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Evaluation of a Problem Centred Project-based Hybrid Module for High School Physics in the Sultanate of Oman

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Abstract: - Proficiency in physics problem-solving is crucial for mastery of the subject and fostering innovative solutions. Yet, high school graduates in the Sultanate of Oman display only average competence in this skill. There is a need to provide students in grades 9-12 with more opportunities to engage with real-world physics problems. To address this, a hybrid module based on Gold Standard Project-Based Learning (PjBL) has been developed. This module, adhering to Merrill's First Principles of Instruction and the Cognitive Apprenticeship framework, is designed to enhance cognitive learning and problem-solving skills specifically for Omani students. It integrates significant problem-solving components into physics instruction using authentic tasks tailored to students' proficiency levels. The module was implemented in a grade nine physics curriculum focused on renewable energy topics. The study involved one physics teacher and 30 students from the Musandam educational governorate, utilizing a single-group pretest and posttest quasi-experimental design to assess the module's effectiveness. The analysis, conducted using a t-test, indicated substantial improvement in both cognitive learning and problem-solving abilities among students. Consequently, this PjBL module, when implemented in a hybrid environment, holds promise for broader application in educational institutions, engineering colleges, and vocational schools to enhance students' physics problem-solving skills.

Keywords: Hybrid Learning, Physics, Problem-solving skills, Project-based learning, Renewable Energy.

I. INTRODUCTION

Problem-solving as an activity that brings students closer to the methodology and meaningful learning of science has long been associated with science, particularly physics. To master physics, students must be able to solve problems (Docktor et al., 2015). Poor problem-solving skills could be one of the reasons for physics education failure, prompting a closer look at this didactic activity (Hernández-Suarez et al, 2022). Students studying physics must not only master concepts but also use them to solve physics challenges. However, there is still a lot of classrooms learning that prioritizes topic mastery over problem-solving talents (Retno et al, 2019). The need for creative learning models that are specially developed and implemented to improve physics problem-solving skills has been discovered (Prahani et al., 2021). The curriculum requires students to build 21st-century skills and higher-order thinking capacities, and project-based learning (PjBL) is in line with this requirement (Fadilah, 2019; Rahmad et al., 2019). Project-based learning (PjBL) and problem-based learning (PBL) have grown as effective student-centered inquiry-based learning techniques that engage students in collaborative groups to solve real-world problems (Jensen, 2015). The project-based learning (PjBL) approach encourages active and deep learning by having students explore real-world scenarios in a collaborative context (Belwal et al., 2020; Hong Sharon Yam et al., 2010). In project-based science learning, primary students' collaborative problem-solving skills improved (Song, 2018). Project-based learning has a significant impact on students' performance and engagement in learning physics (Makkonen et al., 2021; Araujo et al., 2021). Students' learning outcomes are influenced by the interaction of project-based learning methodologies and problem-solving abilities. Furthermore, the use of the project-based learning paradigm in secondary school is strongly advocated (Astra et al., 2019). The critical thinking skills of high school students in several physics subjects are affected by the project-based learning methodology. For example, the PjBL model affects the critical thinking abilities of high school students on energy subjects (Fadilah, 2019) and static fluid learning material (Hamdani, 2020). Students were pushed to use their curriculum knowledge of optics and electromagnetic waves to address real-world problems when PjBL was implemented (Makkonen et al., 2021). Most teachers and students agreed that air-quality experiment instruments should be included in project-based learning (Bonanno et al., 2018). Furthermore, the applied PjBL module matched the prerequisites for engaging gifted students in learning physics (Emafri et al., 2020) and making it entertaining and colorful, as well as meeting 21st-century curriculum and skill expectations (Rahmad et al., 2019). However, the reality is that there is still a lack of physics practical modules, thus students are unable to carry out physics independently. Teachers require assistance to apply PjBL, which necessitates the development of an instructional design framework as well as an

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awareness of how to effectively employ available technologies to engage students in problem-solving situations (Hasni et al., 2016). There is also a lack of understanding of how to facilitate problem-solving teaching and learning in the PjBL setting, and a model to guide implementation has taken a long time to emerge. To develop students' physics problem-solving skills, a practical module is necessary with a project-based learning methodology (Rahmad et al., 2019).

Another common PjBL scaffolding strategy is the use of technology to assist students in their problem-solving efforts (Krajcik, 2014). The growth of the Internet and mobile platforms has generated the opportunity for hybrid learning, which mixes online and in-person interaction time between instructors and students to improve quality and access to learning opportunities. The Internet of Things (IoT) and Artificial Intelligence (AI) have both had an impact on education (Techanamurthy et al., 2020). Future students must be ready to adapt to the fourth industrial revolution fast, student achievement was significantly impacted using virtual laboratories and e-modules in physics instruction during the COVID-19 outbreak (Mufida et al., 2021). During distance physics learning, teachers can change their learning demands based on the characteristics and backgrounds of various students (Mufida et al., 2021). Research on the design of the physics project hybrid module and the activities involved is currently lacking (Makkonen et al., 2021; Hasni et al., 2016). Furthermore, the utilization of technology is currently limited in physics project hybrid modules (Adri, 2020).

Sultanate of Oman is a country that has a well-structured educational system, the government has made the issue of improving the education system a priority to better respond to the requirement for Oman's vision 2040. Unfortunately, students in the Sultanate of Oman perform poorly in a range of subjects, the most important of which is science (Al-Amri et al., 2020). National and international learning tests in Oman show that, as in many other nations, students' performance falls short of the government's goals and students do poorly in science. Using technology as a learning resource could have a big impact on learning activities, change the teaching process, and help students learn better in Oman. Ambusaidi et al. (2022) examined the prerequisites for enhanced execution of science education, alongside prospective approaches to address the obstacles and issues encountered by science educators in Oman. They stressed the significance of putting more effort into using technologies in teaching twenty-first-century skills, such as hybrid learning and e-learning advancements to science education in Oman for the global economy. Belwal et al. (2020) demonstrated the impact of teaching methods, especially, Project-based learning PjBL in Oman. The findings of the study align with Oman's Vision 2040 and one of the country's capacity-building goals, which intends to implement innovative student development and lifelong learning approaches. However, there is still inadequate research to show the impact of such teaching methods in the Omani educational context (Al-Balushi, 2016). Furthermore, few studies on instructional approaches for teaching physics problem-solving to students at Omani schools have been conducted.

In this study, a pedagogical physics project-based hybrid PjBL module was developed and designed for grades (9-12) students in Omani schools. The primary objective of the PjBL module is to enhance students' problem-solving abilities by allowing them to employ theoretical knowledge to address real-world issues. Initially, the Gold Standard PjBL model was implemented, featuring specific activities, guided by First Principles of Instruction and cognitive apprenticeship theory. The four stages of the PjBL module were conducted in both face-to-face F2F sessions and online sessions. This study aims to evaluate the effectiveness of implementing the pedagogical physics project-based hybrid module (PjBL). The PjBL module was designed and implemented for students in grade nine students in the Sultanate of Oman and focused on renewable energy topics. One physics teacher and 30 students in the Musandam educational governorate volunteered to participate in the implementation and evaluation of the module. A quasi-experimental design, employing the pre-and post-test structure of a single group, was employed to evaluate the efficacy of the PjBL module. The assessment of the module primarily centered on measuring the change in both cognitive learning gains and problem-solving skills. The study addressed the following research questions:

1. Is the pedagogical physics project-based hybrid module PjBL effective in improving students’ cognitive learning gains?

2. Is the pedagogical physics project-based hybrid module PjBL effective in improving students’ problem-solving skills?

II. LITERATURE REVIEW

2.1 Merrills' First Principles of Instruction

Merrill's model from 2007, known as the First Principles of Instruction, adopts a problem-oriented approach that emphasizes real-world problem-solving activities. Merrill (2002) posits that the underlying principles of many instructional design theories and methodologies are akin and collectively termed the First Principles of Instruction. According to Merrill, these principles are pertinent to acquiring comprehensive, authentic, and real-world tasks. The model consists of four key stages: activation, demonstration, application, and integration. In the Activation phase of the learning cycle, as outlined by Merrill (2007), learners are encouraged to seek relevant prior experiences that can serve as a foundation for solving a problem. This implies that students can employ their existing knowledge or familiar activities as a scaffold for an unfamiliar task if they commence it with some prior information or activities (Brown et al., 1989). The Demonstration phase involves the use of specific examples illustrating the application of new knowledge to a singular circumstance (Merrill, 2007). Finally, in the Integration phase of the learning cycle, learners should be capable of applying their knowledge in novel ways to new contexts (Merrill, 2007).

2.2 Cognitive Apprenticeship Theory

Cognitive Apprenticeship Instruction (CAI) is a student-centered learning approach rooted in Constructivist theories, enabling students to utilize cognitive tools through real-world experiences. Cognitive apprenticeship, as defined by Collins et al. (1988), involves learning through a guided experience focused on cognitive and metacognitive abilities and processes, rather than physical skills. In the adult learning environment, educators promote the concept of cognitive apprenticeships (Stein, 1998). Within this framework, learners observe how instructors navigate problem-solving processes and cultivate their approaches to finding solutions. Cognitive apprenticeship employs tools such as discussion, reflection, assessment, and validation of the community's collective perspective. Throughout this process, students engage in practice, starting from the periphery and progressing toward the core. The components of CAI encompass modeling, coaching, articulation, reflection, scaffolding and fading, and exploration, as outlined by Yusepa et al. (2018). This approach aligns with Albert Bandura's (1997) theory of modeling, emphasizing the importance of learner motivation and precise imitation of desired skills for successful modeling. Learners are tasked with slightly challenging assignments, relying on assistance and collaboration to complete them (Dennen & Burner, 2008). Various researchers have advocated for and implemented the Cognitive Apprenticeship Model as a framework to enhance learning experiences and develop problem-solving skills (Milojevic et al., 2020). The cognitive apprenticeship method is versatile and applicable in diverse settings, including organizations and schools, as every institution requires a mentor or guide to instruct learners on problem-solving approaches, tool utilization, and application strategies (Korkmaz, 2017).

2.3 Gold Standard Project-based Learning PjBL

Project-based learning (PjBL) is an interactive educational approach designed to boost student engagement and active participation in the learning process. In this method, educators play a key role in energizing the learning environment by fostering collaboration among students for exploration, decision-making, and addressing challenges within projects. PjBL necessitates the implementation of an assessment system that encourages awareness, reflection, and a critical mindset, thereby facilitating profound learning experiences (de la Torre-Neches et al., 2020). Research by Zen and Ariani (2022) indicates that project-based online learning contributes to creating an enjoyable learning environment, influencing student engagement behaviors. Larmer et al. (2015) introduced the concept of gold-standard project-based learning, which represents a theoretical framework that incorporates meticulously researched and classroom-proven project design elements along with effective teaching strategies. The primary objectives for both educators and students revolve around two key aspects: teachers strive to enhance their instructional abilities in alignment with the Gold Standard PjBL, while students focus on acquiring in-depth knowledge and cultivating skills essential for success in their future endeavors. According to Larmer et al. (2015), Gold Standard Project-Based Learning consists of seven fundamental project design elements: (1) a challenging problem or question, (2) sustained inquiry, (3) authenticity, (4) student voice and choice, (5) reflection, (6) critique and revision, and (7) a public product. The objective of the PjBL module is to integrate key managerial and instructional skills and behaviors necessary for implementing Gold Standard Project-Based Learning. The degree to which the PjBL module aligns with the principles of Gold Standard Project-Based Learning is contingent upon these design aspects and their manifestation within the project.

2.4 Hybrid Learning

There has been a growing interest in hybrid learning, commonly known as blended learning, as an innovative educational approach (Olapiriyakul & Scher, 2006). Hybrid Learning integrates two learning environments, namely online learning and face-to-face (F2F) learning (Graham et al., 2013). This approach extends beyond a simple combination of online and traditional instruction, emphasizing the importance of carefully selecting the most suitable environment for implementation (Simarmata et al., 2018; Gedik, 2013). Notably, students exhibit significant enthusiasm for utilizing digital technology as a learning tool (Adri, 2020). A course initially delivered through lectures, involving homework and group project submissions, underwent a redesign to adopt a hybrid format in response to the challenges presented by a large class size. This modification aimed to establish a more flexible learning environment for material distribution, diverse assignments, discussions, collaboration, and streamlined tracking of students' progress (Gedik, 2013). A Collaborative Mobile-Learning Science Module was developed for a Malaysian secondary school. It comprised five online lessons, an initial face-to-face module orientation meeting, and a final face-to-face session to conclude the module (DeWitt et al., 2013). Results indicated that learners actively engaged with the content, teacher, and peers in the discussion forum, underscoring the role of internet communication technologies in fostering collaboration and enhancing science education. Tong et al. (2022) verified that the integration of hybrid learning has a positive effect on students' academic performance. Optimal benefits for both educators and students are achieved by maximizing the strengths of each teaching method and amalgamating the advantages of both online and in-person instruction.

2.5 Conceptual Framework of PjBL Module

In this study, the design and development of the PjBL module aimed at enhancing the problem-solving abilities of high school students (grades 9-12). The module involves the integration of Merrill's First Principles of Instruction (Merrill, 2007) and the Cognitive Apprenticeship Theory (Collins et al., 1989) with the Gold Standard PjBL (Larmer et al., 2015). The module incorporates problem-solving steps outlined by Jonassen (1997), which include articulating the problem space and contextual constraints, identifying, and clarifying alternative opinions, positions, and perspectives of stakeholders, generating potential problem solutions, assessing the viability of alternative solutions through building arguments, articulating personal beliefs, and monitoring the problem space and solution. Techanamurthy et al. (2020) developed a Problem-Solving Flipped Classroom (PSFC) module inspired by Merrill's First Principles of Instruction and the Cognitive Apprenticeship framework. This module was designed to deliver comprehensive instruction to students, focusing on acquiring essential problem-solving skills for the workforce. Results from the implementation of the module showed that students experienced significant learning gains and improvement in problem-solving skills. DeWitt et al. (2013) created a module based on Merrill's First Principles of Instruction and the social constructivist learning theory. The outcomes revealed positive results in the development of Collaborative Mobile-Learning Science. Furthermore, the adoption of the Project-Based Online Learning approach, combined with heightened student engagement, had a positive impact on academic performance (Zen & Ariani, 2022).

In this study, a framework was developed for designing a pedagogical physics project-based hybrid module PjBL for Students in grades (9-12) in the Sultanate of Oman. The module was delivered in a hybrid environment, incorporating both face-to-face (F2F) and online sessions. The purpose of developing the PjBL module is to improve cognitive learning and problem-solving skills.

The hybrid PjBL module encompasses four separate stages, administered over three weeks through electronic platforms and instructional applications. The initial stage (Activation) is conducted during face-to-face (F2F) class sessions, while the second stage (Demonstration) is delivered in online class sessions. The subsequent stages, namely Application and Integration, are executed during F2F and online class sessions, respectively. These procedural steps are systematically organized on the instructional e-platform. It is imperative to elucidate how the problem-solving steps are integrated with the key elements of Gold Standard PjBL within the module framework. Gold standard project-based learning entails the integration of seven pivotal elements. Distributing the problem-solving steps across these seven elements, educators can guide students through the PjBL process in the following manner: (1) A challenging problem or question: Collaboratively identifying a challenging energy problem in group work ensures student involvement and helps guarantee that the chosen problems align with students' knowledge and abilities, (2) Sustained inquiry: Engaging in sustained inquiry involves researching, gathering information, and posing questions related to the energy problem. This step includes analyzing and synthesizing data to formulate a solution, (3) Authenticity: Ensuring the authenticity of the energy problem involves making it relevant to the real world with practical implications, thereby demonstrating the real-world relevance of the students' work, (4) Student voice and choice: Granting students the autonomy to select the energy problem they want to solve and the method they will employ encourages creativity, innovation, and ownership of their learning, (5) Reflection: Throughout the module, students engage in reflection by critically evaluating their progress, identifying areas for improvement, and devising strategies to overcome challenges. This step nurtures metacognitive skills and fosters a growth mindset, (6) Critique and revision: Involving students in critique and revision entails seeking feedback from peers and teachers, evaluating their work, and making revisions based on received feedback. This iterative process enhances understanding of the energy problem-solving method, (7) Public product: Finally, students choose the suitable e-platform or any application to present their solutions to the energy problem through the final projects. This step allows for the sharing of work with a broader audience and provides recognition for their efforts. A pre-test and post-test design were used before and after implementing the PjBL module to measure the change in both cognitive learning and problem-solving skills.

2.6 The Hypotheses Development

Utilizing a quasi-experimental design, relying on the pre-and post-test structure of a single group, is crucial for assessing the effectiveness of the pedagogical physics project-based hybrid module (PjBL). The evaluation aims to determine whether students have shown significant improvement in comprehending the lessons studied in this research. Equally significant is the assessment of potential enhancements in the students' problem-solving skills. In this context, the null hypothesis is formulated as follows:

H1. There is no significant difference between pre-test and post-test scores in terms of cognitive learning gains following the implementation of the pedagogical physics project-based hybrid module PjBL.

H2. There is no significant difference between pre-test and post-test scores in terms of problem-solving following the implementation of the pedagogical physics project-based hybrid module PjBL.

III. METHODOLOGY

3.1 Design

In this study, according to need analysis, the PjBL module was designed to address energy problems for grade nine students at a public school in the Sultanate of Oman. The module was conducted in the second semester of the 2022/2023 academic year, spanning three weeks dedicated to the implementation and evaluation of the pedagogical physics project-based hybrid module PjBL. In the Sultanate of Oman, the academic year consists of two semesters, typically running from September to July. Following the physics curriculum requirements for grade nine, face-to-face classes are normally scheduled for three sessions per week. The study involved a group of grade nine physics students, and one physics teacher. The pre-test was administered three days before the commencement of the PjBL module, while the post-test was conducted three weeks after the intervention. The module is structured to be delivered through a hybrid model, encompassing four stages, including the delivery of three energy lessons and the resolution of energy problems. The PjBL module integrates problem-solving steps using the key elements of the Gold Standard PjBL, guided by the principles of First Principles of Instruction and Cognitive Apprenticeship Theory. The module was designed to improve the learning gains and problem-solving skills of physics students. Despite the implementation period being considered relatively short for maturation, efforts were made to evenly distribute it, minimizing the risk of fatigue and aligning with the grade nine physics schedule.

3.2 Participants

In the Sultanate of Oman, there are 11 educational governorates, each encompassing numerous female and male public schools. This study employs a single-group quasi-experimental methodology to assess the effectiveness of the Pedagogical Physics Project-Based Hybrid Module (PjBL) in enhancing learning and problem-solving skills. It is important to emphasize that in Omani public schools, the study of physics is introduced as a distinct curriculum for students starting in grade 9. The research focused on 30 ninth-grade male students from a selected school in the Musandam educational governorate. In addition, in Oman, the gender-based division of the educational system begins at grade five and continues onward. Given that the study was conducted in a male public school, all participants were male. The module was implemented by a male physics teacher with twelve years of teaching experience at the same school.

3.3 Instruments

The assessment instruments utilized a quasi-experimental design, concentrating on the pre-and post-test outcomes of a single group, each test comprising two sections. The first section gauged participants' learning in the cognitive domain, while the second section assessed their problem-solving skills. The total score for both the pre-test and post-test was set at 100, with the problem-solving domain having a maximum score of 60 and the cognition domain having a maximum score of 40. The cognition domain encompassed 20 multiple-choice questions designed to evaluate theoretical knowledge, whereas three open-ended questions were employed in the problem-solving domain to assess problem-solving skills, decision-making, and troubleshooting skills. Multiple-choice questions were scored based on correct answers, while the open-ended questions were assessed for problem-solving processes using a predetermined rubric. To ensure the content validity of both the pre-test and post-test items, three experts in the field, all with over ten years of teaching experience at the same institution, conducted a thorough review. The experts assessed the items regarding their representation of the module content, as well as the wording and layout. Minor revisions were implemented based on the experts' feedback to enhance the final versions of the tests. Internal validity was confirmed through the establishment of the alpha reliability coefficient (KR20) for both tests. The reliability coefficients were found to be 0.711 for the pre-test and 0.624 for the post-test. Coefficients within the range of 0.60 to 0.70 are generally considered acceptable (George and Mallery, 2003). Scoring for both the pre-test and post-test was based on the provided answer scheme. The quasi-experimental study's internal validity was strengthened by the brief time interval between the pre-test and post-test, minimizing the potential impact of maturation effects.

3.4 Data collection procedures

The study was conducted through a series of sequential steps. Initially, a needs analysis was undertaken to identify the requirements for a physics Project-Based Learning (PjBL) hybrid module aimed at addressing physics problems. The outcomes of this analysis revealed that the problem-solving skills of physics students, particularly those in grade nine, were at a moderate level. Subsequently, the researchers proceeded to design and develop the PjBL module, examining essential components such as objectives, content, instructional strategies, technologies, and appropriate assessment methods. Before implementation, the module underwent scrutiny by experts, who provided suggestions for improvement. The PjBL module is structured around four distinct stages, each addressing energy problems through contemporary technologies, and it is designed to be completed within a three-week timeframe. The initial stage (Activation) takes place during face-to-face class sessions, while the second stage (Demonstration) is delivered in online sessions. The subsequent stages, Application, and Integration, occur in face-to-face and online class sessions, respectively. These procedural steps are systematically organized on the instructional e-platform. It is crucial to clarify how the problem-solving steps are integrated with the seven key elements of the Gold Standard PjBL within the module framework.

This research was conducted to implement the third phase, which involves assessing the module's efficacy in improving students' learning outcomes and problem-solving skills. The assessment instruments utilized included pre-tests and post-tests, each comprising two sections. The pre-test was administered three days before the initiation of the PjBL module, while the post-test was conducted three weeks after the intervention. The module is implemented through a hybrid model, encompassing four stages, including the delivery of three energy lessons and the resolution of energy problems. The module integrated fundamental components of the Gold Standard PjBL, guided by the principles of First Principles of Instruction and Cognitive Apprenticeship Theory. The test was carried out using a "one group pre-test post-test study" that establishes a baseline score through a pre-test and measures the outcome of the treatment through a post-test. Before beginning the practical teaching using the PjBL module, a few paper copies were placed of each pre-test instrument on each participant's desk, face down. A four-digit secret code was employed to match the pre-and post-tests while assessing the data after the study. During the delivery of the pre-test, the students were reminded of the study's confidentiality policies and then inquired if they had any other questions. The participants were told to start the pre-test after setting a 60-minute timer. After that, they were instructed to remain seated while the pre-test instrument was gathered. The post-test was distributed to the students in the same way after the intervention. The combined score for the pre-test and post-test was 100. The questions for both instruments were broken down into three short questions about "design problem type," "decision-making problem type," and "troubleshooting problem type" and twenty multiple choice questions that focused on the specific domain knowledge (maximum of two marks each). The domain of problem-solving has a maximum score of 60 while the domain of domain knowledge has a maximum score of 40.

3.5 Data Analysis Procedures

Descriptive statistics from SPSS version 22 used to analyze the data from both pre-test and post-test, by determining the mean and standard deviation. The data obtained were subjected to analysis using a paired-sample t-test to ascertain if there was a significant improvement in scores following the intervention. The pre-test was conducted three days prior to the implementation, while the post-test took place three weeks after the intervention to ensure retention had occurred. A confidential four-digit code was incorporated into the pre-test instrument to facilitate matching of both pre-test and post-test data at the conclusion of the study for analysis. The students' learning gains in both the cognition domain and problem-solving skills would serve as the criterion for evaluating the module's effectiveness. The data encompassed mean scores, standard deviations, and a paired sample t-test to evaluate the student's learning gains following the implementation of the PjBL module, aiming to determine its effectiveness. Given the study's focus on a singular instance of the PjBL intervention with a limited student population, the normalized gains in students' learning were gauged by differences in pre-test/post-test scores, as outlined by Talbert (2014). Consequently, the effectiveness of the PjBL module was ascertained using the pre-test/post-test model, incorporating calculations of various learning measures for both the cognition domain and problem-solving.

IV. RESULTS

4.1 Cognitive Domain

Comparing the post-test scores to the pre-test scores, most students showed improvement in cognitive domain or learning gains. All the 30 students participated in the pre-and post-tests. The results of the pre- and post-test cognitive domain scores show a statistically significant difference, according to the t-test analysis; t (29) = 17.942, and p = 0.000. As a result, after applying the PjBL module, there was a notable change in the cognitive domain (see Table 1).

Table I: The cognitive domain's mean and standard deviation for the pre-and post-tests

Paired Differences						
Test	**Mean**	**N**	**SD**	**T**	**df**	**Sig (2- tailed)**
Pre-test	18.13	30	2.25	17.942	29	0.000
Post-test	30.03	30	2.51			
Gain	11.9					

*p < 0.005

4.2 Problem-solving domain

There is a statistically significant difference between the problem-solving scores for the pre-and post-tests, according to the t-test analysis: t (29) = 24.960, p = 0.000. As a result, after using the PjBL module, students' problem-solving abilities significantly improved (see Table 2).

Table II: The problem-solving domain's mean and standard deviation for the pre-test and post-test

Paired Differences						
Test	**Mean**	**N**	**SD**	**T**	**df**	**Sig (2-tailed)**
Pre-test	27.87	30	4.10	24.960	29	0.000
Post-test	51.73	30	3.70			
Gain	23.86					

*p < 0.005

V. DISCUSSION

The results obtained from the quasi-experimental pre-test/post-test design with a single group led to the rejection of the null hypothesis. Consequently, a notable disparity was identified between the mean scores of the pre-test and post-test in terms of learning gains, with t (29) = 17.942 and p = 0.000, as well as in problem-solving, with t (29) = 24.960 and p = 0.000, after the implementation of the pedagogical physics project-based hybrid module PjBL. These results showcased the efficacy of the PjBL module in enhancing both cognitive learning and problem-solving abilities. This study demonstrates that the PjBL module effectively promotes learning gains through problem-solving activities in physics classrooms. In the realm of theoretical contributions, this study formulated a module by incorporating problem-solving steps and elements from the Gold Standard PjBL Model. The foundation of the PjBL module is rooted in the First Principles of Instruction (Lo & Hew, 2017; Merrill, 2002) and Cognitive Apprenticeship (Collins et al., 1990). This module proved effective for comprehending physics concepts and addressing authentic problems within hybrid learning environments. The First Principles of instruction used in the PjBL module improved learning. The activation phase was useful as instructors could now determine students' level of prior knowledge as they most had work experience (Merrill, 2007). The demonstration phase also helped improve understanding as when students used the instructional stuff on the e-platform, they learned better in the cognitive and problem-solving domains, as well as practical work. During the application, students collaborate in teamwork on designing and developing the projects. During the integration phases, the students shared the presentation of the final project using e-platforms, social media, or phone applications. The problem-solving activities conducted during class reinforced the concepts learned in a way that enabled students to connect and apply the concepts and ensure effective problem-solving (Vidergor, 2022; Lo & Hew, 2017). This indicates that Merrills' First Principles and Cognitive Apprenticeship could improve students' understanding and skills in applying the fundamental concepts of physics to solving authentic problems. In addition, the outcomes were consistent with the conclusions drawn by Zacharis (2015) and Iskandar et al. (20123), which emphasized that the formative assessments of online class tasks, incorporated into the hybrid module, facilitated meaningful interaction for students with the presented materials. These findings were corroborated by the high learning gains observed in the current study.

VI. CONCLUSION

This study employed a quasi-experimental design, focusing on the pre- and post-test results of a single group of participating students to evaluate the effectiveness of the PjBL module. The results indicated the module's efficacy in enhancing both learning and problem-solving skills among the students. The findings suggest that exposure to authentic, real-world problems during instruction contributes to the improvement of problem-solving skills. This insight is particularly valuable given the lack of substantial empirical evidence in previous studies supporting enhanced problem-solving skills following PjBL intervention in a hybrid setting. PjBL module ensures a significant portion of high school education integrates problem-solving tasks with real-world relevance for practical applications. This research provides valuable insights for science educators and curriculum designers in the field of physics, offering essential components and instructional methodologies of the PjBL strategy for developing problem-solving skills. The study's outcomes can serve as a valuable guide for physics teachers, especially in the context of incorporating contemporary instructional technologies. Future research could explore the application of the Pedagogical Physics Project-Based Hybrid Module PjBL as a framework for teaching problem-solving across various academic subjects. Moreover, the module shows promise for use in problem-solving instruction within vocational institutes and engineering colleges.

VII. DECLARATIONS

Author contribution statement

Fathiya Al-Kamzari & Norlidah Alias: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools, or data; Wrote the paper.

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Ethical statement

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Abbreviations

PjBL: Project-based learning

PjBL Module: Physics Project-Based Hybrid Module

IoT: Internet of Things

AI: Artificial Intelligence

COVID-19: Coronavirus Disease 2019

CAI: Cognitive Apprenticeship Instruction

PSFC: Problem-Solving Flipped Classroom

F2F: Face-to-face

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