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Integrating problem-based learning into the first-year physics laboratory course: A post-COVID-19 scenario at Walailak University, Thailand

Punsiri Dam-o Adamczyk [1], Thammarong Eadkhong [1*], Chitnarong Sirisathitkul [1]

[1] Division of Physics, School of Science, Walailak University, Nakhon Si Thammarat, THAILAND

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Abstract
The fundamentals of physics laboratory for teachers course at Walailak University, Thailand, has been revamped post-COVID-19 to incorporate problem-based learning (PBL) alongside traditional labs. This approach, aligned with the Thailand qualification framework and the United Kingdom professional standards framework, aims to equip future science educators with essential skills. PBL fosters collaborative learning, focusing on experimental design using various tools. Students work in groups, and their assessment, based on rubrics, includes formative evaluation contributing 20% to the course grade. Based on the improvements of completion over progress scores, the PBL process and iterative testing enhanced experimental design, data analysis, presentation skills, adaptability, and problem-solving abilities of the group members. This course demonstrates the potential applicability of PBL to other science laboratory courses, enhancing educators' preparedness for diverse teaching contexts.

Keywords: post-COVID-19, problem-based learning, physics laboratory, United Kingdom professional standards framework, STEM education

INTRODUCTION

The COVID-19 pandemic acted as a catalyst for profound changes in educational practices, prompting educators to explore innovative pedagogical approaches to navigate the challenges posed by the crisis (Fuchs & Fangpong, 2023; Makamure & Tsakeni, 2020). The adaptability and creativity of educators became paramount in achieving course objectives amidst unprecedented circumstances (Baptista et al., 2020), with the effectiveness of educational modalities varying depending on their suitability for different contexts. Problem-based learning (PBL), a prominent approach in traditional settings (Argaw et al., 2017; Aidoo, 2023; Akcay & Benek, 2024), has emerged as a flexible method that could be effectively implemented in diverse subjects and contexts, including distance education (Bumblauskas & Vyas, 2021). Notably, the convergence of PBL and distance education during the pandemic highlighted the potential for critical thinking and creativity fostered by the PBL approach to thrive in remote learning environments. PBL cultivates essential skills such as adaptability, critical thinking, collaboration, and problem-solving, qualities paramount for success in the 21st century (Şahin & Kılıç, 2024). Recent studies have demonstrated the versatility of PBL, showcasing its successful integration with augmented reality technology and its application in enhancing the scientific writing process (Nisa et al., 2024; Rahmasari & Kuswanto, 2023).

Traditionally, first-year undergraduate science courses heavily relied on instructional laboratories, where students followed predefined guidelines to conduct experiments and analyze results under the supervision of instructors. However, the COVID-19 pandemic disrupted laboratory teaching worldwide from 2020 to 2022, prohibiting access to physical laboratories. Using online platforms for laboratory subjects was highly challenging for students and educators (Gamage et al., 2020). In response to this challenge, physics instructors at Walailak University in Thailand devised and implemented a course that allowed students to conduct experiments at home (Dam-O et al., 2024). Through guidance provided by lecturers via Zoom meetings, the course emphasized a hands-on approach to learning, creativity, problem-solving, and self-reliance. In addition to online instructional

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✉ dpunsiri@mail.wu.ac.th ✉ thammarong.ea@mail.wu.ac.th **(*Correspondence)** ✉ schitnar@mail.wu.ac.th

Contribution to the literature

- The article demonstrates the incorporation of PBL into traditional physics laboratory courses for first-year undergraduate students in a teacher education program.
- It uniquely aligns with the Thailand qualification framework (TQF) and the United Kingdom professional standards framework (UKPSF), offering a comprehensive approach to skill development in future science educators.
- The course also provides a valuable case study for implementing PBL in other science laboratory courses, emphasizing its effectiveness in enhancing educational preparedness and adaptability for diverse teaching contexts.

laboratories, the course included a component on problem-based experiments, where students devised their own setups to measure atmospheric pressure at home, demonstrating the adaptability and effectiveness of the approach. Chirikure (2021) pointed out that such home-based practical works are not only alternatives in emergency remote teaching but also empowering, contextualized, and flexible for active learning.

As the education sector looks beyond the immediate impacts of the pandemic, there is a growing recognition of the need to incorporate lessons learned during this period into the design of 21st century classrooms (Naidu, 2024). Elements of distance education that were accelerated during the pandemic have already found their way into on-site or hybrid learning models (Jackson & Szombathelyi, 2022). Cossu et al. (2022) have advocated for reforming teaching modalities in physics laboratories through integrating emerging technologies. At Walailak University, the division of physics has embraced this shift by integrating the PBL approach into a physics laboratory course for first-year students in the teacher education program. In addition to traditional instructional laboratories, students were tasked with conducting their own experiments based on topics of their choice. Incorporating PBL activities in this course allows future science educators to design experiments, construct apparatus, and create lab instruction manuals for hands-on physics laboratories. The process and results of this course, described according to the UKPSF for teaching and supporting learning 2011, offer valuable insights and could serve as a compelling case study for implementing the PBL concept in other laboratory courses. In the following sections, 2 areas of the UKPSF core teaching activity (A1 and A2) are used in describing the method of integrating PBL activities into the first-year physics laboratory course. Three other areas of activity (A3, A4, and A5) correspond to 3 research questions (**RQ**s), as follows.

RQ1. Do physics laboratories designed and developed by first-year students in the teacher education program align with PBL principles? How could instructors assess and provide feedback on these labs? (A3)

RQ2. What are effective ways to develop learning environments and guide students in laboratory course incorporating PBL activities? (A4)

RQ3. How do the PBL lab activities contribute to developing future science educators? (A5)

CONTEXTS AND METHODS

Design and Plan Learning Activities and/or Programs of Study (A1)

In the second trimester of the academic year 2023, the division of physics at Walailak University introduced a new course, 'PHE66-112 fundamentals of physics laboratory for teachers' for students in the teacher education program, specializing in general science and biology. Recognizing the pivotal role of teachers, this program is tailored to equip future science educators with proficiency in experiment design, apparatus construction, and lab instruction preparation. These competencies are essential for their future careers in teaching science at schools. To achieve this objective via a PBL approach, students participated in groups of 3-5 and engaged in a do-it-yourself (DIY) fashion, with weekly updates and a final presentation of their PBL lab activities to instructors. This process embraces several key stages, i.e., learning from existing examples, exploring topics of personal interest, proposing ideas and seeking feedback, developing the experiments, undergoing a phase of trial and error, and ultimately presenting the finalized lab work, as illustrated in **Figure 1**.

In **Figure 1**, the PBL lab sessions spanned 9 of the 12 weeks of the course. During the first 7 weeks, students participated in instructional physics laboratories, focusing on developing laboratory skills together with learning to design physics experiments and preparing their own PBL lab documents using existing learning materials as examples. The instructional physics lab session was supervised by a single instructor for 6-7 groups of students, each comprising 3 members assigned by the course instructors. The duration of each laboratory session was approximately 3 hours. The structured activities encompassed a pre-test assessment, concise laboratory instruction, experimental procedures, report writing, and a post-test evaluation. Each session

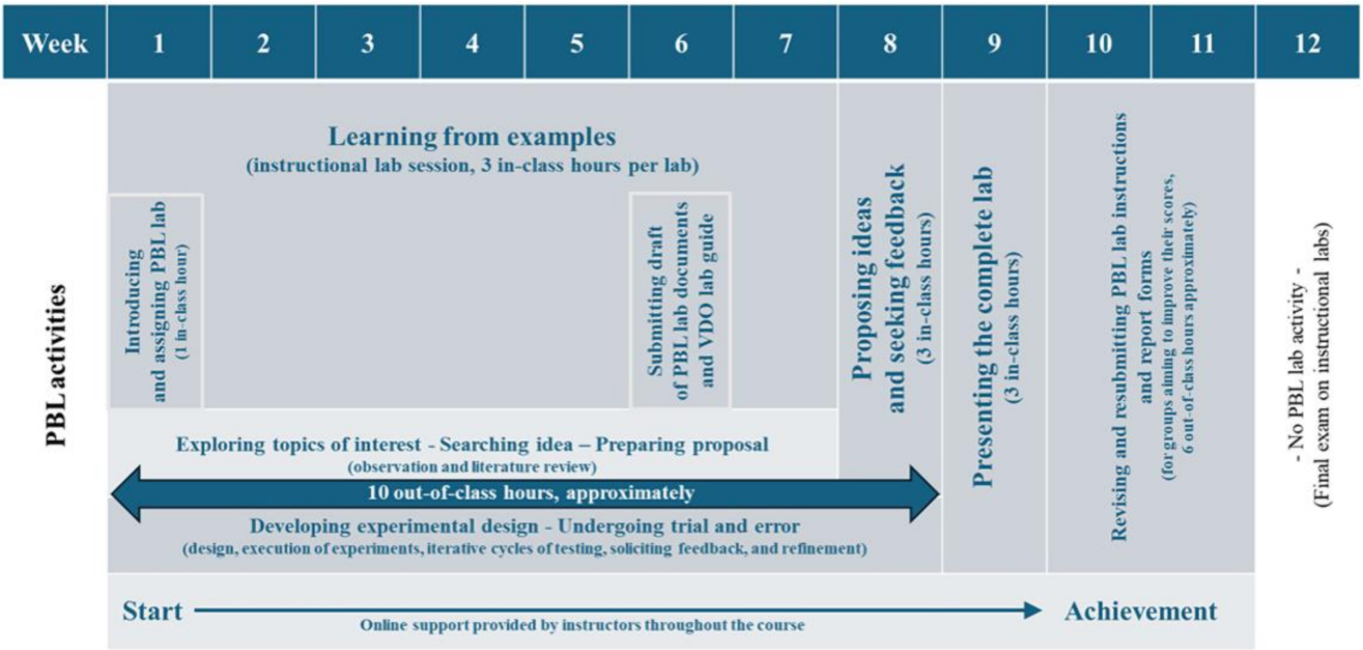


Figure 1. The PBL lab process, implemented over a span of 9 weeks with an additional 2 weeks for improvement (totaling 28 in-class hours and 16 out-of-class hours), is designed to enable students to develop hands-on experiments in physics (online support from instructors was available throughout the course). (Source: Authors' own elaboration)

was accompanied by a detailed instructional manual, which was provided to the students beforehand as online learning material. During these lab sessions, students could seek guidance from the instructor as needed. The students completed these 7 laboratories over 7 weeks. Concurrently, they were encouraged to identify a laboratory experiment that particularly interested them and use them as an example. In the eighth week, students presented their chosen experiment and received feedback from the laboratory instructors, which they then used to refine their activities. In the ninth week, students presented their completed PBL lab assignment, along with the accompanying lab instruction manuals. Additionally, the tenth and eleventh weeks were set aside for student groups aiming to improve their lab instructions and report forms. The revised documents could be completed outside of class and resubmitted online.

Administrating PBL lab sessions imperatively involves the teachers' time constraints, students' preparedness, availability of project resources, and administrative commitments. Aligned with findings by Tain et al. (2023), these 4 challenging factors are considered in implementing PBL in the PHE66-112 course.

Teachers' time constraints

Prior to commencing the PHE66-112 course, a preparatory meeting convened with the lab instructors to delineate their roles and responsibilities. Within the framework of PBL activities, instructors were allocated distinct tasks with 41 hours, including:

1. 6 hours before the course: provision of clear instructions to students, articulation of evaluation criteria, and notification of activity deadlines,
2. 21 hours from week 1-7: facilitation of student inquiries regarding experiment objectives and methodologies proposed,
3. 3 hours in week 8: critique of student experiments and data collection processes,
4. 3 hours in week 9: guidance provided to students to enhance the clarity and efficacy of their lab instructions and reports,
5. 5 hours of online support to assist students who required assistance, and
6. 3 hours for reviewing and scoring the revised version of lab instructions and report forms.

Additionally, all instructors in the course were obligated to provide guidance and advice to students whenever they sought assistance throughout the course, whether through in-person meetings or online channels.

Students' preparedness

During the introductory session in the first week of the course, students were introduced to the PBL lab assignment. They were tasked with collaborating in groups to synthesize, apply, and construct knowledge to tackle challenging problems. In this context, "synthesizing" refers to the process of integrating knowledge from different scientific disciplines, which the students had previously encountered in their lecture courses and other learning platforms. Rather than focusing on isolated concepts, students were required to combine relevant principles from physics, mathematics, and other related fields to propose viable solutions to problems presented during the PBL sessions. Group discussions were instrumental in this process, enabling students to bring together different perspectives and areas of expertise within their group. The formation of these groups was left to the student's discretion. They were allotted 7 weeks to explore, observe, strategize, and develop their experimental designs. Additionally, students were encouraged to seek guidance and advice from course instructors as needed.

Availability of project resources

The students were instructed to conduct a literature review by examining research papers in academic journals and observing physics classes in schools or universities. They were provided with resources and tools supported by the Center for Scientific and Technological Equipment (CSE) of Walailak University.

Administrative commitments

The course aims to empower students to apply theoretical principles learned in classroom settings to practical, real-world scenarios through experiential learning. Additionally, it aims to develop students' ability to design experimental frameworks conducive to teaching and understanding physics within educational institutions. These objectives, articulated within the TQF, outline the course's intended learning outcomes. The selection of PBL as the pedagogical approach aligns with the educational ethos at Walailak University, emphasizing the principles of outcomes-based education theory and the UKPSF. PBL, a highly endorsed teaching methodology across various disciplines, is well-suited to facilitate the achievement of these defined learning outcomes.

Teach and/or Support Learning (A2)

The PBL lab activity was structured around collaborative group work. The students' task was constructing a traditional physics lab exercise for pupils to explore specific physical concepts and solve them. The materials for the traditional physics lab exercise include the lab instruction manual, lab report form, and video lab guide that students need to prepare. The schedule of the PBL lab session in the PHE66-112 course commenced with an introductory session in the first week. This session elucidated the fundamental principles of PBL, emphasizing its efficacy in enhancing physics education by fostering hands-on experimentation and exploration. Furthermore, it highlighted the significance of integrating PBL lab assignments into the curriculum, elucidating their relevance for future educators. Subsequently, instructors presented students with a diverse array of illustrative examples of traditional labs that could be further developed by students in the PBL assignment. In addition to those included in the course, laboratories published in academic journals were introduced to showcase different physics concepts and principles. Students can also learn from the experimental design and data analysis of these laboratories and publications. Noteworthy examples included the traditional physics lab on fluid mechanics (Guerra et al., 2005; Oliveira et al., 2000), the adaptation of smartphone sensors for measuring various physical quantities (Averina & Yusuf, 2023; Dinmeung et al., 2023; Sirisathitkul, 2023), and additional examples related to the collision of objects (Cross, 2022), resonance in sound waves (Monteiro et al., 2023), and momentum (Yardi et al., 2023). The instructors delineated a meticulously structured timeline for implementing PBL lab sessions, specifying deadlines for each phase. The sequential steps outlined encompassed observation, literature review, design, and execution of PBL physics experiments, followed by iterative cycles of testing, soliciting feedback, and subsequent refinement. The PBL lab sessions (excluding 21 in-class hours of learning from examples) were structured to span 7 hours in class, supplemented by approximately 10 hours of out-of-class time designated for homework assignments and further exploration of the concepts covered. **Table 1** outlines the schedule for the PHE66-112 course, encompassing a comprehensive list of lab activities scheduled over a single trimester spanning 12 weeks, with the PBL session and assessment extending from the first to the eleventh week of the course.

In **Table 1**, the instructional physics laboratories offered in this course cover essential topics, including force and motion, mechanical waves, fluid mechanics, electricity, electromagnetic waves, and thermodynamics. Using these laboratories as examples, instructors aim to demonstrate to students the use of traditional and emerging tools available to everyone (Prahani et al., 2024). Examples include the PhET online virtual physics laboratory, Tracker–open-source software for motion analysis, smartphone sensors, and DIY apparatus. These laboratories not only showcase educational tools but also act as catalysts for creativity, inspiring students to envision and create their experiments for future science classrooms.

All course materials pertaining to both instructional and PBL laboratories were accessible to students as electronic files through the e-Learning platform, enabling them to access the resources at their convenience. Additionally, announcements and reminders were regularly posted on the course's Facebook group, providing students with updates and information. In addition to the course instructors, laboratory staff members from CSE were briefed on how to offer prompt assistance to students. They were tasked with providing necessary tools, equipment, and access to laboratory spaces to facilitate the students' experiments. Without step-by-step laboratory instructions for the PBL lab assignment, the course

Table 1. Twelve-week schedule of instructional laboratory and PBL activities in the PHE66-112 course

Week	Instructional lab for 3 hours in class per lab	PBL lab activities (duration in class)
1	Measurement errors and experimental analysis by graphs	1. Introducing to PBL physics lab 2. Giving some examples of PBL physics labs 3. Assigning PBL lab schedule (1 hour)
2	Tracker video analysis of motions	Students'observation and literature review as homework
3	Electric circuit simulation by PhET	Students'observation and literature review as homework
4	Speed of efflux	Students'observation and literature review as homework
5	Simple harmonic motion studies by infrared sensor	1. Students'observation and literature review as homework 2. Reminding of PBL physics lab progress submission next week
6	Sound and light measurements using smartphone sensors	1. Students'observation and literature review as homework 2. Submitting PBL physics lab progress by students
7	Air temperature and humidity measurements using SHT31 sensor with Arduino IDE and Microsoft Data Streamer	1. Students'observation and literature review as homework 2. Preparing for PBL physics lab progress presentation
8	-	1. Presenting PBL physics lab progress and preliminary results 2. Consulting lab instructors 3. Scoring progress (3 hours)
9	-	1. Presenting PBL physics lab report, PBL physics lab set, and video demonstrating their experiment 2. Scoring completion (3 hours)
10-11	Make up laboratory for absent students	Opening for revised submission of PBL physics lab report to make up students' scores
12	Final examination	-

included ample opportunities for guiding and supporting students. Students were encouraged to explore a variety of online resources at their own pace to deepen their understanding of the topics under investigation. These resources supplement traditional lectures by providing alternative explanations, demonstrations, and practical examples. For instance, websites and AI-powered chatbots were used to help students clarify and reinforce their understanding of complex physics concepts that had been introduced during lectures. These resources allowed students to revisit foundational principles as needed and offered personalized explanations based on the specific questions they had. In addition, online videos and interactive simulations provided visual and interactive demonstrations of how these concepts could be applied in the laboratory setting. Rather than simply repeating experiments shown in these videos, students were encouraged to use the demonstrations as a starting point for designing their own investigations, adapting the ideas and techniques to the specific problems they were tasked with solving. If unclear issues arose, guidance was provided face-to-face during the class hour and online any other time. Instructors supervised students in overcoming challenges regarding theory, experimental setup, and result analysis.

RESULTS AND DISCUSSION

Assess and Give Feedback to Learners (A3)

The assessment weightings in the PHE66-112 course are distributed, as follows. Whereas instructional laboratories collectively contribute 60%, the PBL lab assignment accounts for 20%, carrying a substantial weight. This emphasis is justified by students' need to engage in PBL activities, which aligns with the demands of the contemporary workforce. The remaining score comes from the first week of graph analysis (5%) and the final examination in the last week (15%).

During the PBL lab activities within this course, students were required to fulfill the following tasks: preparing a comprehensive lab manual, arranging a lab report containing experimental data, creating a video clip serving as a lab guide, and presenting the lab findings. The lab session should be designed to last approximately 60 minutes, while the accompanying video should be limited to a maximum of 15 minutes. The PBL physics laboratory assessment allocated 5% of the grade for progress and 15% for the completion of lab activities. The instructors used a rubric scoring system, which was collaboratively designed by three instructors on a holistic scale and aligned with objectives of the PBL lab activities. The rubric criteria were also shared with other physics lab instructors, who served as third raters, and sent to all students to invite their feedback and suggestions for revisions before being implemented in the PBL lab assessment. The final version of the rubric, as illustrated in **Table 2**, was also discussed with the students to ensure a clear understanding of expectations.

The PBL activities involved 3 instructors in the assessment of students' work. The instructors evaluated the students' work using a rubric system, as outlined in **Table 2**, to ensure consistency in assessment and minimize the risk of data misinterpretation. The assessment rubric, which guided student work, was presented at the beginning of the course. The instructors

Table 2. Scoring breakdown and rubric criteria for the PBL lab assignment, accounting for 20% of the total score in the PHE66-112 course

Components	Assignment	S	Rubric score
Progress (5%)	Idea of PBL lab (oral presentation)	2	0 – No idea presented 1 – Idea presented but unable to articulate the experimental question 2 – Idea presented and clear articulation of experimental question they aim to explore
	Video lab guide	1	0 – No video provided 1 – Video of their experimental setup and the experiment is presented, partly or fully
	Lab instruction	1	0 – No lab instruction was provided 1 – Lab instruction related to their proposed idea is presented, either partly or wholly
	Lab report form	1	0 – No lab report form provided 1 – A lab report form related to their proposed idea is presented, either partly or wholly
Completion (15%)	Lab demonstration	3	0 – No lab demonstration from the students, either from the actual setup or in a video 1 – Students partially demonstrate their experiment, or all parts are not presented in sequence 2 – Students fully demonstrate their experiment, but some parts are not in sequence 3 – Students fully and sequentially demonstrate their experiment
	Physics concept	3	0 – Complete misconception in physics 1 – Partial misconception in physics 2 – Fully correct physics concept, but not covering all relevant concepts 3 – Fully correct physics concepts and cover all relevant concepts
	Video lab guide	3	0 – No video provided 1 – Partially video of their experimental setup and the experiment is presented 2 – Complete video of the lab guide provided 3 – Complete and engaging video of the lab guide provided
	Lab instruction	3	0 – No lab instruction was provided 1 – Lab instruction partially provided • Lacks key steps or instructions • May contain irrelevant information 2 – Lab instruction is mostly complete • Includes all essential steps but may lack clarity or details in some areas • It may not be well-organized 3 – Lab instruction is clear and complete • Provides all necessary steps in a clear and concise manner • Includes details and explanations for each step • Well-organized and easy to follow
	Lab report form	3	0 – No lab report form provided 1 – Incomplete or inaccurate lab report form, or contains significant errors in variable definition or data recording 2 – Partially complete lab report form • Variable definitions might be partially correct or unclear • Data tables might have formatting issues or missing information 3 – Clear and complete the lab report form • Variables are clearly defined and relevant to the experiment • Data tables are well-designed, clear, and easy to interpret • All data is accurately recorded and presented

Note. S: Score (%)

also communicated with students about the key aspects to focus on during the experiment and what to anticipate from the result analysis. Aligned with the 'analysis' and 'evaluation' levels of Bloom's taxonomy, the PBL lab activity promotes scientific thinking, logical reasoning, and mathematical problem-solving. The scores from all instructors were averaged and then integrated with other course components to determine the final grade.

After being reminded, students submitted their lab titles, drafts of instruction manuals, and lab report form, along with video lab guide during the sixth week. Lab instruction forms and guidelines were provided to the students, as shown in **Appendix A**. These students' materials were examined by the instructors to enhance PBL activities. At the eighth week, each group presented their proposal. The presentation was arranged to be about 10 minutes per group. Students used DIY objects and tools available around them, and one group employed smartphone sensors. During the presentation, the instructors offered guidance to refine their objectives, emphasize critical concepts in line with their goals, and ensure the correct application of physics principles. The presentation was followed by a question and answer (Q&A) session to facilitate student interaction. Questions and suggestions correspond to issues divided into 2 primary categories, i.e., those related to analytical and practical skills. From the presentation and feedback, areas for improvement were identified and exemplified, as follows.

- A well-defined research question is critical for guiding the experiment. Therefore, the experimental question "what do students want to study?" should be clear.
- All variables that could potentially affect the experimental results have to be controlled.
- Groups that conducted experiments solely through observation without gathering quantitative data on relationship of at least 2 variables were advised to enhance their approach.
- Repetition of measurements should be done to ensure the reliability in the experimental data.
- The accuracy of some measurement methods could be enhanced by utilizing more appropriate tools, equipment, and laboratory environments. The students could ask for help from CSE.

In addition to verbal feedback, the instructors provide written feedback to enhance clarity for some specific issues. The report submission before the presentation was therefore mandatory. Based on the student's lab reports, instructors judged that they had improved significantly compared to the beginning week. A live demonstration or video clips for each laboratory were shown during the presentation, with instructors paying close attention and providing responses to students' experiments and reports. Immediate feedback can be helpful because the issues are still fresh in everyone's mind, and students can ask instructors directly. The rubric scores were exchanged among the lecturers at the end of the presentation. The pursuing discussions provided opportunities to address concerns and insights. Improvements were proposed for future courses.

The instructors provided feedback to the students, and significant improvements were observed among the students in the final week following the feedback and suggestions. In the ninth week, each group presented their complete PBL physics lab instruction manual and lab report form, accompanied by a video clip. Eighteen groups of 76 students proposed 17 PBL activities (2 groups proposed a similar physics experiment), as shown in **Table 3**. The most selected topics align with the survey of PBL implementation in physics by Akcay and Benek (2024), namely "matter and heat," "force and motion," "electricity and magnetism," and "work-energy." In evaluating the PBL lab activities, instructors assess both students' individual contributions and the group's overall completion, ensuring that the outcomes align with the 4 domains of PBL principles (Smith et al., 2022).

Table 3. Students' PBL labs in the PHE66-112 course, classified according to key physics concepts and assessed their alignment with PBL principles (APBLP), i.e., flexible knowledge, skills, and capabilities (F); active and strategic metacognitive reasoning (A); collaboration based on intrinsic motivation (C); and problems embedded in real and rich contexts (P) (individual contributions [IC] and group completion [GC] are also checked.)

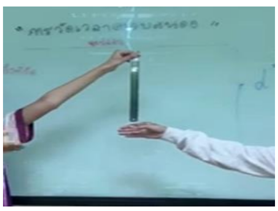
Topics	No	Students' PBL labs	Highlight of students' PBL labs	IC	GC	APBLP			
						F	A	C	P
Force and motion	1	Friction on surfaces 	Exploring the friction coefficient across diverse surface types	✓	✓	✓	✓	✓	✓
	2	Projectile motion with catapult 	Introducing the historical narrative of the catapult as an ancient weapon	✓	✓	✓	✓	✓	✓
	3	Reaction time measurement 	Conducting reaction time measurements among course participants and performing error analysis	✓	✓	✓	✓	✓	✓
	4	Spring constant and Hook's law	Selecting stones of different shapes and colors as counterweights for experimentation	✓	✓	✓	✓	✓	✓

Table 3 (Continued). Students' PBL labs in the PHE66-112 course, classified according to key physics concepts and assessed their alignment with PBL principles (APBLP), i.e., flexible knowledge, skills, and capabilities (F); active and strategic metacognitive reasoning (A); collaboration based on intrinsic motivation (C); and problems embedded in real and rich contexts (P) (individual contributions [IC] and group completion [GC] are also checked.)

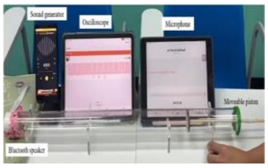
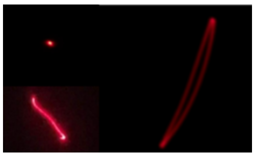
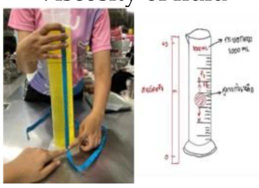
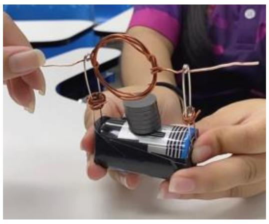
Topics	No	Students' PBL labs	Highlight of students' PBL labs	IC	GC	APBLP			
						F	A	C	P
Mechanical waves	5	Natural frequency of various stick lengths 	Investigating the natural frequencies of vertical sticks of varying lengths	✓	✓	✓	✓	✓	✓
	6	Resonance tube 	Utilizing smartphone applications such as Sound Wave Tone Generator and Arduino Science Journal	✓	✓	✓	✓	✓	✓
	7	Water wave diffraction 	Constructing a basic ripple tank apparatus	✓	✓	✓	✓	✓	✓
	8	Vibration detection of sound wave 	Demonstrating sound wave vibrations by projecting laser shapes onto a screen	✓	✓	✓	✓	✓	✓
	9	Viscosity of fluid 	Exploring the speed of falling objects in different types of fluid	✓	✓	✓	✓	✓	✓
Fluid mechanics	10	Motion of fluid on inclined ropes 	Manipulating variables to analyze water flow through different types of ropes	✓	✓	✓	✓	✓	✓
	11	Water pressure	Demonstrating pressure using a ping-pong ball	✓	✓	✓	✓	✓	✓
	12	Density of sinking and floating objects	Designing boat-shaped testing objects to engage children	✓	✓	✓	✓	✓	✓
	13	Hydraulic lift 	Constructing a hydraulic lift using a plastic syringe	✓	✓	✓	✓	✓	✓

Table 3 (Continued). Students' PBL labs in the PHE66-112 course, classified according to key physics concepts and assessed their alignment with PBL principles (APBLP), i.e., flexible knowledge, skills, and capabilities (F); active and strategic metacognitive reasoning (A); collaboration based on intrinsic motivation (C); and problems embedded in real and rich contexts (P) (individual contributions [IC] and group completion [GC] are also checked.)

Topics	No	Students' PBL labs	Highlight of students' PBL labs	IC	GC	APBLP			
						F	A	C	P
Electricity and magnetism	14	Electroscope	Investigating physics concepts using a toy	✓	✓	✓	✓	✓	✓
	15	Motor 	Investigating physics concepts using a toy	✓	✓	✓	✓	✓	✓
Electro-magnetic wave	16	Light reflection	Visualizing light reflection using laser and fine powder	✓	✓	✓	✓	✓	✓
Thermo-dynamics	17	Thermal conductivity 	Controlling variables to compare conductivity of materials	✓	✓	✓	✓	✓	✓

Note. APBLP: Alignment with PBL principles

In the ninth week, each group of students was allocated 10 minutes to present their PBL lab activities. Video clips of their experiment may be included during these presentations. Making video clips for sharing on the internet enhances content engagement and science communication skills. Each presentation was followed by a 5-minute Q&A session, facilitating discussions with students from other groups and the instructors. The learner-to-content, learner-to-learner, and learner-to-instructor engagements complete the trifecta of student engagement, which Leslie (2020) proposed originally for online teaching. As a result of feedback provided to the students, the instructors observed significant improvement in completing the PBL lab assignments. Observations revealed several areas for improvement within the students' PBL lab instructions and report forms, necessitating corrections to rectify potential misconceptions among pupils. Examples are, as follows.

- In the PBL lab instructions, some specified topics in the template were missing, and information or graphics from other sources were used without proper citation.
- In the lab report form, there are several errors related to measurement results and data analysis, including inaccuracies in calculations, incorrect units or dimensions, and misinterpretations of data.

The students in these groups could revise and resubmit their lab instruction manuals and report forms within the eleventh week. A resubmitted instruction was rescored. In addition, the individual contributions of students were examined from an assignment form (available in **Appendix A**) and observed from students' responses to instructors' questions. The completion of each group assessed from rubric score is shown in **Table 2**.

Regarding the individual contribution, students within each group are allowed to manage their responsibilities independently. Typically, they assigned into 5 specific roles that are

(1) preparing tools and the experimental space,

(2) designing the experimental method,

(3) performing the experiment, recording and analyzing data,

(4) writing the lab instructions, and

(5) creating the video clip.

For the conclusion, group members generally collaborated to work together. Examples of questions ensuring their responsibility are, as follows.

For students responsible for preparing tools and the experimental space:

- What factors led you to choose this specific tool over others?
- How did you control the environment in your experimental space?

For students responsible for designing the experimental method:

- What are the independent, dependent, and controlled variables in this experiment?

Table 4. Statistical analysis of PBL physics lab performance among 76 students in the second trimester of the academic year 2023 (the total score is 20)

Major in teacher education program	Number of students	Average	Maximum	Minimum	Standard deviation
Biology	21	13.62	20	10	2.41
General science	55	14.11	18	10	2.77
Total (biology and general science)	76	13.86	20	10	2.52

- Can you explain the experimental method step by step?

For students responsible for performing the experiment:

- Did you encounter any obstacles during the experiment, and how did you resolve them?
- What was your hypothesis for the experiment? Did the observed outcomes align with your expectations?

For students responsible for writing the lab instructions:

- What components are included in your lab instructions?
- Did you gather additional information from other sources? If so, what information did you find, and where did you find it?

For students responsible for creating the video clip:

- How do you divide the content to be presented and the time in the video clip?
- What is an important point (turning point) that you must present in the video clip?

The instructors observed and evaluated students' responses. If students demonstrated confidence, provided detailed explanations related to their roles, and offered logical reasoning, they were considered to have actively contributed to their group.

In the final process, the students' PBL physics lab outcomes were evaluated according to the rubric criteria outlined in **Table 3**, using the average score provided by PBL instructors. The scores of students in the Teacher Education Program specializing Biology and General Science do not substantially differ, as compared in **Table 4**.

Score data in **Table 4** were the sum of progress and completion scores. The average score of students from the general science major can be observed at 0.49 points higher than that of students from the biology major. The scoring range spans from a minimum score of 10 to a maximum score of 20. On average, students from both majors achieved a score of 13.86.

As shown by the progress score distribution in **Figure 2**, the progress presentations by students in the eighth week were generally satisfying. Every group successfully proposed an idea for their PBL activities, which they presented through a short video clip accompanied by an oral presentation. Nearly 80% of the groups had their ideas approved by the instructors, with only minor revisions suggested. However, about 20% of

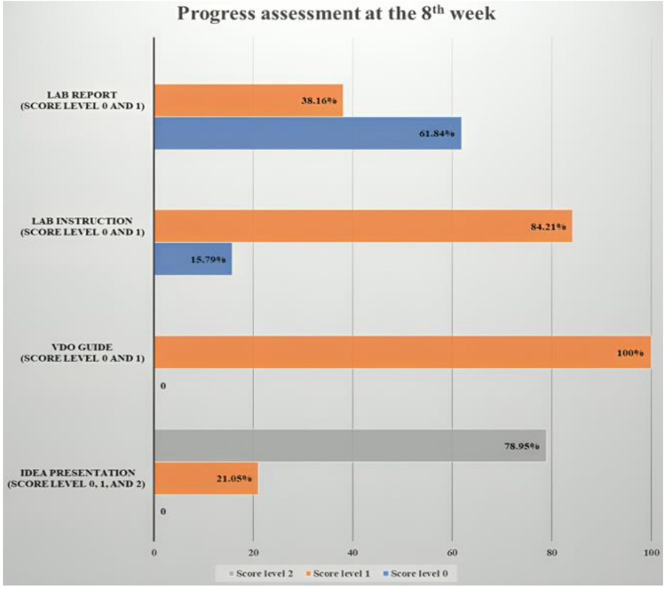


Figure 2. Percentage of student groups achieving progress scores by the eighth week (the average progress score, based on the rubric system, is 4.10 out of 5) (Source: Authors' own elaboration)

the groups were advised to make significant revisions. Additionally, over 80% of the groups completed the first draft of their lab instructions, ensuring alignment with the experimental questions of their PBL lab activities. Approximately 5% of the groups had not prepared their lab instructions due to insufficient time. For the same reason, around 60% of the groups had not yet completed the lab report. Considering this, it is recommended to include a one-week break after the seventh week in future iterations of the course to allow students more time to prepare their materials.

In the ninth week, students presented the completion of their PBL labs. They brought their lab setups, complete with materials, to demonstrate their experiments. Judged by the completion score distribution in **Figure 3**, approximately 60% of the student groups performed well in their lab demonstrations, effectively highlighting key aspects of the experimental process and accurately relating them to physics concepts. While the students' explanations were free of misconceptions, they did not fully cover all the relevant physics concepts linked to their labs. As a result, almost 90% of the groups received an overall score of 2. In the areas of materials–that are video guides, lab instructions, and lab reports–the students incorporated the instructors' suggestions, leading to an overall improvement in their scores, which average at level 2.

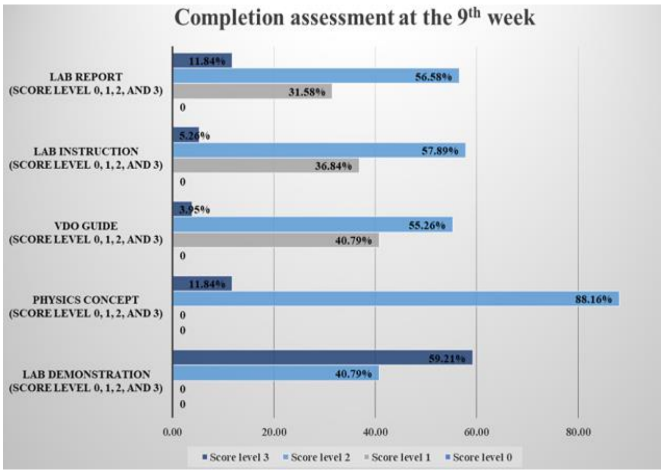


Figure 3. Percentage of student groups achieving completion scores by the ninth week (the average completion assessment, based on the rubric system, is 9.77 out of 15) (Source: Authors' own elaboration)

Develop Effective Learning Environments and Approaches to Student Support and Guidance (A4)

The PBL lab activity tends to be more challenging than the instructional laboratory because experiments are designed and carried out using non-preset apparatus. Furthermore, self-setup laboratories helped them understand physical phenomena in daily life and stimulated critical thinking (Ubaidillah et al., 2023). With the topic of their selection, students in this course collaborated in formulating a hypothesis, designing experiments, and planning data collection. In the context of first-year undergraduate studies, formulating a hypothesis usually involves the application of the physical principles they had already studied, predicting the outcomes of their experiments. The objective was not to discover new principles but to engage students in applying their knowledge to real-world scenarios, thereby reinforcing their grasp of the concepts. Although the students possessed a solid foundation in the relevant scientific principles, they were encouraged to hypothesize about the specific results of their designed experiments, promoting active learning and deeper comprehension through the PBL framework. To motivate and inspire students, instructors encouraged students to share the detailed progress of each experimental step and ask questions in the presentation. Some idea exchanges and suggestions for problem-solving were made among student groups. Such participation contributed to effective learning environments.

To ensure the success of a PBL lab activity, it is essential for the instructors to be flexible and prepared to address a range of issues that may arise (Mansour et al., 2024). Understanding and accommodating students who may face unforeseen circumstances creates a positive learning environment for all students. All instructors realized that students were from various backgrounds and attempted to solve different problems by experimenting with varying demands. Therefore, the guidance by instructors necessary for student's achievement was extended beyond the weekly meeting in-class hours. To this end, the instructors' time allocation to the course must be flexible to accommodate individual cases. In addition to 28 in-class hours and 16 out-of-class hours designated for PBL sessions in this course, the online support for every student in overcoming individual obstacles and fulfilling their lab's objectives is 5 hours per lecturer to assist all students who required assistance.

Engage in Continuing Professional Development in Subjects/Disciplines and Their Pedagogy, Incorporating Research, Scholarship, and the Evaluation of Professional Practices (A5)

Whereas the independence of the PBL lab assignments is intended to lay a foundation for scientific thinking and practical skills, further studies would be needed to empirically validate these potential improvements. While studying for other courses, students may benefit from the skills they gained from this course. These practical skills acquired through PBL activities are also vital for student's future careers in teaching, particularly in environments where educational resources may be limited. The laboratory course should play an essential role in empowering students to apply their knowledge and creativity effectively in solving real-world problems. This crucial goal is shared with those implementing PBL and engineering design process into the physics course for first-year engineering students, as recently exemplified by Marcinauskas et al. (2024) and Ngo (2024). According to Marcinauskas et al. (2024), the traditional delivery enhanced student's learning skills and theoretical physics knowledge and is suitable for traditional examinations with closed-ended questions. On the other hand, the PBL approach promoted teamwork, presentation, and critical thinking skills. Applying knowledge and creativity in solving real-world problems also aligns with the emphasis on making teachers creative, competent, and confident, as derived from the interview and survey by Jelicic et al. (2022) and the work group on "experiments and laboratory work in teacher education" (Bearden et al., 2022). Incorporating the PBL approach is, therefore, one option to prepare students for this, especially students who will be future science teachers (Magaji et al., 2024). When students from the PHE66-112 course become teachers, they have experiences and are equipped with requisite skills in designing experiments, constructing apparatus, and creating lab instruction manuals for their pupils.

Implementing the PBL teaching method in laboratories enhances students' proficiency in hard and soft skills relevant to 21st century learning within the realm of science, technology, engineering, arts, and mathematics (STEAM) education. Indeed, the process shares some similarities with STEAM programs in Ontario, Canada, for students aged 4-13, in which younger children may still rely on direct instructions (Bertrand & Namukasa, 2023). In addition to independence in selecting topics, formulating hypotheses, designing experiments, and collecting data, Pozuelo-Muñoz et al. (2023) suggested that the PBL applications in secondary school and higher education should emphasize students asking themselves questions. In hard skills, the PBL task for this course entails groups of students developing an experimental kit, accompanied by both written and video instruction manuals, to investigate specific physics law or principle. This endeavor demands a comprehensive grasp of relevant physics concepts to ensure accurate experiment design. Moreover, students are tasked with testing the functionality of their experimental kits, thereby refining their laboratory techniques, and sharpening their scientific inquiry skills. This hands-on approach not only cultivates their ability to analyze data and interpret experimental outcomes but also nurtures continual improvement in their work.

Regarding soft skills, group work fosters effective collaboration among team members with diverse perspectives, encourages consideration of differing viewpoints, and facilitates leadership toward achieving successful outcomes. Engaging in peer feedback is essential for developing future science teachers (Leslie, 2020; Morris et al., 2023) inventing experimental kits within constraints enhances the creativity, adaptability, and time management abilities of students. Problem-solving and critical thinking skills are essential for students in resolving challenges and evaluating data to construct comprehensive experimental kits. Additionally, they acquire communication proficiency in written, verbal, and multimedia formats to communicate scientific information effectively.

For lecturers, incorporating PBL lab activity into traditional laboratory courses was challenging. Preparation is an integral part of this transformation, supported by professional experience. Before and during the pandemic, instructors have published research and developed their lab apparatus as replacements for expensive imports. Significantly, instructors benefited from mutual learning and peer interaction.

CONCLUSIONS AND OUTLOOK

The lockdown during the COVID-19 pandemic affected teaching various subjects, especially science laboratory courses. Under the limitations of resources and time, teachers need to be creative in designing teaching methods and utilizing the practical equipment available to students to develop experimental kits. Lessons learned from the COVID-19 situation have made physics laboratory instructors aware of the need to prepare both themselves and their students to cope with various changes that may occur. The course presented in this article was designed and planned differently from other physics laboratory subjects, aligning with the TQF and UKPSF. In addition to completing 7 instructional laboratories, students worked in a group of 3-5 to choose one topic of investigation. Students may use scheduled class hours or their own time to experiment. They were encouraged to manage time and resources effectively. Modernized tools and DIY apparatus could be chosen based on their relevance and students' familiarity with them.

Several key aspects should be considered to implement PBL in a laboratory course effectively. Corresponding to the UKPSF's A1 core teaching activity, it is crucial to ensure that the learning objectives and activities align closely with the principles of PBL. For A2, students must possess a solid foundation in scientific principles relevant to the PBL project. This foundational knowledge provides students with the framework to engage meaningfully with the PBL tasks. By integrating examples and online resources into the PBL framework, students are able to take greater ownership of their learning, using the materials to fill gaps in their knowledge and to inspire creativity in the design and execution of their experiments. The A3 core teaching activity requires clear and well-defined assessment strategies and criteria. Assessment should occur throughout the learning process rather than solely focusing on the final product. To develop effective learning environments and approaches to student support and guidance (A4), time allocation from instructors ensures that students receive the guidance and assistance they need to successfully navigate the PBL tasks and achieve the intended learning outcomes. Working in groups allows students to critically evaluate the relevance of various concepts, identify gaps in their knowledge, and collaboratively formulate hypotheses that guide their experimental approach. It also makes the subject matter more enjoyable and relatable for students, sparking their curiosity and encouraging further study. Finally, the UKPSF's A5 core teaching activity related to professional development aims not only to deepen students' understanding of the individual scientific principles but also to develop their ability to think holistically, a key skill in tackling interdisciplinary challenges in real-world scenarios. The pedagogical design to integrate PBL activities into laboratories course promotes creativity and practical skills for future science educators.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: SUPPLEMENTARY MATERIALS

A. Topic of Interest and Contribution Form

Students are required to fill in **Table A1** to assess readiness for designing PBL activities and submit it via WU e-Learning by February 29, 2024 (only one representative per group needs to submit–group members 3-5 people).

Table A1. Information form

No	Student ID	Program		Contribution and description
		General science	Biology	
1				
2				
3				
4				
5				

Lab title: ……………………………………………………………………………………………………..
Physics concept: ……………………………………………………………………………………………
Sketch of lab setup: …………………………………………………………………………………………
☐ All group members have acknowledged ……………………………………… Signature

B. Lab Instruction Form and Guideline

Title:
☐ Clearly states the name of the experiment
Objectives:
☐ Lists the main goals and learning outcomes of the experiment
Introduction/theory:
☐ Provides background information on the topic
☐ Explains the relevant physical principles, theories, and formulas
Apparatus and materials:
☐ Lists all the equipment and materials required for the experiment
☐ Includes detailed descriptions or images if necessary
Procedure:
☐ Step-by-step instructions on how to conduct the experiment
☐ Clear and precise to avoid confusion
☐ Includes any safety precautions that need to be followed
Data collection:
☐ Specifies what data needs to be collected
☐ Provides tables or templates for recording observations and measurements
☐ Guidelines on how to analyze the collected data
☐ Includes any necessary calculations, graphs, or charts
☐ Instructions on using software tools if applicable
Questions and problems:
☐ A set of questions or problems to reinforce understanding and encourage critical thinking
☐ May include both theoretical and practical questions
Conclusion:
☐ Guidelines on how to write a conclusion based on the experimental results
☐ Emphasizes the importance of comparing the results with theoretical expectations
References:
☐ Lists any books, articles, or online resources that were used or could be useful for further reading
Safety instructions:

☐ Detailed safety protocols related to the specific experiment

☐ General lab safety rules

Appendix (if necessary):

☐ Additional information or resources such as detailed derivations, extended theory, or supplementary data

https://www.ejmste.com