Enhancing Vocational Students' Creativity via Virtual Project Based Automotive Paint Mixing in Teacher Professional Education Program (PPG) Partner School

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ABSTRACT

Vocational education in Indonesia faces significant challenges in providing practical learning that is safe, contextual, and aligned with the demands of Industry 4.0. In automotive bodywork painting, vocational students often face constraints such as limited practice facilities, exposure to hazardous chemicals, and restricted opportunities for creative exploration. This study addresses those challenges by developing and implementing a Virtual Project-Based Learning (VPjBL) model at SMK PGRI 3 Malang, a partner school of the Teacher Professional Education (PPG) Program at Universitas Negeri Malang. Using a Design and Development Research (DDR) approach, the study involved three main stages: (1) development of a VPjBL model using the V-MIX AutoPaint simulation software, (2) validation by vocational education experts and industry practitioners, and (3) limited implementation at the partner school. A total of 36 students from the Automotive Body Engineering program participated. Data were collected using creativity pretests and posttests, observations, and interviews. Quantitative data were analyzed using N-Gain scores, while qualitative data were analyzed thematically. Results showed moderate improvement in all creativity dimensions.—with an average N-Gain score of 0.52. The VPjBL model enabled digital-based creative exploration, improved students' digital literacy, and fostered collaborative skills. Theoretically, these findings provide empirical evidence that integrating VR-supported and project-based learning approaches can enhance creativity, digital competence, and engagement in vocational education. Practically, the VPjBL model offers an innovative framework for schools and teachers to implement safe, interactive, and future-oriented automotive learning aligned with Industry 4.0 and electric vehicle technology development.

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1. Introduction

The increasingly rapid development of automotive technology demands vocational learning that is adaptive, contextual, and integrated with industry needs (Inthachot et al., 2013). One of the essential competencies in the automotive body field is vehicle painting, which requires high creativity, technical precision, and the ability to explore colors and designs that meet industry aesthetic standards (Dias-Oliveira et al., 2024). However, despite the rapid advancement of automotive and digital technologies, vocational learning in this field remains largely conventional and lacks meaningful digital integration. The painting learning process in vocational high schools still relies heavily on direct demonstrations in workshops. Such traditional approaches, combined with limited access to practice facilities, time constraints, and the risk of exposure to hazardous chemicals, restrict students' opportunities for creative exploration and innovation (Alorda et al., 2011; Suryady & Zhafran, 2022).

In response to these challenges, the Virtual Project-Based Learning (VPjBL) approach has emerged as an innovative solution aligned with digital transformation and 21st-century education (Tominaga et al., 2024). VPjBL allows project-based practical learning to be conducted virtually through interactive simulation media, enabling learners to engage in problem-solving and creative experimentation in safe, controlled environments. While previous studies have widely applied VPjBL in general STEM and engineering education to enhance creativity and collaboration, its implementation in vocational contexts such as automotive body painting particularly in virtual color mixing simulations remains underexplored. Therefore, this study extends the application of VPjBL to address creativity development in automotive bodywork learning by enabling students to digitally explore color combinations, test paint compositions, and visualize painting results under varying lighting conditions and work environments (Akafuah et al., 2016; Poschauko et al., 2024; Qi et al., 2022).

The VPjBL model not only facilitates real-world problem-based learning, but also encourages student collaboration in projects that resemble industrial challenges. With the support of design software such as CAD and visual rendering, students can design vehicle body designs, determine color characters, and conduct virtual tests before real painting is carried out. This approach has been proven to increase students' creativity, confidence, and active involvement in practical learning (Nugroho, 2022; Wang et al., 2024).

In vocational education, creativity is a key indicator of graduates' work readiness. Contextual and hands-on learning environments stimulate students' creative potential more effectively (Ates & Aktamis, 2024). The VPjBL model enhances this process by integrating technology-based experimentation that is safe, flexible, and cost-effective. Through digital simulations, students can repeatedly explore color combinations and design variations without the limitations of physical materials or environmental risks (Wu et al., 2024). The incorporation of tools such as CAD design, 3D animation, and augmented reality devices further develops students' digital literacy and aligns learning with Industry 4.0 standards (Mukogawa et al., 2024; Sun et al., 2024). In schools with limited workshop facilities, VPjBL serves as a realistic alternative that fosters creativity, builds digital competence, and encourages collaboration with industry partners through authentic projects and performance-based assessments (Basilotta Gómez-Pablos et al., 2017; Musa et al., 2012). Overall, this model empowers students to design, collaborate, and take responsibility for their digital projects, effectively bridging the gap between virtual learning and real-world production.

Based on the aforementioned gaps, this study is urgently needed to introduce learning innovations that are adaptive to technological developments and aligned with the needs of the modern transportation industry. Vehicle body painting requires a high level of creativity, yet traditional instruction remains limited to manual, workshop-based practices that are often risky, costly, and inefficient. By developing the Virtual Project-Based Learning (VPjBL) model, students in skills-based education programs can digitally explore paint color combinations in a safe, flexible, and collaborative manner. This innovation not only enhances learners' creativity and digital literacy but also addresses the limitations of existing facilities at PPG UM partner schools while strengthening the relevance of learning to industry practices. Therefore, this study aims to design and implement a Virtual Project-Based Car Paint Mixing model to foster creative competence, improve learning effectiveness, and bridge the gap between classroom instruction and real-world industrial demands.

2. Method

This study employs the Design and Development Research (DDR) approach as proposed by Richey and Klein (2007), which emphasizes the systematic process of designing and evaluating educational products. This approach was chosen to systematically design, validate, and evaluate the effectiveness of the developed Virtual Project-Based Learning (VPjBL) model for digital car paint mixing, ensuring that the model is pedagogically sound, technologically feasible, and relevant to vocational education needs.

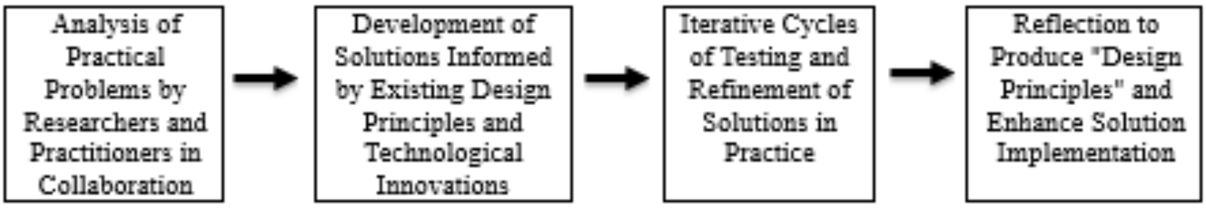

Figure 1. Methods and Design

Stages of the Design and Development Research (DDR) Process

To ensure systematic development and validation of the Virtual Project-Based Learning (VPjBL) model for car paint mixing, this study follows the stages of Design and Development Research (DDR) as adapted from Richey and Klein (2007). The process is structured into four stages, as summarized below.

Table 1. Stages of Design and Development of the Virtual Project-Based Learning (VPjBL) Model for Car Paint Mixing Based on Design and Development Research (DDR) by Richey and Klein (2007)

Stage	Purpose	Activities	Results
Stage 1: Problem Analysis	To identify and analyze real challenges in car paint mixing learning through collaboration between researchers and practitioners.	Conduct observations, interviews, and document reviews to explore the limitations of conventional practices, facilities, and creativity levels.	Comprehensive understanding of learning problems and clear formulation of development needs.
Stage 2: Solution Development	To design an initial VPjBL model based on educational design principles and relevant technological	Develop prototype learning models and digital simulation media using references from learning theories, previous research, and	Draft version of the VPjBL model and digital paint mixing simulation ready for validation.

Stage	Purpose	Activities	Results
	innovations.	industrial standards.	
Stage 3: Iterative Testing and Refinement	To evaluate and refine the model through implementation in real learning settings.	Conduct limited trials, collect feedback from teachers and students, and revise the model based on evaluation results.	Improved and contextually valid VPjBL model suitable for vocational school implementation.
Stage 4: Reflection and Design Principal Formulation	To synthesize findings and derive new design principles for future applications.	Conduct reflective analysis of the entire development process, document results, and disseminate outcomes through publications or training.	Formulated design principles and enhanced strategies for integrating VPjBL into vocational learning.

Subject: Vocational high school students in the Body Engineering and Autonomous Painting expertise program at the PPG partner school of Malang State University, namely SMK PGRI 3 Malang, totaling 36 students. This site was selected because it offers a Body Engineering and Autonomous Painting specialization with limited access to safe painting facilities, making it a representative setting for implementing technology-based learning innovations. The data collection techniques and instruments in this study were arranged based on the stages of developing a Virtual Project-Based Learning (VPjBL) learning model with a Design and Development Research (DDR) approach. At the model development stage, At the model development stage (Stage 1-2), data were collected through document reviews of the automotive body curriculum and existing learning tools to analyze planned instructional conditions. Furthermore, interviews and classroom observations involving lecturers and students were conducted to explore actual learning implementation. The graduate competency profile was also examined through literature studies, interviews with industry practitioners (*Dunia Usaha dan Dunia Industri-DUDI*), and questionnaire distribution. Instruments used at this stage included document review sheets, interview guides, and graduate competency profile questionnaires.

At the validation stage (Stage 3), two types of validation were performed. Internal validation was conducted by experts in vocational learning, fluid mechanics, and aerodynamics using expert judgment instruments to assess the content validity and conceptual soundness of the VPjBL model. Meanwhile, external validation involved program heads, implementing lecturers, and industry practitioners through Focus Group Discussion (FGD) sessions using user validation instruments to ensure practical relevance and applicability.

Finally, at the implementation and evaluation stage (Stage 4), the validated model was applied in a limited classroom setting involving teachers, lecturers, and industry practitioners. They assessed the model's effectiveness and usability through questionnaires and user assessment instruments. The data obtained from these evaluations informed the refinement of the VPjBL model and the formulation of design principles for its broader application in vocational education.

Data analysis in this study employed both qualitative and quantitative approaches to provide a comprehensive evaluation of the developed model. Qualitative analysis was used to interpret input from experts, results from Focus Group Discussions (FGDs), and findings from classroom observations. The qualitative data were thematically analyzed through coding and categorization to identify recurring patterns and themes. To ensure credibility, data triangulation was applied by comparing information obtained from interviews, observations, and document reviews. In addition, peer checking was conducted by involving fellow researchers to review data interpretation and maintain consistency across analytical procedures.

Quantitative analysis was carried out to assess the improvement in students' creativity before and after the implementation of the Virtual Project-Based Learning (VPjBL) model using the N-Gain Score test. The increase category was classified into three levels: high (N-gain ≥ 0.70), moderate (0.30 ≤ N-gain < 0.70), and low (N-gain < 0.30). The N-Gain Score was calculated using the following formula:

$$\text{N-Gain} = \frac{X2 - X1}{100 - X1}$$

Where X_1 represents the pretest score, X_2 the posttest score, and 100 the maximum attainable score. This combination of qualitative and quantitative analyses allowed for a holistic understanding of both the process and the impact of the developed VPjBL model.

Virtual Project-Based Learning (VPjBL) Syntax

The learning syntax in this study was adapted from the Project-Based Learning (PjBL) model proposed by Jalinus et al. (2017) and implemented within a virtual learning environment. The adapted VPjBL syntax consists of six interconnected phases:

1. Driving Question: The learning process begins with a guiding question — 'Why are color quality and paint finish important in the automotive industry?' — to stimulate students' curiosity and contextual understanding.
2. Project Planning: Students design color concepts and develop virtual body-painting ideas using digital simulation software.
3. Scheduling: Students collaboratively plan timelines for research, simulation, and report preparation under teacher guidance.
4. Monitoring: Teachers facilitate students' progress, provide feedback, and oversee the use of virtual color-mixing tools while students compile digital portfolios.
5. Project Evaluation: Students present their virtual painting results, followed by teacher and peer assessment based on creativity and technical accuracy.
6. Reflection: A reflection session concludes the learning cycle, allowing students and instructors to discuss outcomes, lessons learned, and potential improvements, supported by industry feedback.

3. Research Findings

This study aimed to develop and implement a Virtual Project-Based Learning (VPjBL) model on car paint mixing materials to enhance students' creativity. The model was applied at SMK PGRI 3 Malang, a partner school of the Teacher Professional Education (PPG) Program at Universitas Negeri Malang, involving 36 students from the Automotive Body Engineering program.

After the VPjBL implementation using the V-MIX AutoPaint software, the results showed a significant improvement in students' creativity across multiple indicators. The N-Gain analysis revealed an average score of 0.52, indicating a moderate increase in creativity performance. Students demonstrated greater fluency and originality in generating color design ideas, as well as improved flexibility in combining color schemes and visual effects. Observational data also indicated that students became more confident in experimenting digitally and more engaged in collaborative discussions. These findings highlight that the VPjBL model effectively enhanced creative thinking skills while overcoming the limitations of conventional workshop-based learning.

Measurement of student creativity was conducted using an instrument that had been validated by three experts in vocational education and instructional design. The instrument measured four key dimensions of creativity fluency, flexibility, originality, and elaboration. The expert validation process produced an average score of 3.85 out of 4.00, indicating a "very valid" category. Furthermore, the reliability test using Cronbach's Alpha yielded a coefficient of 0.87, confirming that the instrument was highly reliable and consistent. The results of the pretest and posttest were analyzed using the N-Gain score test to determine the effectiveness of the VPjBL model in enhancing students' creativity.

Quantitative Results: Increasing Student Creativity

After the implementation of the Virtual Project-Based Learning (VPjBL) model, students' creativity levels were re-evaluated to determine the extent of improvement. Table 1 presents the comparison of pretest and posttest scores across all creativity indicators.

Tabel 2. Pretest and Posttest Scores of Student Creativity

No	Creativity Indicator	Pretest Average	Posttest Mean	N-Gain	Category
1	Fluency	61.2	78.3	0.44	Currently
2	Flexibility	59.7	80.5	0.52	Currently
3	Originality	56.9	79.1	0.51	Currently
4	Elaboration	58.4	84.7	0.63	Currently
	Average Total	**59.05**	**80.65**	**0.52**	**Currently**

The implementation of the Virtual Project-Based Learning (VPjBL) model on car paint mixing materials led to a statistically significant improvement in students' creativity. A paired sample *t*-test revealed a significant difference between the pretest ($M = 59.05$, $SD = 7.8$) and posttest ($M = 80.65$, $SD = 6.9$) scores, $t(35) = 9.84$, $p < .001$. The calculated effect size (Cohen's $d = 1.63$) indicates a large impact, confirming that the VPjBL model substantially enhanced creative performance.

The most notable improvements were observed in the elaboration and flexibility dimensions, suggesting that virtual project-based learning encourages students to refine ideas and explore diverse solutions more effectively. Qualitative observation data also showed increased student engagement, confidence, and willingness to experiment with color variations in a risk-free digital environment. The V-MIX AutoPaint simulation successfully provided an authentic yet safe space for creativity, bridging the technical and aesthetic demands of automotive bodywork painting while addressing the limitations of traditional workshop-based practice.

The results of data analysis showed a consistent increase in all creativity indicators after the implementation of the Virtual Project-Based Learning (VPjBL) model using V-MIX AutoPaint software. As presented in Table 1, the average pretest score of students' creativity was 59.05, which increased to 80.65 in the posttest, with an overall N-Gain score of 0.52 categorized as moderate improvement. Among the four creativity dimensions, elaboration showed the highest improvement (N-Gain = 0.63), followed by flexibility (0.52), originality (0.51), and fluency (0.44).

To further validate this improvement, a paired-sample t-test was conducted, showing a statistically significant difference between pretest and posttest scores ($t = 5.47$, $p < 0.05$). These results confirm that the VPjBL model had a significant positive impact on enhancing students' creativity. The digital simulation-based learning environment provided by V-MIX AutoPaint allowed students to explore color mixing processes safely and flexibly, bridging both the technical and aesthetic competencies required in automotive body design. This finding demonstrates that integrating virtual project-based learning into vocational education can effectively stimulate creative thinking and problem-solving skills relevant to industry practice.

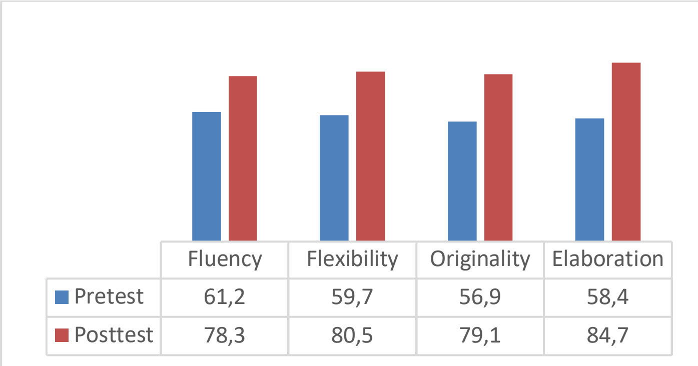

Figure 2. Diagram of Pretest and Posttest Results

The results of the study revealed that all aspects of student creativity namely fluency, flexibility, originality, and elaboration showed improvement within the moderate category. The consistent average N-gain score indicates that the VPjBL model effectively fosters students' creative thinking processes by engaging them in authentic, problem-based virtual projects. This moderate improvement reflects a meaningful pedagogical outcome, as students demonstrated greater ability to generate diverse ideas, adapt to new design challenges, and elaborate on color composition strategies. Furthermore, these findings are consistent with Akafuah et al. (2016), who reported that the use of simulation software in automotive painting enhances not only the efficiency and safety of the learning process but also the precision and creativity of painting outcomes.

Figure 3. Application usage image

One of the key advantages of the VPjBL model is that it provides a risk-free environment for exploratory learning. In conventional practice, mixing car paint is costly, potentially hazardous, and limits students' opportunities to learn from trial and error. In this regard, simulation technology allows students to experiment safely, fostering deeper learning and enhancing visual and technical skills (Wu et al., 2024). Similarly, immersive simulation-based experiences have been shown to improve concept comprehension and long-term knowledge retention (Freina & Ott, 2015).

Moreover, project-based approaches such as VPjBL engage not only technical skills but also affective and social dimensions of learning. Observations and student interviews indicated that collaborative activities in designing color schemes and presenting results fostered a sense of responsibility, project ownership, and increased self-confidence. For instance, students reported that working together on virtual color simulations encouraged them to take initiative and experiment without fear of mistakes. These findings align with Meschut, Janzen, and Olfermann (2014), who highlighted that granting students full responsibility for projects enhances participation and intrinsic motivation, and with Basilotta Gómez-Pablos et al. (2017), who found that project-based learning combined with digital media significantly increases students' emotional engagement.

4. Discussion

Enhancement of digital skills is also a key outcome of the VPjBL model. During the digital paint mixing simulation, students not only learned to mix colors but also applied basic principles of color theory, utilized design tools, and presented visualizations of their results. Observed improvements in creativity measured quantitatively using pretest and posttest N-Gain scores showed moderate increases across all dimensions: fluency (0.44), flexibility (0.52), originality (0.51), and elaboration (0.63), with an overall average N-Gain of 0.52. These results indicate that VPjBL effectively supports students' technical and cognitive skills, while also providing potential growth in digital literacy. These findings are consistent with Poschauko et al. (2024), who reported that simulation-based vocational learning strengthens both digital competencies and technical skills, and that modularized content with interactive simulations is effective for conveying engineering concepts to students from diverse backgrounds.

Furthermore, VPjBL provides a practical solution to the limited practice facilities in many vocational schools in Indonesia. Many schools lack complete painting laboratories due to budget constraints, limited space, and high operational costs. By using a simulation-based approach, VPjBL allows students to engage in practical learning efficiently and safely without compromising learning quality. Evidence from previous studies supports this approach: Qi et al. (2022) found that real-world problem-based learning supported by digital media can effectively replace limited practice facilities while maintaining learning outcomes. Similarly, Iskandar et al. (2023) demonstrated that technology-enhanced PjBL in engineering education increased conceptual understanding, learning motivation, and student creativity. This is further reinforced by Wibawanto et al. (2022), who reported that interactive visual simulations can improve practical learning outcomes up to twice compared to conventional methods. In the present study, the implementation of VPjBL at SMK PGRI 3 Malang involving 36 students of the Automotive Body Engineering program showed a moderate increase in all creativity dimensions, with an average N-gain score of 0.52 across fluency, flexibility, originality, and elaboration. Interviews with teachers further confirmed that VPjBL enabled students to explore color mixing safely, practice repeatedly without wasting materials, and collaborate effectively, despite the school's limited workshop facilities.

From an instructional design perspective, the VPjBL model aligns with the 4C/ID framework, which has been applied in VR-based vehicle painting training (Tate, 2024). Observations and student performance data indicate that the use of VR simulation supports the acquisition of complex technical skills, including spray angle accuracy, color composition balance, and eye-hand coordination. Additionally, feedback from instructors confirmed that students were able to practice these skills in a safe and controlled environment, overcoming the limitations of conventional workshops and providing practical, hands-on experience that mirrors real industry conditions.

In the context of learning theory, the VPjBL model integrates the Design-Based Learning (DBL) approach (Anderson, 2017), allowing students to learn not only from content but also through designing, revising, and evaluating their work, thereby fostering deep reflective learning. This aligns with findings by Mutohhari et al. (2021), who reported that integrating engineering and design approaches (STEM–EDP) in vocational education significantly enhances students' complex skills. Furthermore, the use of simulation software in digital automotive learning provides concrete and contextual experiences, improving the quality of interactions between students and content (Puradimaja, 2023). Wahyudi et al. (2023) also demonstrated that online project-based learning in automotive creative production subjects significantly increases student creativity and productivity.

VPjBL also facilitates meaningful collaboration between educational institutions and industry. In this study, the digital designs and virtual project outputs were validated by industry practitioners through Focus Group Discussions (FGDs) and assessment questionnaires, ensuring that the learning products met professional standards. This collaboration provides added value beyond what conventional learning methods can offer. Beccaria et al. (2019) emphasized that industry involvement in project-based vocational learning accelerates curriculum alignment with workforce needs. In the context of car painting simulations, students gained practical experience that closely mirrors professional design processes used in established automotive companies, bridging the gap between vocational education and real-world industry practices.

Furthermore, the flexibility offered by VPjBL is particularly valuable in the context of post-pandemic education. Students can continue their exploration outside the classroom using personal computers or laptops, fostering self-directed learning that supports lifelong education. This flexibility not only enhances learning in automotive body painting but also suggests that VPjBL can be adapted to other vocational subjects, such as electronics, welding, or mechatronics, to extend its usefulness and impact. As Tominaga et al. (2024) emphasize, future engineering education will increasingly rely on modular, flexible, and digital-based learning models, making approaches like VPjBL highly relevant for modern vocational training.

No less important is the role of teachers in the successful implementation of VPjBL. Theoretically, the success of automotive simulation learning media depends on teachers' readiness to adopt technology and facilitate digital learning processes (Munawar et al., 2022). Therefore, teacher training and the development of digital competencies at the school level are crucial to ensure the sustainability and effectiveness of this learning model.

In the development of similar learning technologies, Xiong (2022) demonstrated that multi-layer architecture-based simulation software in automotive education particularly VR engine disassembly can be applied efficiently in technical training. This finding supports the technical feasibility and scalability of V-MIX AutoPaint as a simulation system specifically for car paint mixing, directly aligning with the objectives of the VPjBL model developed in this study.

In conclusion, the implementation of the VPjBL model using V-MIX AutoPaint significantly improved students' creativity across all measured dimensions, with moderate gains in fluency, flexibility, originality, and elaboration (average N-Gain = 0.52). This study demonstrates that digital simulation-based project learning provides a safe, flexible, and contextually relevant platform for technical and aesthetic skill development in automotive body painting. Practically, the model offers a scalable approach that can be adopted by vocational schools to enhance creative learning while overcoming limitations of conventional workshops. Future research can explore the integration of additional industry-based scenarios, advanced VR features, and quantitative assessment of digital literacy to further validate and extend the model's effectiveness.

5. Conclusion

Based on the findings, it can be concluded that the Virtual Project-Based Learning (VPjBL) model for digital car paint mixing, developed based on digitally integrated PjBL principles, effectively enhances students' creative thinking skills. Students showed improvement across all four dimensions of creativity fluency, flexibility, originality, and elaboration with an average N-Gain score of 0.52, categorized as moderate. The model provides a safe and flexible environment for digital exploration, fosters collaborative project work, and strengthens students' digital literacy. Its implementation at SMK PGRI 3 Malang demonstrates that VPjBL can overcome the limitations of conventional practice facilities and offers a scalable, innovative alternative for technology-based vocational learning. Future research can explore further applications across other vocational subjects, integration with advanced VR tools, and the assessment of long-term impacts on students' creativity and digital competence.

6. Acknowledgments

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7. Conflict of Interest

The authors declare that they have no competing interests or financial relationships that could have influenced the outcome of this research.

8. Author Contributions

Dani Irawan contributed to the conceptual design of the study, led the development of the VPjBL model, and coordinated the overall research process and manuscript preparation. Citra Kurniawan conducted the literature review, assisted in model implementation, and contributed to data collection and analysis. Erwin Komara Mindarta provided expertise in vocational education, supported the development of learning materials, and contributed to the interpretation of findings. Syarif Suhartadi facilitated collaboration with the partner school, assisted with technical validation, and provided feedback on the final revision of the manuscript. All authors read and approved the final version of the manuscript.

9. Data Availability Statement

The authors state that the data supporting the findings of this study will be made available by the corresponding author, [dani.irawan.ft@um.ac.id], upon reasonable request.

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