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ORIGINAL

Enhancing Welding Engineering Education Through a Problem-Based Learning Factory Model: Design, Implementation, and Outcomes

Mejora de la formación en ingeniería de soldadura mediante un modelo de fábrica de aprendizaje basado en problemas: diseño, implementación y resultados

Azmil Azman[1,2], Wakhinuddin[1], Arwizet[1], Junil Adri[1]

[1]U1 Universitas Negeri Padang, Technical and Vocational Education. Padang, Indonesia.
[2]Universitas Ekasakti, Department of Mechanical Engineering. Padang, Indonesia.

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Corresponding author: Junil Adri

ABSTRACT

This study aims to design and implement the Problem-Based Learning Factory (PBLF) learning model in Welding Engineering courses in vocational education. The research approach uses the Dick and Carey model which focuses on systematic instructional design, including needs analysis, goal formulation, learning strategy development, implementation, and formative evaluation. The validity of the model was tested through Focus Group Discussion (FGD) with experts, while its practicality and effectiveness were measured through observation and questionnaires to students and lecturers. The results showed that the PBLF model was valid with an average Aiken's V of 0,85, practical with an achievement level of 87 %, and effective in improving student learning outcomes with an average increase in value of 25 %. This model integrates theories and practices that are relevant to the industrial world, while improving students' cognitive, psychomotor, and affective skills. Formative evaluation showed that model iterations resulted in significant improvements in the learning module.

Keywords: Problem-Based Learning Factory; Engineering Education; Welding Engineering; Problem-Based Learning; Learning Factory; Skills-Based Education.

RESUMEN

Este estudio tiene como objetivo diseñar e implementar el modelo de aprendizaje Fábrica de Aprendizaje Basado en Problemas (PBLF) en cursos de Ingeniería de Soldadura en la formación profesional. El enfoque de la investigación utiliza el modelo de Dick y Carey, que se centra en el diseño instruccional sistemático, incluyendo el análisis de necesidades, la formulación de objetivos, el desarrollo de estrategias de aprendizaje, la implementación y la evaluación formativa. La validez del modelo se evaluó mediante Discusiones en Grupos Focales (DGF) con expertos, mientras que su viabilidad y eficacia se midieron mediante la observación y cuestionarios a estudiantes y profesores. Los resultados mostraron que el modelo PBLF fue válido con una V de Aiken promedio de 0,85, práctico con un nivel de logro del 87 % y eficaz para mejorar los resultados de aprendizaje de los estudiantes con un aumento promedio del 25 %. Este modelo integra teorías y prácticas relevantes para el mundo industrial, a la vez que mejora las habilidades cognitivas, psicomotoras y afectivas de los estudiantes. La evaluación formativa mostró que las iteraciones del modelo generaron mejoras significativas en el módulo de aprendizaje.

Palabras clave: Fábrica de Aprendizaje Basado en Problemas; Educación en Ingeniería; Ingeniería de Soldadura; Aprendizaje Basado en Problemas; Fábrica de Aprendizaje; Educación Basada en Habilidades.

INTRODUCTION

Skills-based education plays a strategic role in supporting economic development and meeting the demand for competent workers across various industrial sectors.[1] As a crucial element of the education system, this approach focuses on equipping students with technical and practical skills aligned with labor market needs.[2] However, vocational education institutions in Indonesia continue to face significant challenges, particularly in addressing the gap between graduate competencies and industry demands.[3] According to the Directorate of Vocational Education, approximately 65 % of vocational education graduates fail to meet industry expectations, especially concerning technical skills and hands-on experience.[4]

This issue is particularly pronounced in the context of Welding Engineering courses, where students often struggle to bridge the gap between theoretical knowledge and real-world applications. The primary obstacles in welding education is the insufficient integration of practical training with classroom theory.[5] Students frequently encounter difficulties in analyzing welding defects and determining appropriate welding parameters—two critical competencies required in the field.[6] Furthermore, the predominant theory-based learning approach leaves little room for developing critical and analytical thinking skills, which are essential for solving real industrial problems.[7]

To overcome this challenge, a learning model is needed that not only provides practical experience but also trains students in solving complex problems. Problem-Based Learning Factory (PBLF) emerged as an innovative solution that integrates a problem-based learning approach with project-based practice. This approach is designed to provide a learning experience that is relevant to the industrial world through a syntax that includes problem analysis, action planning, product implementation, and evaluation of results.[8]

The PBLF model offers the advantage of creating authentic and student-centered learning. In this model, students are invited to work in groups to solve real case studies faced by the industry. This process not only enhances students' technical competence but also develops critical thinking skills, teamwork, and communication skills.[9] In addition, by emphasizing outcome-based evaluation, PBLF provides students with the opportunity to learn from their mistakes and continuously improve the quality of their work.[10]

Several previous studies have shown the effectiveness of problem-based learning approaches in increasing student engagement and learning outcomes. Problem-based learning allows students to connect theory with practice more effectively.[11] Meanwhile et al., found that this approach improves students' ability to deal with complex situations that require creative solutions.[12]

This study aims to design and implement the PBLF model in Welding Engineering courses in vocational education. In addition to evaluating the validity, practicality, and effectiveness of the model, this study also aims to provide a basis for further development, including the integration of modern learning technologies such as virtual reality-based simulations. Thus, this study is expected to provide a significant contribution in creating learning that is more relevant to the world of work and improving the quality of vocational education in Indonesia.

METHOD

This study employs a Research and Development (R&D) approach using the Dick and Carey model. This model provides a systematic framework for designing, implementing, and evaluating instructional systems to ensure effective learning outcomes.[12] This method was chosen because it emphasizes a structured and iterative approach to address educational challenges. The study was conducted in the Welding Engineering course at a vocational education institution over one semester, involving 25 final-year students. Each stage of the study aimed to address gaps between theoretical learning and industry demands.

Needs Analysis

The needs analysis stage aims to identify gaps between student competencies and industry requirements. Needs analysis is a crucial step in instructional design, as emphasized by Stefaniak, to ensure that learning objectives align with real-world demands.[12]

Questionnaire: A questionnaire was distributed to 50 Welding Engineering students and lecturers. The survey focused on previous learning experiences, understanding of welding techniques, and the importance of hands-on learning. Using a 5-point Likert scale, results revealed that 78 % of students felt insecure about their basic welding skills, and 85 % emphasized the importance of practical, hands-on learning.

Lecturer Interview: Semi-structured interviews were conducted with five Welding Engineering lecturers to gain in-depth insights into learning challenges. Lecturers reported that students often struggle with analyzing welding parameters that influence weld quality.[13] Industry Needs Analysis: A literature review and discussions with industry practitioners revealed essential competencies such as analyzing welding defects and selecting appropriate welding parameters.[14]

Formulation of Learning Objectives

Based on the needs analysis, learning objectives were developed to align with industry requirements.

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According to Bloom's taxonomy, the objectives are categorized into cognitive, psychomotor, and affective domains, Cognitive Competence: Students can analyze the causes of welding defects based on welding parameters. Psychomotor Competence: Students can perform welding tasks following industry standards with precise parameter adjustments. Affective Competence: Students demonstrate teamwork skills, professionalism, and responsibility.(15)

Instructional Analysis

The Problem-Based Learning Factory (PBLF) syntax was developed based on the needs analysis and learning objectives. According to Barrows, problem-based learning emphasizes critical thinking, problem-solving, and knowledge application in real-world contexts.(16)

In developing the PBLF syntax, several key components are involved, including:

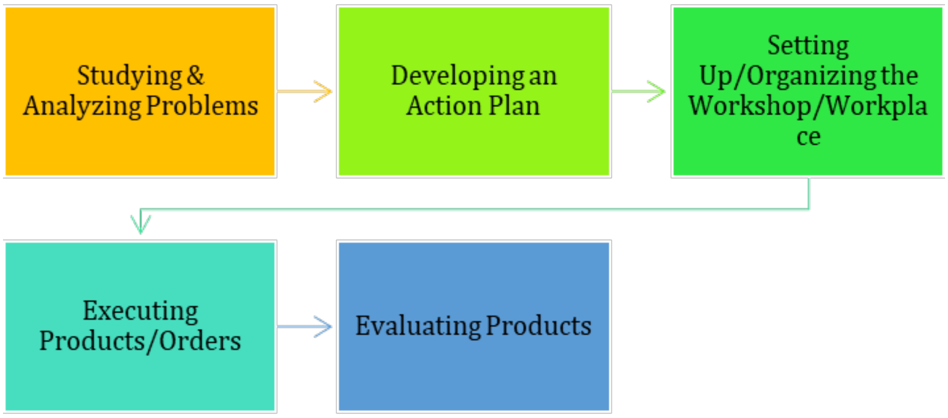

Figure 1. Syntax Problem Based Learning Factory (PBLF)

Studying & Analyzing Problems: Learners are presented with real-world problems occurring in industrial environments and conduct in-depth analyses. Developing an Action Plan: Learners formulate strategic steps to address the identified problems. Setting Up/Organizing the Workshop/Workplace: Learners prepare and arrange a suitable work environment for implementing solutions. Executing Products/Orders: Learners implement solutions by producing products or fulfilling orders according to established standards. Evaluating Products: The outcomes are evaluated to ensure the quality and effectiveness of the applied solutions.

Development of Learning Strategies and Media

Learning strategies and media were developed to support cognitive, psychomotor, and affective competencies. This is consistent with Mayer's Cognitive Theory of Multimedia Learning, which emphasizes integrating multimedia for effective learning outcomes.(17)

Learning Module: Designed based on the PBLF stages, including step-by-step guides and assessment rubrics. Digital Simulation: CAD-based simulations provide virtual experiences of welding scenarios. Video Tutorial: Step-by-step welding guides are available on an online platform. Practical Checklist: Ensures proper preparation and safety compliance before welding activities. Self-Reflection and Practice Guide: Enables students to identify errors and plan improvements. Lecturer's Guide: Includes rubrics and monitoring guidelines. The module was validated through a Focus Group Discussion (FGD) with experts, and feedback was incorporated to enhance clarity and comprehensiveness.

Implementation

The implementation phase spanned eight weeks and was structured into three key sessions, each serving a distinct purpose in the learning process. The first session was the Introductory Session, where students were introduced to the modules and relevant case studies. This session aimed to provide foundational knowledge and set the stage for the upcoming activities. Next was the Practice Session, which involved group-based assignments conducted under the supervision of the lecturer. This phase emphasized collaboration, critical thinking, and the practical application of the concepts introduced earlier. Finally, the Reflection Session allowed students to present their findings and reflect on the challenges they encountered during the process. This session encouraged self-assessment and group discussion, reinforcing the lessons learned throughout the implementation phase.

Formative Evaluation and Revision

The formative evaluation was carried out using a variety of methods to gain comprehensive insights into the effectiveness of the learning process. One method used was a questionnaire, which assessed student satisfaction with the learning modules. This provided quantitative data on how well the modules met student expectations and needs. In addition, interviews were conducted with both lecturers and students. These interviews offered qualitative feedback, capturing personal experiences and suggestions for improvement from different perspectives. Observation was also employed to monitor student engagement and ensure that they adhered to the set parameters throughout the sessions. This method helped identify behavioral patterns and areas needing attention. The findings from these evaluations were instrumental in refining the evaluation rubrics. They also informed the introduction of more challenging case studies, aimed at deepening student understanding and enhancing the learning experience.

Data Analysis

Quantitative data from pretest-posttest scores and questionnaires were analyzed using descriptive statistics.[18] Qualitative data from interviews and observations were thematically analyzed to provide deeper insights into student experiences.[19]

RESULTS AND DISCUSSION

Needs Analysis

The needs analysis stage is crucial for identifying gaps in student competency in the Welding Engineering course and aligning educational outcomes with industrial requirements.[20] Needs analysis is a fundamental step in curriculum design to ensure the relevance and effectiveness of educational programs.[21] This stage involved distributing questionnaires to students, conducting interviews with lecturers, and analyzing relevant literature related to industry demands.

Student Questionnaire Results

A total of 50 Welding Engineering students participated in a survey using a 5-point Likert scale questionnaire. The questionnaire assessed aspects such as confidence in welding skills, critical thinking abilities, and the relevance of the curriculum to industrial needs. The results are as follows: Technical Skills: 78 % of students reported low confidence in basic welding skills, such as setting welding machine parameters and identifying welding defects. Critical Thinking Skills: 82 % of students expressed difficulty in analyzing technical problems and determining appropriate solutions in welding contexts. Learning Relevance: 85 % of students felt that theory-dominated learning was insufficient in addressing real-world challenges. Extensive hands-on experience during academic studies plays a crucial role in boosting self-efficacy and increasing employment prospects for engineering graduates. Ongoing practical training enables students to build confidence in applying their acquired skills in professional settings and strengthens their competitiveness in the labor market.[22]

Interview with Lecturers

Semi-structured interviews were conducted with five Welding Engineering lecturers to gain qualitative insights into the challenges students face in understanding more technical welding concepts. Based on the interviews conducted Vempala, the lecturers highlighted significant gaps in students' understanding of welding parameters, such as voltage, current, and welding speed, which directly affect weld quality.[13] One lecturer even stated, "Students often struggle to determine the appropriate welding parameters. They require a more hands-on learning approach to bridge the gap between the theory taught in class and actual industrial practice. This statement reflects a gap between the theoretical knowledge learned by students in the classroom and their ability to apply that knowledge in real-world settings. In many cases, students find it challenging to connect the theory they study with the conditions and challenges they encounter when they enter the industry, especially in determining and adjusting the right welding parameters.

This observation is consistent with the findings who stated that experiential learning plays a crucial role in skill development.[23] Experiential learning provides students with the opportunity to deepen and master skills through direct practice, which in turn enables them to be better prepared for real-world situations.

Therefore, it is essential for educational programs in Welding Engineering to design more applicable, practice-based learning methods. Such an approach will help students better understand and master critical welding parameters and reduce the gap between theory and industrial practice. This experiential learning approach will also enhance students' overall technical skills, preparing them to contribute more effectively in the workforce, which demands practical expertise and quick, accurate problem-solving.

Literature Review and Industry Analysis

A literature review was conducted to align learning outcomes with industry expectations. The National

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Welding Association acording Idibia, et al., identified key competencies required in welding professionals: Proficiency in identifying and analyzing welding defects (e.g., cracks, porosity, and slag inclusions).[24] Mastery of welding parameters (e.g., current, voltage, and electrode type). Ability to collaborate effectively in team-based industrial projects. Similarly, research by González highlights the importance of integrating real-world case studies into technical education to bridge competency gaps.[25]

Key Findings from Needs Analysis

The combination of data obtained from questionnaires, interviews with lecturers, and literature analysis reveals an urgent need to implement a practice-based learning approach in Welding Engineering. According to the research conducted by Adri et al, the findings show that learning approaches emphasizing hands-on experience and real-world problem-solving have great potential in improving students' understanding of the material being taught.[9]

This approach not only provides students with stronger technical skills but also trains them to think critically when facing various challenges in the industry. Furthermore, research by Lee, et al. highlights the importance of curriculum relevance to real-world needs, where direct involvement in solving real problems can fill the gaps in technical skills and critical thinking often found in traditional learning systems.[26]

Thus, educators in Welding Engineering must consider the importance of designing curricula that allow students to engage directly in practical activities that reflect real-world conditions and issues. This will not only enhance their technical competencies but also better prepare them to contribute to an ever-evolving industry. This practice-based approach is expected to bridge the gap between the theory taught in the classroom and the skills needed in the professional world.

Table 1 Summary of Needs Analysis Results

Measured Aspects	Percentage of Students	Information
Technical Skills	78	Lack of understanding of welding parameters.
Critical Thinking Skills	82	Difficulty analyzing and solving problems.
Relevance of Learning	85	Theory-based methods are less effective.

The results presented in table 1 highlight key areas in the Welding Engineering curriculum based on the needs analysis. A total of 78 % of students lack an understanding of welding parameters, indicating a deficiency in technical skills. Additionally, 82 % of students struggle with analyzing and solving problems, highlighting the need for improved critical thinking skills.

Furthermore, 85 % of students find theory-based teaching methods less effective, as they are not sufficiently relevant to industrial practices. Therefore, these findings support the adoption of innovative learning models, such as the Problem-Based Learning Factory (PBLF) model, which integrates industrial case studies into the curriculum.[27] This approach can help bridge the gap between theory and practice while enhancing students' technical and critical thinking skills.

Validity of the Model

The PBLF model was validated through a Focus Group Discussion (FGD) involving five experts: two senior lecturers, one industry practitioner, and two instructional design experts. This validation aimed to assess the model's rationality, syntax, media, and alignment with industrial requirements. The validation process began with the presentation of the PBLF model by the researchers, including its syntax and supporting media. This was followed by a discussion and assessment phase, where experts provided in-depth evaluations of the model's components. To ensure a structured evaluation, each expert assessed the model using a 5-point Likert scale, and the Aiken's V value was calculated to determine the validity of each component.

The validation results showed that the model's rationality demonstrated a strong alignment with industry needs. The learning syntax was considered logical; however, experts suggested clarification, particularly regarding the evaluation stages. The instructional media were found to be effective, although the addition of more visual aids was recommended to enhance understanding. Overall, the final Aiken's V value was 0,85, indicating a high level of validity.[28]

Revisions based on expert feedback included clarifying the stages of product evaluation, adding interactive visual diagrams to illustrate welding parameters, and expanding the case studies to encompass more complex welding scenarios. These revisions contributed significantly to the refinement of the PBLF model, ensuring that it is both theoretically sound and practically applicable. Furthermore, experts recommended the integration of advanced technologies, such as Augmented Reality (AR) and Virtual Reality (VR), to enhance the hands-on learning experience.[29]

Practicality of the Model

The practicality of the Problem-Based Learning Factory (PBLF) model was evaluated through questionnaires, interviews, and observations during the implementation of learning.[30] This evaluation aimed to determine the extent to which the model is easy to apply and relevant in helping students comprehend Welding Engineering material. The assessment involved 25 students and three lecturers teaching Welding Engineering courses.

Student Questionnaire Results

A 5-point Likert scale questionnaire was administered to students after eight weeks of model implementation.[31] The questionnaire evaluated several indicators, such as the ease of following the learning syntax, the relevance of learning media, and the model's contribution to understanding the material.[32] The findings are as follows: Ease of Learning Syntax As many as 87 % of students stated that the learning syntax, consisting of five stages—analyzing problems, preparing action plans, organizing the workplace, implementing products, and evaluating product results—was easy to understand and follow. According to Sombria, clear and structured learning stages are crucial for enhancing student engagement in problem-solving-based learning.[33] Relevance of Learning Media As many as 85 % of students considered that supporting media, such as learning modules, video tutorials, and digital simulations, were very helpful for understanding welding parameters before practice. This aligns with Kirschner cognitive theory of multimedia learning, which emphasizes the importance of interactive media in facilitating deeper understanding.[34] Improved Understanding of Material As many as 90 % of students felt that this model provided a more in-depth learning experience than previous lecture-based methods. One student remarked, "The modules and video tutorials really helped me understand the basic concepts before practicing. I felt more confident when trying to set the welding parameters directly on the welding machine."

Feedback from Lecturers

Lecturers provided positive feedback regarding the clarity of the learning guide and the flexibility of the model in its application. According to the lecturers, the PBLF syntax, particularly the action plan preparation and product evaluation steps, offered a clear structure to guide students effectively. As stated by Shanta & Wells, a well-structured problem-solving framework is fundamental for fostering critical thinking and independent learning among students.[35] One lecturer commented, "This model really helps me in guiding students, especially at the welding result evaluation stage. The guidance provided makes it easier for me to give objective assessments."

Observation Results During Implementation

Observations during the implementation revealed that students were more actively engaged in the learning process. In the group discussion stage, students demonstrated enthusiasm in analyzing problems and developing action plans. They shared opinions and collaborated to complete the case studies. During the practice stage, students applied theoretical knowledge to improve welding parameters, producing welded joints that met quality standards.

Key findings from the observations include: Student Involvement Students were more active in asking questions and participating in discussions, which enhanced their critical and analytical thinking skills. This finding is supported by Warsah, who argued that collaborative learning environments encourage student participation and cognitive development. Improvement in Practice Outcomes The quality of welding practice outcomes improved compared to the pre-implementation stage, with fewer welding defects detected in the students' work. This indicates that the PBLF model effectively bridges theoretical knowledge and practical skills.[36]

Student Feedback

Some students suggested incorporating more complex case studies to enhance their understanding. They felt that the case studies during implementation were too simple to represent real-world challenges. For instance, students proposed adding scenarios involving welding on materials with varying thicknesses or in difficult welding positions. As one student noted, "I wish there were more challenging case studies, such as welding on thin materials or in vertical positions. This would help us be more prepared for industrial conditions."

Practical Conclusion

Overall, the PBLF model is highly practical for application in Welding Engineering education. Its structured syntax, relevant media, and significant contribution to student understanding make it a promising approach for vocational learning. Suggestions from students and lecturers, such as incorporating more complex case studies

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and developing interactive learning media, will serve as a basis for further improvement of the model.

Model Effectiveness

The effectiveness of the Problem-Based Learning Factory (PBLF) model is evaluated through measuring student learning outcomes, observing their involvement during the learning process, and analyzing input from lecturers and students. This assessment aims to determine the extent to which the PBLF model enhances students' cognitive, psychomotor, and affective competencies to meet the demands of the industrial world. As Bell emphasizes, experiential learning that integrates theory and practice can significantly enhance skill development and knowledge application.(37)

Student Learning Outcomes

The effectiveness of the PBLF model was assessed by comparing pre-test and post-test results conducted before and after the model's implementation. The pre-test measured students' baseline knowledge of welding, including understanding welding parameters and analyzing welding defects, while the post-test evaluated improvements in their competencies. The findings are as follows: Value Enhancement: The average pretest score was 60, while the average posttest score increased to 75, reflecting a 25 % improvement. Cognitive Competence Enhancement: 85 % of students answered analysis questions related to welding parameters correctly on the posttest, compared to 60 % on the pretest. Psychomotor Competence Improvement: Practical results demonstrated a significant reduction in welding defects, such as cracks and porosity, with 80 % of students producing welds that met industry quality standards.

Table 2. Summarizes the results of the students' pretest and posttest

Indicator	Pretest Average	Posttest Average	Increase (%)
Welding Parameter Analysis	58	75	29
Identification of Product Defects	62	78	26
Welding Result Quality	60	74	23

Observation During Learning

Direct observations during the eight weeks of model implementation highlighted increased student engagement and participation. Key findings include: Group Discussion Activities: Students actively participated in group discussions, exchanging ideas to solve case studies. They identified problems, such as welding defects caused by incorrect parameters, and developed solutions using module guidance. This supports Saleem, Kausar & Deeba social constructivism theory, which emphasizes learning through collaboration.(38) Confidence in Practice: During the practical stage, students showed increased confidence in setting welding machine parameters, such as current and voltage, leading to better welding outcomes.(39) Critical Thinking Skills: Students demonstrated improved analytical skills in relating welding parameters to weld quality. They provided critical reflections on errors encountered during practice sessions. One student noted: "Group discussions helped me understand the relationship between theory and practice. I also felt more confident when trying new parameters on the welding machine."

Impact on Affective Competence

In addition to cognitive and psychomotor improvements, the PBLF model positively impacted students' affective competencies, such as teamwork and motivation. Observations revealed: Increased involvement in group discussions. Enhanced collaboration to complete tasks and mutual support during welding practices. 90 % of students reported that this learning experience boosted their motivation to delve deeper into the material. These findings align with the framework of Goleman's emotional intelligence, which underscores the importance of interpersonal skills in collaborative learning environments.(40)

Revisions Based on Formative Evaluation

Formative evaluations during implementation provided valuable feedback to refine the model. Key revisions included: Learning Module Improvements: Case studies were updated to include more complex challenges, such as welding on materials of varying thicknesses or in vertical positions. Development of Learning Media: The weld evaluation step-by-step guide was revised for clearer instructions on assessing weld defects using industry standards. Technology Integration: Virtual reality-based simulations were proposed to provide students with realistic experiences before engaging in direct practice. As highlighted by Chi and Wylie, such interactive tools enhance active learning and comprehension.(41)

The evaluation results confirm that the PBLF model effectively enhances Welding Engineering students' competencies. Improvements in pre-test post-test scores, observations of student engagement, and feedback from lecturers and students demonstrate that the model successfully integrates theory with practice. This alignment with industrial needs represents a critical step in preparing vocational graduates to excel in competitive work environments.

Implications and Suggestions

The findings of this study indicate that the Problem-Based Learning Factory (PBLF) model significantly enhances the relevance of vocational education to industry requirements. This model not only improves students' technical competencies but also fosters critical thinking, teamwork, and confidence in solving complex problems. By integrating theory with practice, the PBLF approach creates an authentic, relevant, and workplace-aligned learning experience.

Implications for Vocational Education

The study highlights the PBLF model as an innovative approach to bridging the competency gap between vocational education graduates and industry expectations. Key implications include: Reinforcement of Practice-Based Learning: PBLF provides systematic guidance for incorporating real-world industrial case studies into the learning process. This enhances students' ability to directly apply theoretical knowledge to practical situations. Relevance to Industry: Through a problem-based approach rooted in industry challenges, this model ensures that students not only understand fundamental concepts but also develop the capacity to solve complex problems independently or collaboratively. 21st Century Skills Development: PBLF supports the cultivation of critical thinking, problem-solving, and collaboration skills, which are essential for the modern workplace. Adaptation Across Disciplines: While this study focuses on Welding Engineering, the PBLF model can be adapted to other fields, such as Mechanical Engineering, Information Technology, and Electrical Engineering. For instance, case studies could be designed around challenges in automation, coding, or hardware development.

Integration of Modern Learning Technologies

A significant opportunity for enhancing the PBLF model lies in the integration of modern learning technologies. Tools like Augmented Reality (AR) and Virtual Reality (VR) can provide students with more interactive and immersive experiences. Examples include: Virtual Reality Simulation: Students can practice welding techniques in a virtual environment before performing hands-on tasks, minimizing safety risks and accelerating the learning curve. Real-Time Data Analysis: Integration of IoT (Internet of Things) devices enables real-time feedback on parameters such as current and voltage, improving students' understanding of quality control in welding processes.

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Recommendations for Further Research

This study identifies several avenues for future exploration: Long-Term Evaluation: Future research should assess the long-term impact of the PBLF model on graduates' job readiness and performance in the workplace. Cross-Disciplinary Testing: The effectiveness of the PBLF model should be evaluated across different vocational disciplines, including Mechanical Engineering, Information Technology, and Healthcare. Non-Technical Skills Assessment: Research should investigate the PBLF model's impact on non-technical skills, such as communication, time management, and adaptability. Technology Integration: Further studies should explore the effectiveness of integrating AR/VR technologies in enhancing students' engagement and learning outcomes in industry-based simulations.

CONCLUSIONS

The Problem-Based Learning Factory (PBLF) model is a valid, practical, and effective approach for Welding Engineering courses in vocational education. Validation with experts resulted in an Aiken's V score of 0.85, showing high validity. The model integrates theory and practice through real-world case studies. The syntax easy to follow and benefiting from modules, simulations, and tutorials. Observations showed increased engagement, collaboration, and confidence. A improvement in learning outcomes reflects enhanced problem-solving, teamwork, and critical thinking skills. Despite limitations like a small sample size and single-course implementation, future research can expand to other fields and incorporate AR/VR technologies. Overall, PBLF has strong potential to improve vocational education and prepare globally competitive graduates.

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AUTHORSHIP CONTRIBUTION
Conceptualization: Azmil Azman, Junil Adri.
Data curation: Azmil Azman, Wakhinuddin.
Formal analysis: Arwizet, Junil Adri.
Research: Azmil Azman, Wakhinuddin, Arwizet, Junil Adri.
Methodology: Azmil Azman, Wakhinuddin.
Project management: Azmil Azman.
Resources: Arwizet, Junil Adri.
Software: Azmil Azman, Junil Adri.
Validation: Azmil Azman, Wakhinuddin, Arwizet, Junil Adri.
Display: Azmil Azman.
Drafting - original draft: Azmil Azman, Junil Adri.
Writing - proofreading and editing: Junil Adri.