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Article abstract

The integration of innovative learning models is essential for preparing vocational high school (VHS) students with 21st-century skills. This study aimed to explore the need for a Problem-Based Flipped Learning (PBFL) model with a Science Technology Engineering Mathematics (STEM) approach tailored to the needs of vocational high school students. Employing a qualitative descriptive method, the study involved 33 vocational high-school students and three mathematics teachers. Data was collected through interviews, observations, and questionnaires, with validity using triangulation. The results indicated that 87.9% of students endorsed the incorporation of PBFL-STEM, highlighting its efficacy in promoting collaboration and critical thinking. Educators emphasized its capacity to bridge theory and practice for enhanced industry alignment. Nonetheless, insufficient technology infrastructure and inadequate teacher preparation have been recognized as impediments to effective adoption. To tackle these issues, this study employed adaptive solutions, including the utilization of readily available technology (e.g., smartphones) and the provision of continuous teacher mentorship for better implementation. This research identified that the PBFL-STEM approach is extremely pertinent for vocational high schools, providing significant possibilities to cultivate students' 21st-century talents. This study showed that vocational schools can quickly fix these problems by encouraging teachers to improve their skills and ensuring that they understand the importance of new ways of learning for giving students a good education.

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Abstract

The integration of innovative learning models is essential for preparing vocational high school (VHS) students with 21st-century skills. This study aimed to explore the need for a Problem-Based Flipped Learning (PBFL) model with a Science Technology Engineering Mathematics (STEM) approach tailored to the needs of vocational high school students. Employing a qualitative descriptive method, the study involved 33 vocational high-school students and three mathematics teachers. Data was collected through interviews, observations, and questionnaires, with validity using triangulation. The results indicated that 87.9% of students endorsed the incorporation of PBFL-STEM, highlighting its efficacy in promoting collaboration and critical thinking. Educators emphasized its capacity to bridge theory and practice for enhanced industry alignment. Nonetheless, insufficient technology infrastructure and inadequate teacher preparation have been recognized as impediments to effective adoption. To tackle these issues, this study employed adaptive solutions, including the utilization of readily available technology (e.g., smartphones) and the provision of continuous teacher mentorship for better implementation. This research identified that the PBFL-STEM approach is extremely pertinent for vocational high schools, providing significant possibilities to cultivate students' 21st-century talents. This study showed that vocational schools can quickly fix these problems by encouraging teachers to improve their

skills and ensuring that they understand the importance of new ways of learning for giving students a good education.

Introduction

The paradigm shift in global education in recent years has increasingly emphasized the importance of developing 21st-century skills, such as critical thinking, collaboration, communication, and problem-solving, in order to prepare students for a rapidly evolving world that is influenced by technological advancements and globalization (Azhary & Ratmanida, 2021). However, in the Indonesian context, graduates of vocational high schools (SMK) face significant challenges in securing employment, with the Central Statistics Agency (BPS) reporting that SMK graduates contributed the highest proportion to the open unemployment rate (TPT), reaching 11.26% as of August 2021 (Hermawan, 2023). Similar trends are observed at the regional level, such as in Garut Regency, West Java, where SMK graduates experience the highest unemployment rates compared to other educational levels (Rosmana et al., 2022). This misalignment between the skills imparted in SMKs and the demands of local industries is increasingly critical in the context of the Industrial Revolution 4.0, where industries require workers who are not only technically skilled but also proficient in 21st-century competencies (Dishon & Gilead, 2021; Hansen & Woronov, 2013). In response, government initiatives, like the Ministry of Education and Culture's Excellent Vocational School Program, aim to align vocational curricula with industry requirements, as demonstrated by implementations in schools, such as SMKN 1 Rangkas Bitung (Ahmanda, 2022; Winanti, 2023). Moreover, studies have shown that vocational graduates who undergo certified training programs are less likely to experience unemployment, emphasizing the need for industry-oriented curricula, practical training, and collaborative partnerships with the industrial sector, to enhance the competitiveness of SMK graduates (Budi et al., 2021; Maryanti & Apriana, 2019).

One trend is the implementation of problem-based learning (PBL), which has demonstrated efficacy in enhancing students' problem-solving abilities and self-efficacy, particularly in science, technology, engineering, and mathematics (STEM) fields. For instance, (Peranginangin et al., 2019) demonstrated that PBL, contextualized with local culture, improved students' problem-solving skills and engagement. Furthermore, a meta-analysis conducted by (M. Yusuf et al., 2022) revealed that PBL is effective in developing critical thinking and problem-solving skills in medical education, suggesting its potential applications across multiple disciplines. Both findings corroborate the effectiveness of PBL as a pedagogical approach that engages students and equips them with essential 21st-century skills (Peranginangin et al., 2019; R. Yusuf et al., 2022). In the context of Indonesian vocational education, however, the application of PBL remains underexplored, despite its potential to address the specific needs of SMK students, such as improving their ability to solve practical, industry-relevant problems. Research by Marsono et al. (2019) and Peranginangin et al. (2019) highlights the importance of aligning learning methods with local industrial demands. It indicates that integrating PBL with STEM in SMK curricula could enhance students' readiness for the workforce by bridging gaps between theoretical knowledge and practical skills.

Overall, the global education paradigm shift emphasizing 21st-century skills is reflected in integrating innovative pedagogical approaches, such as PBL and collaborative learning, supported by technological advancements (Aslam et al., 2023; Stanikzai, 2023). These strategies enhance students' problem-solving and critical thinking abilities and prepare them to communicate and collaborate effectively in various environments (Thoib, 2021)). As educational institutions continue to adapt to these changes, ongoing research and practice are crucial for improving the effectiveness of these approaches.

The integration of 21st-century skills (critical thinking, collaboration, communication, and problem-solving) in education is crucial for student success in a globalized world (Saavedra & Opfer, 2012). Research suggests that these skills are interrelated and can be assessed through multiple measures, including self-reports, standardized tests, and observational methods (Aulia & Utami, 2021; Trevallion & Nischang, 2021). Effective implementation requires overcoming barriers, such as time constraints and a lack of professional development (Naqvi et al., 2023). To create 21st-century skills in vocational education in Indonesia, specific problems must be dealt with, such as a lack of technology, difficulty in getting teachers trained, and different levels of standardization in the curriculum across schools. For example, many vocational schools have trouble offering hands-on STEM-based learning because they do not have enough tools or resources (Rizaldi et al., 2020). Teachers can use various measures, including professional development programs and curriculum guidelines, that would support skill integration (Haryani et al., 2021). Innovative approaches, such as gamified frameworks and integrated curricula, show promise in developing and assessing these skills (Gündüzalp, 2021; Kipp et al., 2018). Indicators for assessing effectiveness include contribution, time management, and problem-solving abilities. Designing activities that incorporate these skills across disciplines can enhance their acquisition (Demir & Zengin, 2023).

Field observations indicate that many vocational high-school (SMK) students in Indonesia exhibit low collaboration skills, with a survey of 250 students showing that over 60% struggle with teamwork and communication. This gap stems from teacher-centred approaches that limit opportunities for meaningful collaboration and infrastructural challenges, such as inadequate access to cooperative-learning tools. In Indonesia’s vocational education system, collaboration is essential for preparing students to meet industry demands (Haryani et al., 2021). Approaches like Problem-Based Learning (PBL) and STEM can address these deficiencies by fostering teamwork and active participation, even within constrained resources (Dilekçi & Karatay, 2023). Consistent with Lu (2019), insufficient interpersonal and collaborative skills impede group interactions and individual learning. Therefore, it is crucial to focus on the development of collaboration skills through more student-centred learning approaches and by encouraging active participation in discussions and group work.

The importance of preparing students for the workforce through vocational education is gaining increasing attention, commensurate with the growing demand for skilled labour across various industries. The competency-based approach in vocational high schools has proven effective in enhancing students' practical skills, ensuring their readiness to face labour-market challenges. Yudiono et al. (2019) emphasize that production-based learning is an efficacious model. It aligns educational outcomes with industry requirements and develops teamwork, problem-solving, and decision-making skills. This model enhances students' technical capabilities and prepares them for real-world challenges through a collaborative learning environment. The integration of 21st-century skills in vocational education is crucial for enhancing the competitiveness of graduates in the labour market. Mutohhari et al. (2021) highlighted the challenges of implementing these competencies, emphasizing the need for a creative learning environment so as to develop critical thinking and problem-solving abilities. Widayana (2023) also stressed that proficiencies, such as collaboration and communication, are essential for students to compete in the competitive job market. This integration prepares students for immediate employment and equips them with lifelong learning skills that are vital in the ever-evolving world of work.

The role of technology in vocational education should not be overlooked. The paradigm shift in learning that is currently starting to move towards the use of blended-learning models seems unavoidable. As stated by Delcker (2022), it emphasizes the importance of incorporating digital tools into vocational training. This approach enhances the learning experience and ensures that students are well-versed in technological advancements that are becoming increasingly prevalent in the workplace. By focusing on practical skill development, integrating 21st-century competencies, and leveraging technology, vocational schools can produce graduates who are not only technically proficient but also adaptable and prepared to meet challenges.

Recent studies have emphasized the positive effects of technological integration on active and collaborative learning in education. Digital tools have been shown to boost student engagement, interaction, and learning outcomes (Vali, 2023;Wibowo et al., 2023). Technology-rich environments designed for specific educational purposes have improved final exam scores and increased student motivation (Donkin & Kynn, 2021). Digital technologies promote more interactive learning activities, correlating with better learning outcomes (Wekerle et al., 2022). Tools, such as Web 2.0 applications and interactive response systems, enhance active learning and retention (Wang, 2020;Adam, 2020). Well-designed technology-enhanced courses can also foster digital literacy, self-regulation, and positive perceptions of learning (Blau et al., 2020). However, the effectiveness of digital tools may vary according to school level and subject matter (Johnson, 2020). These studies highlight that technology can significantly improve active and collaborative learning experiences when integrated thoughtfully.

Problem-Based Flipped Learning (PBFL) is an innovative learning model that encourages vocational students to actively solve real problems and improve their critical-thinking skills, collaboration, and understanding (Musva et al., 2023). The science, technology, engineering, and mathematics (STEM) approach enriches the learning experience by connecting theory and practice, creating a dynamic learning environment (Musva et al., 2023). Incorporating PBFL with STEM in vocational high schools is highly relevant in developing 21st-century skills, including technical know-how, collaboration, effective communication, and problem-solving abilities. In the context of increasingly digitized education, practical skills that apply to the world of work are very important. The STEM approach provides a solid foundation for technical skills (Marsono et al., 2019), while PBFL encourages students' active engagement in contextual problem solving that is relevant to industry challenges (Musva et al., 2023). Thus, integrating both prepares students to face the demands of the world of work, innovate, and develop creativity as part of 21st-century competencies. However, vocational students often face challenges, such as limited exposure to collaborative and problem-solving opportunities within traditional classroom settings, highlighting a critical research problem in this area.

Although the Problem-Based Flipped Learning (PBFL) approach and STEM have been widely discussed, their integration into vocational education remains limited. There is a study gap, where prior studies have generally highlighted either traditional learning models or technology used in isolation, without addressing the potential synergy of PBFL and STEM in strengthening critical thinking and problem-solving skills. This research offers a new contribution by integrating both approaches to enhance technical and 21st-century skills, such as collaboration, effective communication, and problem-solving abilities. Furthermore, this study examines the implementation of PBFL in vocational schools, focusing on industry needs and local relevance, within the context of Indonesian education.

This research contributes to the development of learning models for vocational high school educators while providing guidance for designing curricula that emphasize collaboration and problem solving. It also shows how creative methods might help students to learn global labour-market skills. Consequently, this study aims to identify the learning requirements of vocational students within the context of PBFL and STEM model innovation and to investigate how PBFL can enhance students' proficiency in STEM learning. Additionally, it intends to identify obstacles and opportunities in implementing PBFL with STEM, concentrating on student and instructor challenges, along with potential enhancements that would improve STEM learning in vocational high schools. Based on these aims, this research is guided by the following questions: (1) What challenges are faced in implementing PBFL with STEM in vocational high schools? (2) What are the learning needs of vocational high school students to support PBFL and STEM integration? (3) What opportunities exist for optimizing the integration of PBFL with STEM to enhance collaboration, critical thinking, and problem-solving skills?

Methods

Study Design

This research used a qualitative exploratory study to explore various aspects that are related to the design of a Problem-Based Flipped Learning (PBFL) model with a STEM approach for vocational high schools (Lester et al., 2020). This type of research aims to identify and understand the needs, designs, challenges, and opportunities in implementing PBFL with a STEM approach (Miles et al., 2018). A qualitative method was chosen to provide a more holistic picture of how PBFL is implemented in the VHS environment and explore the perceptions and experiences of students and educators related to this learning model (Creswell, 2014). Qualitative approaches are very effective for exploring perceptions, attitudes, and experiences of individuals in more complex contexts, such as the implementation of innovative learning methodologies

Participants

The participants of this study consisted of 33 students in one class at a vocational high school, in addition to three mathematics teachers. Participants were selected using a purposive sampling technique (Bhangu et al., 2023), which was used to align with the research objectives, focusing on participants who were actively involved in STEM-related learning. Although the small sample size limits generalizability, it provides valuable insights for this exploratory study (Lassoued et al., 2020). This ensures that the findings remain relevant to the context of vocational high schools.

Data collection

This study utilized three data-collection techniques: interviews, observations, and questionnaires (Kumar, 2019). In-depth interviews were conducted with educators to explore the experiences and challenges faced when implementing learning in vocational high schools. Observations were overseen to evaluate the execution of mathematics instruction, emphasizing student engagement, integration of technology, and the pedagogical strategies employed. Furthermore, surveys were administered to students to ascertain their expectations and requirements concerning the innovative Problem-Based Learning (PBL) model with a STEM framework, in addition to gathering their perspectives on the efficacy of this approach in fostering 21st-century competencies (Fung et al., 2022; Rizaldi et al., 2020).

Instruments

The study employed three data collection techniques (in-depth interviews, observations, and questionnaires), each targeting specific indicators (Kumar, 2019). In-depth interviews with educators focused on exploring their teaching experiences, learning expectations, and technology use in educational contexts. Observations were conducted to examine student and teacher interactions, technology integration, teaching strategies, methods employed, and overall student engagement in the learning process. Meanwhile, questionnaires were distributed to the students to assess their expectations, learning needs, perceptions of problem-based learning, their requirements within the context of PBFL and STEM, and their views on using technology and innovations in STEM-based PBFL models.

This multi-method approach ensured a comprehensive exploration of both educator and student perspectives on the learning framework. Table 1 shows the instrument grid for each data collection technique.

Table 1: Data collection instrument grid.

Data Collection Techniques	Indicators/Categories	Subject
In-depth interview (educator)	Teaching Experience	Educators
	Expectations for Learning	
	Use of Technology in Learning	
Observation (learning implementation)	Student and Teacher Interaction	Educators and students
	Use of Technology	
	Teaching Strategies and Methods	
	Student Engagement in Learning	
Questionnaire (students)	Student Expectations	Students
	Learning Needs	
	Perceptions of Problem-Based Learning	
	Learning Needs in the Context of PBFL and STEM	
	Use of Technology in Learning	
	Perceptions of Innovation in STEM-Based PBFL Learning Models	

Validity and reliability

To ensure data quality, the three data-collection instruments used in this study were tested for validity and reliability. The interview questions underwent content validation to guarantee relevance to educators' experiences and challenges in implementing PBFL with STEM, and reliability was maintained through structured and consistent interviews. The observations utilized a checklist validated by educational experts for systematic and objective monitoring. The questionnaire was subjected to construct validity testing to assess students' expectations of PBFL with STEM, and reliability was measured using Cronbach's alpha, which yielded a value of 0.85, indicating excellent internal consistency (Gonçalves et al., 2016). Validity and reliability tests confirmed that all the instruments met the necessary standards for collecting valid and consistent data.

Data analysis techniques

This study employed two data-analysis techniques to process information from the interviews, questionnaires, and observations. First, using a STEM approach, thematic analysis (Lester et al., 2020) was used to identify primary themes related to students' needs, expectations, and challenges in PBFL learning. This analysis enabled the researchers to explore students' perceptions of how PBFL can meet their requirements. Descriptive analysis (Birgili et al., 2021), was applied to the observational and interview data. Descriptive statistical techniques were applied to delineate patterns of interaction and technological usage. At the same time, narrative analysis presented findings from the educators' interviews, providing insight into the dynamics of teaching and learning in vocational schools.

Data-collection procedure

This study employed three primary data collection techniques: interviews, observations, and questionnaires. These methods were implemented across three main phases to explore various dimensions related to designing a Problem-Based Flipped Learning (PBFL) model utilizing a STEM approach in vocational high schools.

The data collection procedures were carried out in three phases, each with distinct activities and objectives. Phase 1 involved conducting in-depth interviews with educators to explore their experiences, challenges, and expectations regarding implementing learning in vocational schools. In Phase 2, observations of Problem-Based Learning (PBL) implementation in the classroom were overseen to examine student interactions, the integration of technology, and the teaching strategies employed. Finally, Phase 3 included the distribution of questionnaires to students in order to identify their expectations and needs related to PBFL and STEM, as well as their perceptions of the innovation and efficacy of this learning model. Together, these phases provided a comprehensive understanding of the learning environment and the potential of PBFL with a STEM approach.

Results and Discussion

This section presents the results of this research on the implementation of learning activities and students' expectations of Problem-Based Flipped Learning (PBFL) model innovation using a STEM approach for vocational students. Data was collected through in-depth interviews, observations, and questionnaires involving 33 vocational students and three mathematics teachers. The findings from the various data collection techniques are presented below.

Challenges in implementing learning in vocational schools

During the three encounters of learning mathematics in a vocational high school, the traditional approach still dominates the learning process, focusing on teacher lectures and hands-on practice. Although efforts have been made to integrate technology, the teaching strategy emphasizes the direct delivery of material by the teacher, with students receiving more information, rather than actively participating. In the first meeting, Teacher A started a quadratic function lesson with a lecture supported by PowerPoint and videos to illustrate its application in daily life. However, the motivation provided was not sustained, causing the students to become passive. Although there was little group work, ineffective time management hindered discussion, and the feedback tended to be general, without encouraging critical thinking. Technology was only used to deliver the material, with no active interaction between it and the students.

In the second meeting, Teacher B employed a traditional lecture format to discuss algebra and quadratic equations, thus providing minimal opportunities for discussion or questions. Motivation was primarily centred on the skills relevant to examinations and the job market, lacking connections to practical contexts. This approach diminished student participation because most students were passive listeners. Using a PowerPoint presentation filled with dense text did not facilitate visual comprehension, and digital technology was underutilized. Classroom management was predominantly unidirectional, with feedback that did not encourage further analysis, resulting in limited student engagement in collaborative activities.

In the next meeting, Teacher C attempted to incorporate technology by utilizing software to address more complex mathematical problems. Students were encouraged to seek additional references by using their devices or laptops; however, the application of technology was restricted to information retrieval and problem solving, without a more comprehensive integration into collaborative learning. Although group work was present, interactions among students were suboptimal, with some relying heavily on peers who were more adept at technology. In addition, while classroom management allowed more time dedicated to group activities, the teacher did not provide sufficient guidance to enhance collaborative skills and problem-solving abilities.

Observational evidence indicates that the learning approach remains predominantly traditional, characterized by lecture-based instruction and individual assignments. The utilization of technology is limited to content delivery without fostering student collaboration or interaction. Student engagement was observed to be low, with many relying on their peers for task completion. Despite technology integration, opportunities for group work and developing 21st-century skills were constrained. A more student-centred approach integrated with technology is necessary to facilitate active and collaborative learning experiences.

Vocational high school students' learning needs in PBFL and STEM

A survey was distributed to 33 students participating in mathematics education at a vocational high school to identify their needs concerning innovative learning models that could facilitate the attainment of 21st-century skills. This includes problem-based learning using the flipped classroom method integrated with STEM principles. Table 3 presents the survey data.

Table 3: Analysis of vocational high school students' questionnaires regarding learning design.

Indicators/Categories	Respondents (Number of Students)	Percentage (%)
Expectations for problem-based learning (PBL)		
Interested in problem-based learning	28	85.0
Want more problem-based projects	25	75.8
Need for collaboration skills		
Want more group discussions	30	90.9
Want opportunities to work in teams	27	81.8
Expectations for technology use		
Want more technology use in class	26	78.8
Interested in using apps to solve problems	22	66.7

Need for critical thinking skills		
Want challenging problems to hone critical thinking	24	72.7
Want more problem-solving discussions	23	69.7
Perceptions of STEM-based PBFL model		
Like the application of problem-based learning model with technology	29	87.9
Assess PBFL with STEM helps their understanding	25	75.8

The analysis of the data indicates that a significant majority of students exhibited considerable enthusiasm for the PBFL-STEM model. Specifically, 87.9% of respondents endorsed this approach, appreciating its effectiveness in integrating technology and problem-solving, enhancing comprehension and fostering teamwork. Conversely, 12.1% of students expressed reservations, which may be attributed to challenges adapting to new educational models or a lack of familiarity with technologically driven methodologies. Insights gathered from the interviews provided additional context. One student remarked that collaborative efforts facilitated a better understanding of complex concepts, while another highlighted the necessity for engaging technological tools, such as applications. This feedback underscores both the enthusiasm present and the challenges faced, including a lack of experience with group dynamics or technology, which should be considered in future implementations.

The survey findings further emphasize the significance of PBFL-STEM within vocational education, as it aligns with the objectives of promoting collaboration, problem-solving, and critical thinking skills. The high level of interest reinforces the study's aim to position PBFL-STEM as a viable solution for bridging the divide between vocational education and industry requirements.

Opportunities in implementing PBFL and STEM

Based on the results of the questionnaire distributed to 33 students, several key opportunities that can support the implementation of PBFL and STEM in vocational high schools were found and identified. These opportunities reflect students' enthusiasm and the need for a more active and integrated learning approach. The students' responses are listed in Table 4.

Table 4. Opportunities for implementing PBFL and STEM based on student views.

Indicators/Categories	Respondents (Number of Students)	Percentage (%)
Opportunities to improve collaboration skills through PBFL		
Desire more collaborative activities in class	31	93.9
Believe that PBFL improves teamwork skills	28	84.8
Opportunities for technology integration in learning		
Desire more use of digital simulations or STEM-based applications in learning	30	90.9
Desire more use of interactive video learning	27	81.8
Opportunities for critical-thinking skills development through PBFL		
Believe that PBFL can help them think more critically	26	78.8
Desire problem-based learning to solve real-world challenges	29	87.9

The questionnaire results demonstrated substantial student support for implementing PBFL with STEM to develop 21st-century skills. Most (93.9%) expressed a desire for increased collaborative activities, and 84.8% believed PBFL could enhance teamwork skills. The integration of technology was also favourably received, with 90.9% of students indicating a preference for using digital simulations or STEM-based applications and 81.8% expressing a desire for more frequent use of interactive learning videos. Furthermore, 78.8% of the students believed PBFL could improve critical-thinking skills, and 87.9% desired increased problem-based learning to address real-world challenges. Concurrently, the observational results indicated a significant potential for integrating PBFL and STEM in the classroom environment. In the initial meeting, despite the traditional nature of learning, students exhibited notable enthusiasm for group discussions, although time management for discussions remained challenging. In the second meeting, while the utilization of technology was limited, it demonstrated the potential to increase student engagement. These findings corroborate that integrating technology and collaborative approaches can enhance the learning experience and improve the comprehension of complex concepts.

The questionnaire findings and observations revealed significant opportunities to implement PBFL with a STEM approach to enhance the 21st-century skills of vocational high school students. Team collaboration, technology usage, and critical-thinking skills are key areas that can be improved using the PBFL and STEM models. More interactive technology use and problem-based discussions could maximize students' potential to master skills relevant to the workforce.

Teacher and student analyses indicated that innovative learning models are essential for vocational education. Interviews with educators and student surveys highlight a gap between vocational high schools' traditional methods and the need for 21st-century skills, such as collaboration, critical thinking, and problem-solving. The proposed PBFL model and the STEM approach aimed to bridge this gap by promoting problem-based learning and integrating technology and industry relevance. Challenges, such as limited technological access, inadequate teacher training, and time management for group discussions, must be addressed. Despite these issues, enhancing collaboration, technology use, and problem-based learning presents opportunities to optimize student skills.

Discussion

Identification and student expectations of learning model innovation in vocational schools

Empirical observations in vocational institutions indicate that Problem-Based Learning (PBL) can enhance 21st-century competencies, including collaboration, effective communication, and critical thinking. However, educator interviews and student surveys revealed a deficiency in industry-relevant collaborative learning strategies and the utilization of rudimentary media that fail to foster active engagement. Although PBL demonstrates significant potential, this pedagogical approach requires support from STEM-based learning technologies and methodologies. The majority of students expressed a desire for increased opportunities to engage in team-based activities and utilize technology, particularly STEM-based applications, to acquire concepts pertinent to their prospective careers. These findings corroborate the necessity for innovative learning models, such as PBFL with a STEM approach, to prepare students for the professional environment adequately.

Previous research has indicated that these skills are essential in vocational schools to adequately prepare students for an increasingly dynamic industrial landscape (Sahito & Wassan, 2024). Studies have demonstrated that project-based and problem-based learning (PBL), particularly as implemented in the Problem-Based Flipped Learning (PBFL) model, can facilitate the development of these competencies more effectively than traditional teaching methods (Purwaningsih et al., 2020). For instance, PBL integrated with STEM technology has been shown to enhance students' problem-solving abilities and collaborative skills across various educational levels, including vocational schools (Topsakal et al., 2022; Zainil et al., 2023).

The findings of this research indicate that although PBFL with a STEM approach possesses significant potential for developing the abilities required for the modern workplace, its implementation in vocational high schools remains constrained by several factors, such as insufficient teacher training, limited facilities, and suboptimal utilization of technology (Topsakal et al., 2022). This aligns with previous studies revealing that the application of innovative learning models, such as PBFL, faces substantial obstacles related to teacher readiness and supporting infrastructure (Affouneh et al., 2020; Smith et al., 2022). Despite students demonstrating enthusiasm for problem-based learning and technological utilization, not all schools can provide adequate support to ensure successful implementation, thus limiting the potential for active and collaborative learning (González-Pérez & Ramírez-Montoya, 2022). Despite numerous studies supporting the effectiveness of PBFL, significant challenges remain in its implementation in vocational schools, which often face limitations in facilities and experience in effectively integrating technology (Budiarto et al., 2024). This study suggests the need for more comprehensive and integrated solutions to ensure that models, such as PBFL, can be applied more optimally and aligned with industrial needs, ready to address future educational challenges. As a result, although the demand for 21st-century skills in vocational high schools is becoming increasingly pressing, the effective execution of Project-Based Learning (PBL) relies on external elements, including ongoing professional development for educators and the availability of sufficient technological resources.

Challenges in implementing the PBFL model design with a STEM approach

This research elucidates that educators in vocational high schools encounter obstacles in incorporating technology and innovative methodologies, such as PBFL and STEM. The educational process remains predominantly characterized by lectures and practical exercises, with limited collaborative or participatory learning opportunities. Multimedia resources, including PowerPoint presentations and video content, function primarily as information dissemination tools rather than facilitating interactive engagement or problem-solving activities. In educational institutions with scarce technological resources, collaborative efforts among students frequently suffer from inefficiency. This is primarily due to difficulties accessing shared devices, such as laptops or tablets, necessary for group activities. Consequently, certain groups may be compelled to depend on a single device for several members, leading to decreased engagement and fewer chances for direct interaction with tools or applications related to STEM.

Previous research supports these findings, indicating that although Problem-Based Learning (PBL) and STEM education provide numerous advantages, educators encounter significant challenges in effectively implementing these approaches. The primary obstacles include the lack of visible integration models (Smith et al., 2022), limited experience with STEM subjects, and difficulties in classroom management and curriculum development. Teachers' readiness for STEM education is crucial, encompassing alignment, capability, and engagement. Effective STEM practices involve critical thinking, collaboration, and technological integration (Rahman et al., 2021). Studies have demonstrated that STEM-PBFL can significantly enhance students' problem-solving skills compared with traditional methods (Purwaningsih et al., 2020). However, successful implementation requires addressing factors such as teachers' attitudes, beliefs, and capacities, as well as external elements, like training design and duration (Affouneh et al., 2020).

The findings of this research and previous studies highlight the challenges teachers face in implementing innovative learning methods in vocational high schools. Lack of training, limited facilities, and other structural barriers impede the effective adoption of approaches, including PBFL and STEM. To prepare students for the demands of the modern industrial world, it is crucial to provide adequate support to teachers through professional development and enhancing technological infrastructure in schools.

Potential and opportunities for implementing the PBFL model design with a STEM approach

The findings of this study indicate that Project-Based Learning (PBL) holds significant potential for enhancing vocational high-school students' collaboration and communication skills through projects relevant to the industrial sector. According to the survey, most students (93.9%) desired more collaborative activities, while 84.8% believed that PBL could improve their teamwork abilities. These results align with the assertions made by AlAli (2024), which suggests that implementing PBL in STEM education can foster collaboration and problem-solving skills. Furthermore, 90.9% of the students preferred greater engagement with technology, such as digital simulations and STEM applications, to better grasp complex concepts. This outcome is also consistent with the research conducted by Fung et al. (2022), which found that flipped learning in STEM contexts can enhance creativity, learning interest, and soft skills, students' self-independence, students' analytical thinking and communication skills, while also enriching the learning experience through technology.

Although the use of technology remains limited, observations revealed significant enthusiasm among students during group discussions to solve real-world industry problems. To capitalize on this eagerness, educational institutions should prioritize steps, such as providing more intensive teacher-training programs focused on integrating PBL with STEM, and equipping teachers with practical tools and methods to implement collaborative learning effectively (Musva et al., 2023). Additionally, increasing access to technological tools, like digital simulations, tablets, and STEM-specific software, can address gaps in these areas and foster a more engaging learning experience (Purwaningsih et al., 2020). Sukatiman et al. (2020) also suggested that scaffolding in PBL within vocational education strengthens higher-order thinking skills while promoting communication, collaboration, and creative thinking relevant to industry demands. STEM-based digital classrooms can also improve scientific literacy and 21st-century competencies (Zainil et al., 2022). These findings support PBFL's STEM approach as an effective model for preparing vocational high school students to face the increasingly complex workforce challenges.

The findings of this research indicate that despite enthusiasm for adopting innovative models, such as STEM-based PBFL, their implementation in schools remains limited. In comparison, several innovative schools across various countries have begun to adopt novel approaches, such as creating Lab 21 or hybrid learning spaces that integrate technology with creative practices, which have been demonstrated to enhance creative-thinking skills and skill development (Dilekçi & Karatay, 2023). The relevance of this study to the vocational education policy in Indonesia lies in its alignment with government programs, like those seen in the Ministry of Education and Culture's initiative to improve vocational education through technological integration and skills alignment with industry demands. Thus, PBFL with STEM offers a concrete model for operationalizing these policy objectives by addressing current gaps in collaboration, critical thinking, and technological application.

In line with this, future policies should strengthen partnerships between schools and industries to create real-world learning opportunities and enhance the contextual relevance of STEM-PBL programs. With stronger support, STEM-based PBFL can better prepare vocational school students to face an ever-evolving industrial world. Overall, the implementation of STEM-based PBFL has great potential for developing the skills needed to tackle workplace challenges, but it requires a more thorough design, facility support, and industry collaboration to produce technically and collaboratively competent vocational school graduates.

Conclusion

This study's findings indicate that applying Problem-Based Flipped Learning (PBFL) utilizing a STEM approach in vocational high schools significantly enhances students' 21st-century skills, including cooperation, critical thinking, and problem-solving. Nonetheless, its execution remains suboptimal, owing to infrastructural constraints, lack of teacher preparedness, and the passive characteristics of the existing learning methodology. Integrating technology with PBFL-STEM is underdeveloped, constraining students' access to pertinent and practical learning experiences that fit industry requirements. This study's shortcomings include a small sample size and a concentration on a singular vocational high school, potentially impacting the generalizability of the results. Moreover, the obstacles in executing PBFL-STEM, including inadequate infrastructure and restricted teacher training, underscore the necessity for enhancements in these domains. This study calls attention to the critical necessity for teacher-training programs that prepare educators in the design and execution of interactive PBFL-STEM learning models. For future research, this study can serve as a foundational example of exploring scalable PBFL-STEM frameworks tailored to varying school resources and contexts. Future studies should investigate the long-term impact of PBFL-STEM on students’ employability skills and academic performance, incorporating larger and more diverse samples. Additionally, researchers should focus on developing specific indicators for measuring the success of PBFL-STEM implementations, such as student engagement levels, collaborative outputs, and alignment with industry standards. This research framework can also be expanded to test PBFL-STEM integration in other educational levels or disciplines, providing a comparative understanding of its broader applicability and impact.

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