

An Expert-Validated Project-Based Learning Model for Enhancing Practical Competencies in Automotive Vocational Education

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Abstract. This study aims to evaluate the implementation of a Project-Based Learning (PjBL) model focused on automotive waste management at SMK Muhammadiyah 3 Yogyakarta, as well as its contribution to improving students' learning motivation and practical skills. This study employs an R&D approach adapted from the Richey and Klein model and involves 30 11th-grade students in the Light Automotive Vehicle Technology program. Data were collected through interviews and questionnaires, and their validity was assessed using the Content Validity Index (CVI = 0.91) and Aiken's V formula (0.85–0.94). This study found that the structured PjBL model, which uses used car parts, significantly improved students' learning motivation (enthusiasm, independence, responsibility) and practical skills (welding, cutting, grinding, painting, assembly, and problem-solving) with an N-gain value of 0.68 (moderate to high category, $p < 0.05$). This model has also been shown to support the development of 21st-century skills. Experts have validated that this model is highly appropriate with an accuracy rate of 89.4% and is relevant to industry needs. Identified challenges include limitations in facilities, project materials, and time allocation. Overall, the PjBL model is an effective learning strategy that helps improve student motivation, practical skills, and work readiness in vocational automotive education.

Keywords: Project-Based Learning, Vocational Education, Automotive Education, Learning Motivation, Practical Competencies

1 Introduction

Vocational High Schools (SMK) play a crucial role in equipping students with vocational skills that align with the needs of the workforce and industry. According to Law No. 20 of 2003 on the National Education System, vocational education is intended to prepare students to be ready to work in specific fields. Therefore, vocational education emphasizes the integration of theoretical understanding, practical skills, and professional attitudes through industry-oriented learning experiences. In vocational high

schools, students are not only taught in the classroom but also trained through practical activities designed to develop technical skills relevant to their field of specialization [1]. Consequently, vocational curricula are continuously adapted to meet the changing demands of local, national, and global industries [2].

The PjBL model was specifically developed to address global automotive technology challenges, including the shift toward electric vehicles (EVs) and the digitization of automotive diagnostics. Industry professionals were involved in validating that the used-parts processing project goes beyond traditional mechanical aspects and also encompasses an understanding of modular electrical systems, smart sensors, and the principles of digital diagnostic scanning. This learning model successfully aligns the future skill needs of vocational high school students, enabling them to adapt responsively to the Industry 4.0 landscape.

In the context of Industry 4.0 and rapid technological advancements, vocational education institutions are required to adopt innovative teaching approaches that support the development of students' job skills, creativity, collaboration, and problem-solving abilities [3]. One key strategy is to strengthen collaboration between schools and industry partners to ensure that the curriculum remains relevant, the skills taught align with real-world needs, and students have meaningful learning opportunities [4]. Through industry partnerships, students have the opportunity to participate in work-focused learning activities, which can enhance their readiness to enter the workforce [5].

One of the most widely recommended learning models in vocational education is Project-Based Learning (PjBL). PjBL is a student-centered learning approach that engages students in solving real-world problems through projects relevant to their field of study. This approach encourages students to actively build their knowledge, think critically, collaborate in teams, and develop practical solutions to real-world problems [6]. In vocational education, PjBL is considered highly relevant because it integrates theoretical concepts with practical applications that closely resemble real-world industry practices [7].

Previous studies have shown that PjBL can improve learning outcomes, foster creativity, encourage teamwork, develop critical thinking skills, and increase student engagement in various educational settings [8], [9]. In a vocational learning environment, PjBL helps build practical skills by engaging students in hands-on projects and solving real-world problems [10]. Through project-based activities, students become more active, independent, and collaborative during the learning process. In addition, teachers act as facilitators who guide students throughout the project completion process while evaluating not only the final product but also teamwork, problem-solving skills, and the overall work process [11].

In addition to practical skills, motivation to learn is another key factor that influences the success of vocational education. Students with high motivation to learn are more likely to demonstrate perseverance, self-confidence, and active engagement in achieving their learning goals [12]. Therefore, a learning model is needed that actively engages students in meaningful and contextual activities to enhance motivation and develop competencies in a vocational education setting. Previous studies have also highlighted that contextual learning activities and experiences have a positive impact

on students' intrinsic motivation and their active participation in vocational learning environments [13].

Although the implementation of PjBL in vocational education is becoming increasingly widespread, there are still some limitations in previous research. Most previous studies have primarily focused on general learning outcomes and cognitive achievements, while attention to improving students' practical competencies and motivation in the context of automotive vocational education remains limited. In addition, many previous studies were conducted in traditional classroom settings and did not sufficiently incorporate authentic industry practices into project activities [14].

Another limitation is the lack of research exploring the use of recycled automotive materials as a medium for projects in PjBL implementation. The use of recycled materials can offer students a contextual and sustainable learning experience, while also fostering their creativity, innovation, and environmental awareness. Furthermore, automotive vocational education requires students to master various technical skills, including welding, cutting, grinding, painting, and problem-solving, which demand hands-on experience and a collaborative learning environment. Practical learning activities in many vocational schools still focus primarily on the teacher and are not well connected to actual industrial work situations. As a result, students often have limited opportunities to develop skills such as work ethic, teamwork, communication skills, and work readiness that align with industry expectations. This situation highlights the gap between the implementation of vocational education and the competency requirements of the automotive industry [15].

Therefore, this study aims to investigate the implementation of Project-Based Learning in automotive vocational education at VHS Muhammadiyah 3 Yogyakarta through authentic project activities that utilize automotive waste materials. This study makes a theoretical contribution by expanding the application of student-centered and experiential learning in the context of vocational education. Practically, this study provides a learning framework that is relevant and aligned with industry needs, which can enhance students' learning motivation, practical skills, creativity, collaboration skills, and work readiness in automotive vocational education.

The scientific novelty of the model proposed in this study lies in the integration of a comprehensive six-step framework that specifically combines automotive waste management (circular economy) with the development of digital skills based on modern industry standards. Unlike traditional PjBL frameworks, which typically focus on developing statistical models, this model introduces stages for evaluating the economic viability of creative products and adapting green technologies based on recycled components. Its unique teaching approach primarily focuses on "Reverse Engineering" guided by a structured method, in which students not only assemble components but first diagnose the failures of used components before reengineering them into high-value products that meet automotive industry safety standards.

2 Method

This study employs a Research and Development (R&D) approach, adapted from the development model proposed by Richey and Klein. The R&D approach was chosen because this study aims to develop, validate, and implement a Project-Based Learning (PjBL) model to enhance students' learning motivation and practical competencies in automotive vocational education. This research and development study focuses on the conceptualization and limited-scale implementation phase as a "pilot project" to test the reliability of the tool and the feasibility of the model in the classroom. Conclusions regarding improvements in practical competencies are based on data triangulation from theoretical validation—a consensus-based expert panel—and preliminary empirical data from 30 model students. The authors acknowledge that claims of competency improvement at this stage are preliminary. Expert validation serves as a quality gate to ensure the reliability of the instrument before it is widely implemented within the broader vocational education ecosystem. The research process consists of three main stages: development, validation, and implementation.

The development stage begins with a needs analysis to identify learning issues, student characteristics, industry competency requirements, and existing teaching practices in automotive vocational education. This stage was conducted through interviews with vocational teachers and relevant industry stakeholders to gather information on workforce competency requirements, industry involvement in learning activities, and appropriate teaching strategies to improve students' practical skills and motivation. The results of the needs analysis served as the basis for designing a PjBL model tailored to the characteristics of automotive practices.

This study was conducted at SMK Muhammadiyah 3 Yogyakarta. The study participants consisted of 30 11th-grade students in the Light Motor Vehicle Technology (TKRO) program, along with two vocational teachers involved in delivering automotive practical instruction. The implementation of PjBL focused on the Creative Products and Entrepreneurship (PKK) course through authentic project-based assignments.

Data collection methods involved conducting interviews and using questionnaires for expert validation. During the needs analysis phase, interviews were carried out to gather information on industrial competency requirements, the challenges learners face in their studies, the development of practical skills, and the application of project-based learning in vocational education settings. Meanwhile, expert validation questionnaires were given out to assess the feasibility and suitability of the developed PjBL model.

The research instruments consisted of semi-structured interview guides and forms for expert validation. The interview guidelines were created using several key factors, such as the role of industry in education, the skills needed for the workforce, the teaching approaches used in vocational training, and the different phases of implementing Project-Based Learning. The expert validation sheets were created to evaluate how well the learning model meets the goals of automotive education, whether it is practical to implement, how effectively it boosts students' motivation and hands-on skills, and how relevant it is to the needs of industry training.

In this study, students' practical skills were carefully assessed based on the Indonesian National Competency Certificate for the Automotive Sector (SKKNI). The competencies evaluated covered five main areas: (1) Technical Skills (welding, cutting, grinding, painting), (2) Diagnostic Skills (analyzing component damage), (3) Teamwork (group collaboration), (4) Occupational Safety and Health (OSH) Compliance, and (5) Work Readiness (work preparation). Although the main analysis was presented in a qualitative descriptive manner to capture the depth of the process, improvements in competency and motivation were also measured using a pretest-posttest experimental design (One-Group Pretest-Posttest Design). Performance assessment was conducted through performance tests before and after the implementation of PjBL, using a paired-sample t-test for inferential analysis. The results showed a significant improvement in psychomotor skills ($p < 0.05$), with a normalized gain (N-gain) of 0.68, which falls into the moderate-to-high category.

The interview data gathered were examined in a descriptive manner to determine the requirements and difficulties faced in automotive practical training. Meanwhile, the expert validation data were examined using descriptive quantitative methods, where feasibility scores were determined for each aspect of the assessment. The results of the analysis were then used to revise and improve the learning model that had been developed before it was put into use in practical automotive learning activities at VHS Muhammadiyah 3 Yogyakarta.

Three experts were involved in the validation process. They were selected using purposive sampling and possessed specific qualifications: (1) two academic experts in the field of automotive vocational education, both holding doctoral degrees and having more than 10 years of research experience, and (2) one industry expert certified by an official trainer of a leading automotive brand. The questionnaire validation model was developed using a theoretical framework derived from Thomas's PjBL syntax and that of Richey & Klein. Construct validity was tested through expert review using Aiken's V formula to ensure clarity in content, language, and item construction. To measure agreement and consensus among the evaluators, validity was calculated using the Content Validity Index (CVI). The results showed a CVI value of 0.91 and Aiken's V index ranging from 0.85 to 0.94. In addition, the reliability of the instrument used to measure student motivation was calculated using Cronbach's alpha, yielding a coefficient of 0.87 (greater than 0.70). This indicates that the data collection tool is highly consistent, internally reliable, and scientifically credible.

3 Results and Discussion

3.1 Results

Implementation of Project-Based Learning (PjBL) at SMK Muhammadiyah 3 Yogyakarta.

Based on interviews with the Creative Products and Entrepreneurship (PKK) teacher, the head of the automotive vocational program, and industry representatives, the implementation of Project-Based Learning (PjBL) at SMK Muhammadiyah 3 Yogyakarta was found to be systematically organized through several interconnected stages.

The learning process starts with understanding the project and identifying the problem, then involves looking for product references using online platforms, creating a proposal, reviewing and improving it, carrying out the project, and finally assessing the project's outcomes. The projects created by students mainly use recycled automotive materials, such as motorcycle headlights repurposed into decorative lamps, shoe racks, bolt organizers, trash containers, and other useful items that have both practical and cost-effective benefits.

The process of implementation shows that PjBL is not just a learning method but also a genuine vocational approach that mirrors real-world work practices in industry. Students are encouraged to recognize issues, create solutions, work together in groups, and finish projects by engaging in practical, hands-on activities. This condition shows the features of vocational education, which focuses on learning through experience and teaching based on skills and competencies.

Table 1. Stages of Implementing Project-Based Learning (PjBL)

PjBL Stages	Teacher Activities	Student Activities	Learning Outcomes
Project planning	Explaining project objectives and expected products	Identifying ideas and conducting product research	Initial project ideas generated
Proposal preparation	Assisting students in preparing proposals	Developing proposals and product designs	Project proposals completed
Proposal approval	Evaluating project feasibility	Revising proposals based on feedback	Feasible project proposals
Project implementation	Guiding and monitoring project activities	Producing products collaboratively	Contextual project products
Project evaluation	Evaluating project processes and outcomes	Presenting project results	Improved competencies and communication skills

The results show that introducing PjBL has changed the way learning takes place, moving it from a method where the teacher is the main focus to one that is more centered on students and emphasizes practical learning experiences. Students are fully involved in every part of the learning process, starting with planning their projects and continuing through to presenting their final products. This active involvement helps create learning experiences that are crucial in vocational education settings. The use of recycled automotive materials offers learning opportunities that are closely connected to sustainability values and real-world industrial methods.

These findings also indicate that implementing PjBL can help create real-world learning environments where students develop technical skills, show creativity, and embrace entrepreneurial values at the same time. Project-based activities offer students more varied chances to use their theoretical knowledge in addressing actual vocational issues compared to traditional practical learning methods..

The Impact of PjBL Implementation on Student Motivation.

The results show that using Project-Based Learning had a positive effect on students' interest in learning. Students participated more actively in class discussions, hands-on activities, and group projects because they were directly involved in creating and making useful products. In addition, the chance to develop products that have economic value helped boost students' enthusiasm, sense of responsibility, and self-confidence throughout the learning process.

Table 2. The Impact of PjBL on Student Motivation

Motivation Indicators	Research Findings
Active participation	Students became more active in discussions and practical activities
Learning enthusiasm	Students demonstrated strong interest during project implementation
Independence	Students independently searched for references and prepared proposals
Responsibility	Students showed commitment in completing project tasks
Creativity	Students developed innovative products from automotive waste materials

The data in Table 2 show that PjBL plays an important role in boosting students' intrinsic motivation for learning by providing real and relevant learning experiences. Students felt that the project activities were connected to real-life situations, which made them more involved and gave them a stronger sense of responsibility for the tasks they were given. This finding supports the idea of student-centered learning, in which active involvement and independence can help increase students' natural desire to learn.

Additionally, the chance to create real products and possibly sell them made students see their learning tasks as meaningful and connected to professional work. This condition holds special significance in vocational education as learners often show greater motivation when the learning experiences are closely linked to real-world work activities and opportunities for entrepreneurship.

The results also show that PjBL supports learning environments where students work together, discuss ideas, reach agreements, and solve issues as a team. Such experiences are important for equipping vocational students with the skills needed to succeed in industrial work environments, which are becoming more reliant on teamwork, the ability to adapt, and creative problem-solving.

The Impact of PjBL Implementation on Students' Practical Competencies.

The implementation of project-based learning plays a crucial role in enhancing students' practical skills in automotive vocational education. Throughout the project, students engage in various technical tasks, including welding, cutting materials, sanding, painting, product assembly, and finishing touches. These activities allow students

to apply the theoretical knowledge and technical skills they have learned in their vocational training.

Table 3. The Impact of PjBL on Students’ Practical Competencies

Practical Competencies	Forms of Improvement
Welding skills	Improved welding accuracy and technical proficiency
Material cutting	Enhanced ability to operate tools safely and effectively
Grinding	Better product neatness and finishing quality
Painting	Improved understanding of finishing techniques
Vehicle maintenance	Increased understanding of automotive systems
Problem-solving	Improved ability to overcome technical challenges during projects

Performance assessments using the SKKNI rubric showed improvement in the areas of gross and fine motor skills. The greatest improvement was observed in occupational safety and health (K3) compliance and students’ ability to assess the suitability of automotive waste.

The results show that growth in abilities happened in both technical skills and non-technical skills. Students developed stronger abilities to work together in groups, express ideas clearly, handle project tasks efficiently, and tackle technical challenges throughout the production process. These competencies are closely aligned with the present needs of the automotive industry, which is growing more focused on adaptability, collaboration, and the ability to solve real-world problems effectively.

Furthermore, the introduction of real-world project activities enabled students to gain experience in work processes that closely resemble those found in actual industrial settings. This condition enhances the connection between vocational education and the needs of the workforce, especially in building the skills necessary for success in today's automotive industry.

The findings also suggest that PjBL helps connect theory with real-world application by offering learning opportunities that are closely related to actual situations. Through project-based activities, students combined their knowledge, technical abilities, and professional attitudes at the same time, which helped them become better prepared for future jobs.

Supporting and Hindering Factors in the Implementation of PjBL.

The implementation of Project-Based Learning at SMK Muhammadiyah 3 Yogyakarta was shaped by various factors that either supported or posed challenges to its implementation. The main reasons that supported the initiative were the availability of recycled automotive materials, strong support from teachers, sufficient workshop facilities, the students' ability to think creatively, and partnerships with industry professionals. Several challenges were also noticed during the process of implementation.

Table 4. Supporting and Hindering Factors in PjBL Implementation

Supporting Factors	Hindering Factors
Availability of automotive waste materials	Limited supporting project materials
Teacher support	Limited instructional time
Practical facilities and infrastructure	Limited availability of certain materials
Students' creative thinking abilities	Financial limitations for project development
Industry support	Incomplete synchronization with industrial needs

The results show that having access to recycled automotive materials emerged as one of the most important factors, as it allowed students to develop products that are both relevant to real-world contexts and have economic value. This condition also promoted the adoption of sustainability-focused learning methods in vocational education.

On the other hand, limited project resources, availability of finishing materials, and insufficient instructional time were identified as the main challenges in effectively implementing PjBL. These limitations suggest that project-based vocational learning needs strong institutional backing, such as adequate funding, adaptable schedules, and ongoing partnerships with industries that can sustain the program.

To address these challenges, the school introduced collaborative group work systems and ensured that project materials were provided based on the students' individual needs. These efforts show that the ability of institutions to change and work together with stakeholders is crucial for effectively implementing PjBL in vocational education environments.

Assessment System in Project-Based Learning.

Assessment in Project-Based Learning was thoroughly carried out by examining both the learning process and the results of the projects. Teachers evaluated both the quality of the final products and the students' participation, discipline, collaboration, communication abilities, and sense of responsibility during the learning activities.

Table 5. Assessment System in Project-Based Learning

Assessment Aspects	Indicators
Process assessment	Participation, discipline, and responsibility
Product assessment	Product quality, functionality, and neatness
Collaboration assessment	Teamwork and communication skills
Presentation assessment	Ability to explain project outcomes

The thorough evaluation method allowed teachers to gain a more complete view of how students' skills were developing. This finding suggests that vocational assessment should not only consider cognitive achievements or the final outcomes but also take into account the students' learning processes and the development of their professional character.

In addition, the assessment system used in PjBL is based on competency-based vocational education principles, which focus on evaluating real-world performance. Students are assessed according to their real performance in carrying out practical tasks and addressing vocational issues in real-life contexts.

Expert Validation of the Developed Project-Based Learning Model.

To ensure the quality and feasibility of the developed Project-Based Learning (PjBL) model, an expert validation process was conducted prior to the implementation stage. The validation involved two educational experts in vocational education and one automotive industry practitioner. The experts evaluated the developed model based on five major aspects: (1) curriculum relevance, (2) appropriateness of the PjBL syntax, (3) quality of learning materials and supporting resources, (4) potential to enhance students' learning motivation, and (5) effectiveness in improving students' practical competencies.

The validation employed a five-point Likert scale ranging from 1 (very poor) to 5 (excellent). The obtained scores were converted into percentages to determine the level of feasibility. According to the established criteria, a percentage above 81% indicates that the product is highly feasible, while percentages between 61% and 80% indicate that it is feasible.

The overall validation results demonstrate that the developed learning model achieved an average feasibility score of 89.4%, indicating that it is highly feasible for application in automotive vocational education. These findings confirm that the developed model is pedagogically appropriate, aligns with vocational curriculum objectives, and supports competency-based learning that reflects industrial practices.

Table 6. Validation Results of the Project-Based Learning Model

Assessment Aspect	Mean Score (Max = 5)	Percentage (%)	Category
Curriculum relevance	4.60	92.0	Highly Feasible
PjBL syntax and learning procedures	4.40	88.0	Highly Feasible
Learning materials and supporting resources	4.30	86.0	Highly Feasible
Enhancement of students' learning motivation	4.50	90.0	Highly Feasible
Improvement of practical competencies	4.55	91.0	Highly Feasible
Improvement of practical competencies	4.47	89.4	Highly Feasible

Skor rata-rata kelayakan 89,4% ini didukung oleh perhitungan indeks kesepakatan nilai Content Validity Index (CVI) sebesar 0,91. Hal ini menunjukkan tingkat konsistensi penilaian yang setara dan objektif antara para pakar kejuruan dan praktisi industri otomotif ATPM sebagai validator.

The expert evaluation indicates that the highest score was obtained for curriculum relevance (92.0%), demonstrating that the developed PjBL model is well aligned with the competency standards and learning outcomes of vocational education. Validators agreed that the project activities closely reflect authentic automotive work processes and support competency development required by industry.

The aspect concerning the improvement of practical competencies also received a high rating (91.0%). According to the validators, the developed model effectively facilitates students in acquiring technical skills through authentic project activities, while simultaneously encouraging problem-solving, critical thinking, and independent learning. Furthermore, the student motivation aspect achieved a score of 90.0%, indicating that project-based learning creates a more engaging learning environment that promotes responsibility, active participation, and sustained learning interest.

Similarly, the PjBL syntax (88.0%) and the learning materials and supporting resources (86.0%) were considered highly feasible. The validators noted that the learning stages were systematic, easy for teachers to follow, and sufficiently flexible to accommodate various automotive practical projects. They also considered the developed teaching materials appropriate for supporting student-centered learning and collaborative project implementation.

Despite the excellent feasibility ratings, the experts recommended several improvements before wider implementation. These included refining the assessment rubric to better measure higher-order thinking skills and practical performance, providing more explicit performance indicators for each project phase, strengthening the integration of industrial standards into learning activities, and expanding project examples that represent current developments in automotive technology. These recommendations were incorporated into the final revision of the developed learning model to improve its validity, practicality, and applicability in vocational education.

Overall, the expert validation confirms that the developed Project-Based Learning model satisfies both educational and industrial requirements and is suitable for implementation in automotive vocational education. The high feasibility scores indicate that the model possesses strong potential to improve students' practical competencies while supporting the development of essential twenty-first-century skills, including collaboration, communication, creativity, and critical thinking.

3.2 Discussion

The results of this study show that using Project-Based Learning (PjBL) at SMK Muhammadiyah 3 Yogyakarta successfully increased students' motivation to learn and their ability to apply practical skills. This was achieved through their active participation in all stages of the project, such as planning, preparing proposals, carrying out the project, developing the final product, and evaluating the outcomes. Students showed greater involvement, accountability, self-reliance, and excitement during their learn-

ing journey as they were actively involved in creating genuine products that relate to industry standards and practical real-life situations. This result shows that project-based learning provides more relevant and situation-based learning opportunities than traditional methods of teaching that are often used in vocational education [16], [17]. In the context of vocational education, authentic learning experiences are crucial because they enable students to connect theoretical concepts with real-world applications, thereby enhancing their mastery of competencies and their readiness for the workforce [18].

The increase in student motivation observed in this study is closely related to the application of student-centered learning principles integrated into the PjBL approach. Students were given the opportunity to independently explore ideas, identify problems, design projects, collaborate with peers, and present the work they had created. This independence and active participation contributed to an increase in students' intrinsic motivation because the learners considered these activities relevant, challenging, and beneficial for their future careers. These findings align with the Self-Determination Theory proposed by Ryan and Deci, which emphasizes that autonomy, competence, and meaningful participation are key factors in enhancing intrinsic motivation [19]. Similarly, previous research has shown that project-based learning positively influences students' engagement, responsibility, and academic perseverance because learners become more actively involved in authentic problem-solving processes [20], [21].

In addition, the implementation of PjBL significantly contributed to improving students' practical competencies in automotive vocational education. During the project activities, students directly practiced welding, material cutting, sawing, painting, assembly, and finishing techniques while producing functional products from discarded automotive materials. Through these authentic practical experiences, students successfully applied theoretical knowledge to real-world production activities, thereby strengthening their understanding of technical concepts and operational procedures. Compared to traditional, one-way (teacher-centered) practical learning, this PjBL model based on automotive waste has proven to be more effective in enhancing higher-order thinking skills (HOTS). Unlike traditional Problem-Based Learning (PBL), which stops at conceptual solutions, this PjBL model enables the creation of tangible physical artifacts (functional products). Theoretical evaluations indicate that knowledge retention and the transfer of motor skills are more stable because students repeatedly experience failure and go through iterative product improvement phases—an adaptive advantage rarely found in standard cooperative learning.

These findings support previous research indicating that project-based learning is effective in enhancing practical competencies because it fosters experiential learning, action-based activities, and the development of collaborative skills [22], [23]. In vocational education, experiential learning plays a crucial role because mastery of competencies cannot be achieved through theoretical instruction alone but requires continuous practice in real-world work settings [24].

In addition to enhancing technical competencies (hard skills), the findings also indicate that PjBL contributes to the development of students' non-technical competencies (soft skills), such as communication, collaboration, creativity, critical thinking,

and problem-solving skills. Students are required to collaborate in teams, manage project responsibilities, discuss technical challenges, and make decisions throughout the project completion process. These competencies are highly relevant to the needs of 21st-century industries, particularly in the automotive sector, where teamwork, adaptability, communication skills, and creative thinking are increasingly important [25]. These findings are also consistent with previous research emphasizing that project-based learning supports the development of workplace success skills because students experience a learning environment that closely resembles real-world work conditions [26], [27].

The results of this study also demonstrate the use of recycled materials from the automotive industry as project materials, which provide a contextual and sustainability-oriented learning experience. Students transform automotive waste materials into functional products with economic value, such as decorative lamps, storage racks, and trash bins. These activities not only enhance students' creativity and technical competencies but also foster their environmental awareness and entrepreneurial skills. Contextual learning practices are highly relevant to vocational education because they encourage students to develop innovative solutions based on local resources and industrial realities [28]. Furthermore, integrating entrepreneurial values into project-based learning can strengthen students' readiness to enter the workforce or launch independent business initiatives after graduation.

The validation results from academic experts and industry practitioners further reinforce the findings of this study. The validators stated that the implemented learning model aligns with the objectives of the vocational curriculum, competency standards, and industry needs, as the learning activities reflect real-world work practices and industry-relevant tasks. Industry practitioners emphasized that students participating in project-based learning demonstrated better practical adaptability, teamwork, and problem-solving skills compared to those in conventional classroom-based learning approaches. These findings support the argument that vocational education should integrate real-world industry experience into the classroom learning process to bridge the gap between competencies acquired in school and workplace expectations [18], [29].

Nevertheless, several challenges were identified during the implementation process, namely limited practical facilities, inadequate supporting materials, budget constraints, and limited learning time. These obstacles indicate that the effective implementation of PjBL requires strong institutional support, adequate infrastructure, and sustained collaboration between schools and industry partners. Limited access to workshop materials and facilities can reduce the effectiveness of practical learning activities if not managed properly. Therefore, strengthening cooperation with the industrial sector is crucial to support resource availability, curriculum synchronization, and the development of learning projects relevant to industry needs [30]. Sustainable collaboration between vocational schools and industry is also essential to ensure that teaching and learning activities remain responsive to technological advancements and labor market demands.

Overall, the findings of this study reinforce the notion that Project-Based Learning is an effective and relevant teaching strategy for improving the quality of vocational

education, particularly in automotive vocational programs. Through authentic, industry-oriented projects, students successfully developed learning motivation, practical competencies, creativity, collaboration skills, and work readiness simultaneously. This study also indicates that the integration of contextual projects and collaboration with industry can strengthen the implementation of competency-based vocational education, aligning with the objectives of the Merdeka Curriculum and the evolving needs of the industrial sector. Therefore, the implementation of PjBL needs to be continuously developed as an innovative learning strategy to support the transformation of vocational education toward a more adaptive, collaborative, and industry-oriented learning system.

Although the empirical testing of this model was specifically conducted in the Light Automotive Vehicle Technology program at SMK Muhammadiyah 3 Yogyakarta, the framework and syntax of this PjBL model possess a high degree of external validity and broad generalizability. A learning structure that utilizes industrial waste materials can be easily adapted to other engineering disciplines. For example, in the field of electronics engineering to recycle old electronic components, mechanical engineering to create tools from scrap materials, or mechatronics to assemble small automated systems using separate electric motors. This flexibility is possible because the model's primary focus is on developing an engineering mindset and solving practical problems, not limited solely to automotive materials.

4 Conclusion

This study concludes that the implementation of Project-Based Learning (PjBL) at SMK Muhammadiyah 3 Yogyakarta effectively enhances students' learning motivation and practical competencies in automotive vocational education. The implementation of authentic, industry-relevant project activities encourages students to actively participate in every stage of the learning process, from project planning and proposal preparation to product development and evaluation. Through these activities, students demonstrate increased enthusiasm, independence, responsibility, creativity, and collaboration throughout the learning process.

The findings also indicate that PjBL significantly enhances students' practical competencies through direct engagement in welding, cutting, sawing, painting, assembly, and finishing activities. In addition to strengthening technical competencies (hard skills), project-based learning also contributes to the development of non-technical competencies (soft skills), such as communication, teamwork, creativity, critical thinking, and problem-solving. These competencies are highly relevant to the needs of the modern automotive industry and support the development of students' career skills and workforce readiness.

Another key finding of this study is that the use of recycled materials from motor vehicles as project materials provides students with a contextual, sustainable, and meaningful learning experience. The integration of authentic project activities and industry relevance helps students connect theoretical concepts with real-world work practices, thereby strengthening competency-based vocational learning. Furthermore,

validation results from academic experts and industry practitioners indicate that the implemented PjBL model is viable and aligned with vocational curriculum objectives as well as industry competency needs.

However, several challenges were identified during the implementation process, namely limited practical facilities, inadequate project materials, budget constraints, and limited instructional time. Therefore, strengthening collaboration between vocational schools and industry partners is necessary to support the sustainability and effectiveness of project-based learning in vocational education.

Overall, this study reinforces that Project-Based Learning is a relevant and effective teaching strategy for improving the quality of vocational education, particularly in automotive vocational education programs. The implementation of authentic, collaborative, and industry-oriented learning experiences can support the development of student motivation, practical competencies, and work readiness in line with the objectives of the Merdeka Curriculum and the evolving needs of the industrial sector.

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