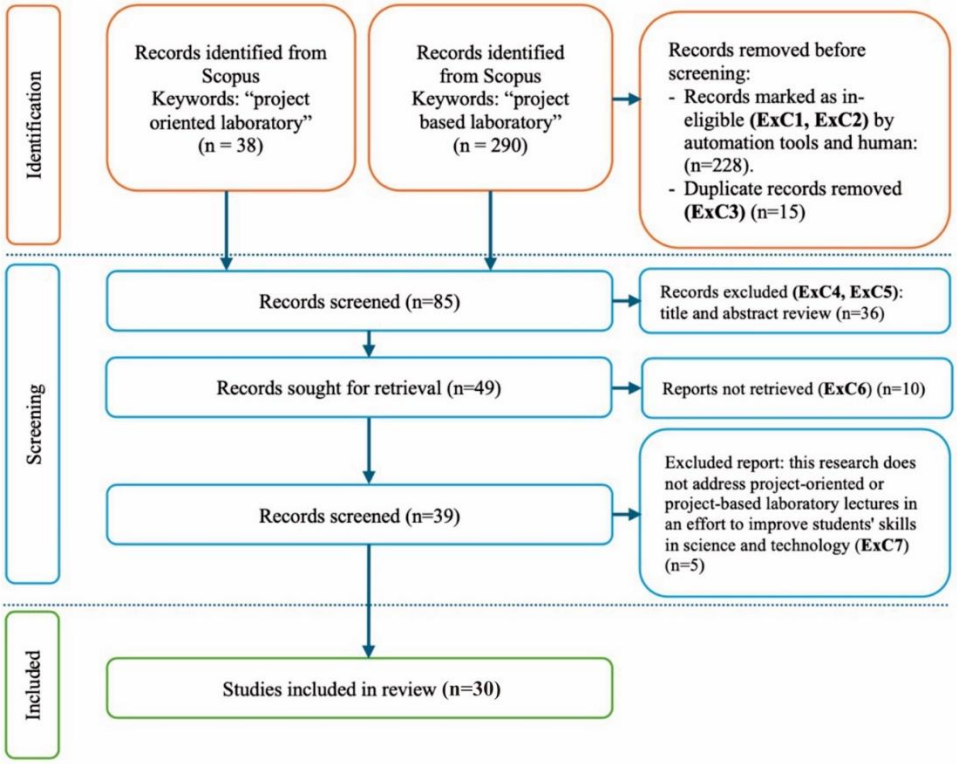

Figure 1. Prisma 2020 flow diagram.

Data analysis in this study used the thematic analysis method. Thematic analysis is a technique for identifying, analyzing, and reporting themes or patterns in data. The important components of each theme are taken for analysis. According to Braun & Clarke, (2006), there are six steps in thematic analysis. The first step is data identification, followed by data coding as the second step. The third step involves finding themes and compiling codes, while the fourth step is applying the codes to the data. Next, the fifth step is to determine relevant themes, and finally, the sixth step is to compile a theme report and relate it back to the research questions.

Results and Discussion

The transformation of laboratory learning from conventional approaches to POLs has had a significant impact on science and engineering learning. Based on an analysis of the literature over the last 30 years, POLs offer a more innovative approach, providing students with hands-on experience in solving problems through real projects. This approach not only enhances concept understanding but also 21st century skills, such as problem solving, collaboration, and technology utilization. Based on the articles analyzed, the implementation of POLs is still limited to the fields of Engineering and pure science. There are also not many projects completed by students that relate to SDGs issues such as environmental problems.

An analysis of articles published in the last 30 years on POLs and PBLs shows a significant increase in interest in these approaches across various disciplines. Here are the main findings based on the analysis:

a. Research subjects
   POLs and PBLs have been applied in various fields, including engineering (electrical, mechatronics, informatics), biological sciences, chemistry, and even consumer science. Implemented projects range from software application development Paturca et al., (2018), robotics control Torres-Salinas et al., (2022), to environmental research such as geology-based disease distribution (Mouri, 2020).

b. Benefits of Implementation
   In general, this approach enhances students' technical, collaboration and problem-solving skills. For example, the application of POLs in electrical engineering showed an increase in students' understanding of fuzzy logic control Torres-Salinas et al., (2022), while in informatics, web-based projects such as "software as a service" helped students understand modern software development (Kautsar & Sarno, 2019).

c. Innovation and Linkages to SDGs
   Some projects have relevance to SDGs. For example, the development of renewable energy systems such as wind turbines and electric bicycles by Misoc et al., (2020) supports SDG 7. However, few studies explicitly align POLs with solving global environmental problems.

The summary of the analysis of 30 articles is shown in Table 2.

Table 2. Summary of a systematic literature review on the application of POLs and PBLs in science and technology students over the last thirty years (1993-2024).

Author, year	Subject Research	Findings	Projects completed by students
(Paturca et al., 2018)	Biomedical Engineering Student	POLs improved students' understanding of software development, robot control, and team collaboration.	- Development of a LabVIEW application to control the motion of the robotic arm orthosis. - PC interface design for rehabilitation parameters.
(Manam et al., 2021)	Electrical and instrument engineering students in India	Implementation of PBL using National Instruments tools (LabVIEW, Multisim, myRIO, ELVIS ii+) enhanced students' understanding of speed measurement as well as programming. PBL also facilitates the integration of hardware and software for simulation and real measurements.	- Simulation of speed measurement using LabVIEW. - Hardware development with myRIO and ELVIS ii+ for speed measurement system.
(Mielmann, 2021)	Consumer Sciences student, North-West University, South Africa	The implementation of online-based research projects during the covid-19 pandemic showed an increase in students' critical skills and reflective abilities. Students are able to integrate ICT to complete quantitative research independently.	Students complete an online research project that includes data collection on "Need-for-Touch" in online food shopping, report writing, presentation, and critical reflection on their experience during the project.
(Lokare et al., 2020)	Computer engineering undergraduate students in India	The application of PBL and CL methods improved learning outcomes by 15%-20% over traditional methods. Client-based projects promote practical skills and concept understanding.	- Commercial website development based on client needs. - Design of application protocols such as FTP, DNS, and HTTP. - Simulation of routing protocols using NS-2.
(Torres-Salinas et al., 2020)	Control engineering student at Universidad Autónoma de Querétaro	The application of fuzzy logic in DC motor control learning shows improvement in understanding of non-classical control concepts and practical skills.	Students develop control loops for DC motors, including the design stage of data acquisition card (DAQ), fuzzy controller, and system implementation using fuzzy logic.
(Baluarte-Araya, 2020)	Information systems engineering student at the National University of San Agustín, Peru	The PBL approach enhances students' database design skills and professional competencies through the integration of theory and practice in the laboratory.	Students design and implement databases for real organizations, including conceptual, logical, and physical models, using tools such as MySQL, TOAD, and programming languages such as Java.
(Pierucci, 2019)	Telecommunications engineering student in the master's program at the University of Florence	CDIO (conceive, design, implement, operate) and PBL based learning methods improve students' ability to understand wireless communication standards, real system implementation, and industry collaboration skills through internships.	- Analysis of LTE standards: Students design subsystems for LTE networks including uplink and downlink logic using data analysis tools. - MATLAB simulation: Simulation of LTE network parameters, such as OFDM, fading channel, and performance testing with SINR (Signal-to-Interference-Noise Ratio). - Use of ZigBee Devices: The project utilizes the OpenMote platform to build an IoT system with smart sensors and gateways.

Author, year	Subject Research	Findings	Projects completed by students
(Kautsar & Sarno, 2019)	Informatics engineering student at Muhammadiyah Sidoarjo University	The implementation of microframework-based tools to support PBL and LBE showed 90% user satisfaction and task completion time <5 minutes.	Students develop web-based software, such as "Software as a Service" for their academic needs, including digital reports.
(Davies, 2019)	Medical Geology Student	PBL improves students' understanding of the relationship between geology and health and research skills.	Disease distribution research project related to environmental and geological factors in South Africa.
(Paturca et al., 2018)	Electrical and Mechatronics Engineering Student	POLs enhances students' understanding of embedded control, microcontroller programming, and multidisciplinary teamwork.	- Design and implementation of BLDC motor control system. - Embedded system programming for automatic trolley motion control.
(Blanding & Meah, 2015)	First Year Electrical Engineering Students	Laboratory-based projects improve understanding of measuring instruments, circuit design and problem solving.	- Assistive technology project for people with disabilities. - Energy-saving lighting project for remote areas.
(Misoc et al., 2013)	Renewable Energy Engineering Student	POLs improved students' understanding of renewable energy concepts, design skills, and team collaboration.	- Sun tracking system. - Savonius wind turbine. - Solar powered air conditioning system. - Electric bicycle.
(Sinha, 2013)	K-12 students in rural schools (ASU Outreach)	Project-based programs increase K-12 students' interest in STEM and awareness of engineering career opportunities.	- Balsa Wood Bridge Building Contest. - Saturday Engineering Workshop using Lego Mindstorms and CNC equipment. - Computing Summer Camp.
(Roshan & Moallem, 2011)	Mechatronics and Electrical Engineering Students	POLs enhances the integration of sensor, actuator, control and programming concepts in embedded system design.	- Air levitation system project. - Pendulum motor control. - 1-DoF robot arm control.
(Brown & Lu, 2011)	Electrical and Computer Engineering Students	Team collaboration improves efficiency, programming skills, and understanding of object-based programming concepts.	- Programming Rubik's Cube features in Java and C++. - Graphical interface (GUI) design for the Rubik's Cube game.
(Bauer & Fedák, 2010)	Electrical engineering student at Delft University of Technology and Technical University of Kosice	The use of multimedia-based eLearning and virtual laboratory improves students' understanding in electronic power control and electric drive. PBL method is used to improve practical skills and integration of theory with real applications.	Students study the electric drive system of hybrid cars, including the analysis of DC-DC converter and DC-AC inverter through simulation and virtual laboratory. They also design and analyze the motor drive subsystem.
(Alba-flores, 2007)	Electrical and Mechatronics Engineering Student	POLs improves understanding of embedded systems, hardware safety, and sensor-actuator integration.	- Car turn signal simulation. - Simple piano keyboard control. - Distance measurement with IR sensor. - Control of a small autonomous robot car.
(Mclauchlan & Texas, 2007)	Electrical and Computer Engineering Students	POLs improves design, project management and integration skills of microprocessor-based systems.	- Control design for a six-legged hexapod robot. - Implementation of sensors and microprocessor control system.
(Cooper & Kerns, 2006)	Organic Chemistry Student	PBL improve problem-solving skills, collaboration and positive perceptions of science.	- Project on synthesizing organic compounds through nitration of various substrates.

Author, year	Subject Research	Findings	Projects completed by students
			- Identification and analysis of compounds using spectroscopy (NMR, IR).
(Dvonch et al., 2006)	Engineering and Applied Science Students	POLs enhances students' understanding of non-contact measurement technology and interdisciplinary research skills.	- Development of a CO measurement system using GFCR. - Thermal profile study for military power systems. - Scientific balloon photogrammetry study. - Thermal diagnostic system for solar sails.
(Pastor Mendoza et al., 2006)	Electrical and Electronics Engineering Students	POLs improves understanding of digital system design, hardware integration, and top-down design methods.	Design and implementation of 8-bit microcontroller-based embedded systems using finite state machines (FSM) or Petri Nets.
(Zimmer et al., 1999)	Microelectronics Engineering Student	POLs improves the understanding of hierarchical design, behavioral modeling, and simulation efficiency of analog systems.	Hierarchical design and modeling of analog circuits such as PLLs using VerilogA and VHDL-AMS.
(Sucar et al., 2005)	Electrical engineering and robotics students	- The integration of virtual laboratory and intelligent tutoring system (ITS) helps to accelerate and improve the learning process. - Students with ITS performed better than the control group. - POLs improves collaboration, creativity and problem solving skills.	Simulation of a robotics project using a virtual laboratory and ITS.
(Craig, 1999)	Biochemistry, Biotechnology Student	The POLs approach enhances laboratory skills, problem solving and in-depth understanding of biochemistry.	- Purification of threonine dehydrogenase (TDH) enzyme from E. coli. - Characterization of TDH enzyme. - Original research project using TDH enzyme.
(Cruz-Rivera, 1998)	Computer and Electrical Engineering Student	PBL improves understanding of hardware and software integration and team skills.	- Home appliance controller. - Home/automotive security system. - Robotics applications. - Automatic irrigation system.
(Caverly, 1997)	Electrical Engineering Student	PBL improves analog microelectronic system design understanding and practical skills.	- Design and simulation of CMOS current mirror. - CMOS push-pull amplifier design. - Design of adjustable switched capacitor filter.
(Mariappan, n.d.)	Mechatronics student	Project-based mechatronics laboratories enhance understanding of the integration of mechanics, controls, electronics and computers.	- Creative redesign project of a mechatronics product (e.g., digital scale). - Reverse engineering project of mechatronics products. - Final project of mechatronics product design and prototype (e.g., autonomous vehicle and CNC machine).
(Joenathan et al., 1995)	Optical Engineering and Physics Students	POLs improves students' design skills, problem solving, and work readiness in the field of applied optics.	- Interferometer design for rough surface measurement. - Laser beam collimation tester with spiral grating.

Author, year	Subject Research	Findings	Projects completed by students
			- Polarization rotator.
(Torrey, 1994)	Electrical Engineering and Postgraduate Students	POLs improves students' understanding of simulation, design, implementation, and testing of power electronics circuits.	- Design and implementation of DC-DC converter. - Single phase inverter design. - Power electronics related final project.
(Ume & Timmerman, 1993)	Mechanical Engineering Student at Georgia Tech	The project-based approach enhances hardware-software integration and cross-disciplinary understanding for microprocessor design.	- Light sensor-based automatic window blind control system. - Blood flow simulation using flapper valve. - Bar code scanner. - "Heads-up" car dashboard display.

RQ1.What is the potential of implementing POLs in supporting practical learning in the field of science education that is integrated with SDGs issues?

POLs have been recognized as an important innovation in science education for their ability to improve students' technical and non-technical skills. This approach reflects a shift from traditional laboratory models that are passive and procedural towards learning that is inquiry-based, learner-centered, and connected to real problems. Findings from the literature analysis suggest that POLs consistently create a relevant and interactive learning environment, encouraging students to engage in complex, applied projects (Bell, 2010; Kaldi et al., 2011).

For example, in electrical engineering, students are able to design fuzzy logic-based motor control systems that reflect advanced technological applications (Torres-Salinas et al., 2020). In biochemistry, POLs enable students to conduct original research related to clinical enzymes, strengthening laboratory analysis skills (Farnham & Dube, 2015). In the context of sustainability, POLs are also being applied to guide students in environmentally themed field projects (Espino-Díaz et al., 2025; Konieczny, 2024).

However, in the context of science education, the application of POLs is still very limited. This approach has great potential to be adapted in science practicum to integrate science learning with SDGs issues, such as water pollution, energy conservation and waste management. POLs can be a strategic tool to connect scientific knowledge with environmental concerns and build critical and collaborative thinking competencies.

RQ2. What are the main challenges faced in the implementation of POLs in the context of science education?

One of the key challenges found in this study is the lack of implementation of POLs in science education compared to engineering and pure science. Most POLs projects are still focused on developing technology and control systems, while pedagogical aspects to support contextualized science learning have not been developed much. In addition, the integration of POLs with SDGs issues is not yet optimal. While there are projects relevant to SDG 7, such as the development of wind turbines and electric bicycles (Misoc et al., 2013), very few POLs projects are explicitly geared towards addressing issues such as climate change mitigation (SDG 13) or waste management (SDG 12) (Kleespies & Dierkes, 2022; Laurett et al., 2022).

Other challenges include limited laboratory infrastructure, lack of lecturer training in inquiry-based project facilitation, and curriculum support that has not been adaptive to the POLs approach. Previous studies have shown that the availability of technologies such as LabVIEW and simulation platforms is critical, yet often unavailable in institutions with limited resources (Lee et al., 2010; Manam et al., 2021). The success of POLs largely depends on the readiness of lecturers as facilitators, who need intensive training to be able to effectively integrate this approach in learning (Uddin et al., 2020).

RQ3. How can POLs implementation schemes be proposed to optimize their contribution to project-based science learning and global issues?

To address these challenges, a contextualized and structured POLs implementation scheme for science education is needed. The scheme starts from the identification of a contextual issue relevant to the SDGs (e.g. plastic waste, water conservation, or clean energy), which is then developed into a problem formulation and project objectives. Students then design an experiment and develop the project collaboratively, with subsequent stages including experiment execution, data collection, and analysis of results. The project concludes with a presentation of results and critical reflection on the learning process and the impact of the solutions developed.

This implementation process is divided into three main phases: pre-lab (issue identification, planning, and project design), lab (experiment execution and data collection), and post-lab (process-based analysis, reflection, and evaluation). This approach not only increases the relevance and engagement of students in the practicum, but also strengthens the role of science education in facilitating learning that is meaningful, applicable, and aligned with sustainable development.

Conclusion

This study concludes that although POLs have been proven effective in improving conceptual understanding, practical skills, and 21st century competencies, their implementation in the context of practical learning in the field of science education is still very limited. The results of a systematic review of 34 articles show that POLs have been mostly applied in engineering and pure science fields, such as electrical engineering, biochemistry, and information technology, while the field of science education has not adopted this approach thoroughly. In addition, the integration of POLs with global issues such as the SDGs has also not been strategic, as most projects still focus on technical aspects without being geared towards solving real environmental problems such as climate change or waste management. To address this challenge, the research recommends that science practicum learning adopt a POLs approach through a structured implementation scheme, starting from the identification of contextual issues relevant to SDGs, problem formulation, project design and implementation, to critical reflection and process-based evaluation. By explicitly integrating POLs in the science education practicum curriculum, it is hoped that students will not only gain a strong scientific understanding, but also be able to contribute creatively to solving global challenges.

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