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Differentiated Problem Based Learning Elevates Vocational Student Collaboration Skills

Pembelajaran Berbasis Masalah Berdiferensiasi Meningkatkan Kolaborasi Siswa Vokasi

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General Background Collaboration skills are essential competencies in contemporary education, particularly within problem-based and interactive learning environments. **Specific Background** Problem-Based Learning integrated with deep learning and differentiated approaches has been proposed to support meaningful engagement and teamwork among vocational students. **Knowledge Gap** However, empirical evidence on how differentiated PBL combined with deep learning systematically strengthens collaboration skills in formal vocational education remains limited. **Aims** This study aims to examine the application of differentiated PBL with deep learning to strengthen students' collaboration skills through iterative classroom action cycles. **Results** The findings show a progressive increase in collaboration skills from 30.22% in the first cycle to 87.21% in the third cycle, accompanied by improved teaching quality from 46% to 87%, indicating a strong positive relationship between instructional quality and collaborative performance. **Novelty** The study introduces the integration of differentiation across material, process, and product within PBL and combines qualitative and quantitative observations in a vocational classroom context. **Implications** These results highlight the importance of adaptive instructional design, learning style mapping, and structured group interaction to foster inclusive, collaborative learning aligned with 21st-century competencies.

Highlights
- **Progressive cycles demonstrate substantial growth in cooperative performance indicators**
- **Adaptive grouping and varied learning products support inclusive participation dynamics**
- **Instructional quality aligns consistently with improved teamwork engagement**

Keywords
Collaboration Skills; Problem Based Learning; Differentiated Learning; Deep Learning; Vocational Education

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INTRODUCTION

In the era of globalization and the Industrial Revolution 4.0, collaboration skills are a key competency required by workers across various industrial sectors (Oktoviani et al., 2024). Collaborative skills support more effective student collaboration processes. Collaborative skills can also enhance problem-solving abilities. Based on these benefits, students need to be prepared and developed from an early age, one way being through the educational process. Collaborative skills development can be achieved through learning strategies that combine active student interaction, group-based problem-solving training, and in-depth cognitive exploration (Özdeniz et al., 2023). In education, the term deep learning approach is currently known, which is one solution that can strengthen collaborative skills through attentive, meaningful, and enjoyable learning (Wijaya et al., 2025).

Deep learning allows students to understand concepts theoretically and apply them in real-world contexts through teamwork (Fajari, 2020). PBL models with a differentiated approach are increasingly relevant in supporting experiential learning and social interaction, where students are given the freedom to explore solutions to real-world problems in heterogeneous groups (Chrzan-Rodak et al., 2022). Deep learning is a pedagogical approach that emphasizes cognitive depth, conceptual understanding, critical reflection, and the application of knowledge in real-world contexts (Wijaya et al., 2025). This approach differs from the understanding of deep learning in the realm of artificial intelligence. Deep learning is indirectly measured through five indicators of collaboration skills: idea contribution, time management, problem-solving, teamwork, and investigative techniques.

However, challenges remain in implementing a differentiated PBL approach, particularly to support deep learning at various levels of education. Previous research shows that many schools still employ teacher-centered methods, which limit student engagement in collaborative and problem-based activities (Hastuti et al., 2024). Teacher readiness in managing deep learning-based learning is also a critical issue, where a lack of understanding of innovative strategies leads to instructional learning that does not facilitate teamwork. Furthermore, infrastructure and integration of digital technology to support collaboration and PBL are still limited, particularly in educational settings with limited access to technology (Siemens, 2005).

Several previous studies have examined collaborative learning, personalized learning, and technology integration to enhance learning effectiveness. These include research on the risks of negative collaboration in digital learning environments and the proposal of mitigation strategies to enhance the effectiveness of immersive learning (Sun et al., 2025). The development of a collaborative learning environment based on an intelligent tutoring system (ITS) to enhance the effectiveness of group learning, emphasizing adaptation and personalization to enhance collaborative skills (Youssef et al., 2025). A study of personalized federative learning that can enhance student engagement in problem-based learning (Makanda et al., 2025). Previous research on the readiness of prospective teachers to integrate artificial intelligence (AI) in education highlights the importance of strengthening teachers' pedagogical competencies to adopt technology-based learning (Guan et al., 2025). Finally, there is research developing a cloud-edge collaborative learning model that utilizes cloud-based technology to support more effective team-based learning (Zhang et al., 2025).

In addition, other studies also focus on optimizing collaboration in learning. Liu et al. (2025) examined how differentiation strategies in project-based learning can improve students' collaboration and active participation in PBL-based learning. George et al. (2024) examined the process of fostering collaboration and innovation between generations in the modern workplace. From a technological infrastructure perspective, Chung et al. (2021) explored the integration of augmented reality (AR) in collaborative learning, showing that this technology can improve conceptual understanding and collaboration in problem-based learning. Table 1 shows the details of the comparison between previous research and this study.

[Table 1 about here]

Empirical Gaps and Research Contributions

From these studies, it can be concluded that collaboration-based learning supported by technology has great potential in improving 21st-century skills, including collaboration skills. However, research that specifically examines the integration of problem-based learning (PBL) with a differentiated approach to create deep learning in formal education is still very limited. Therefore, this study aims to explore how the application of Deep Learning in Problem-Based Learning with a Differentiated Approach can strengthen students' collaboration skills in the 21st century. It should be noted that the term deep learning in this study does not refer to artificial intelligence algorithms, but rather a deep learning approach that relies on conceptual understanding and reflective engagement of students (Hasanah & Pujiati, 2025). We determined the main research question "How can the integration of deep learning and differentiated learning in PBL improve the collaboration skills of vocational high school students?". The novelty of this research is the implementation of learning that applies the PBL model with a differentiation approach to create in-depth learning as an effort to improve students' collaboration skills.

We examine the comparative implementation of Inquiry Based Learning (IBL), Project Based Learning (PjBL), and Problem Based Learning (PBL) models without a differentiated approach. We found that integrating PBL with a differentiated approach and deep learning offers a more inclusive learning experience. PjBL and IBL can emphasize student exploration and self-directed learning (Austin, 2025), but these models often fail to systematically accommodate diverse learning profiles.

PBL without differentiation can neglect students' cognitive readiness and learning styles (Dalila et al., 2022); as a result, gaps in participation and learning outcomes occur in group work. This research combines the depth of reflection provided by immersive learning with differentiated product design and adaptive grouping strategies. This model allows students to contribute meaningfully according to their own abilities. This research does not create a new model, but rather evaluates how the use of PBL and differentiated approaches can create more meaningful, reflective, and collaborative learning experiences.

This study evaluates the application of a differentiated PBL strategy in formal learning through three cycles of classroom action research (CAR). The results are expected to provide practical insights for educators in optimizing PBL to support in-depth learning and enhance students' collaborative skills. Theoretically, this study contributes to the development of a differentiated PBL model to support deep learning and collaboration skills. Practically, this study emphasizes the importance of mapping students' learning styles and cognitive levels to design inclusive group assignments. Based on the theoretical framework, this study hypothesizes that the higher the quality of differentiated PBL implementation by teachers, the higher the collaboration skills demonstrated by vocational students. This study also formulates several research questions to be answered, namely:

(i) How is the implementation of PBL combined with a deep learning approach and differentiation in the dimensions of material, process, and product in the 11th grade RPL class at SMKN 13 Bandung?
(ii) How do students' collaboration skills change after implementing PBL with a deep learning approach and differentiation through three CAR cycles?

What is the relationship between the quality of PBL implementation by teachers and the improvement of students' collaboration skills during three learning cycles?.

METHODS

This study uses a three-cycle Classroom Action Research (CAR) method that aims to evaluate the application of deep learning in problem-based learning with a differentiated approach in database learning to improve students' collaboration skills. Methodologically, this study is novel in integrating differentiated learning across CAR cycles and combining qualitative and quantitative observations in a vocational school context.

The research subjects consisted of 34 students of class XI RPL 2, SMK Negeri 13 Bandung. The purposive sampling technique was used as the sample selection method. The research subjects were selected based on the recommendations of subject teachers and their suitability for the research objectives. The criteria for research subjects were classes with relatively low collaborative interaction skills during previous learning activities. The research process has gone through the school's permission stage and coordination with the class teacher, while considering the principles of ethical research, such as maintaining the confidentiality of the subjects' identities.

The roles in this study involve teachers as learning facilitators, students as active participants, and observers as recorders of the development of the implementation of learning strategies. The research stages consist of planning, implementation, observation, and reflection. Figure 1 shows the stages of research that have been carried out and the action plan that will be carried out in the proposed period.

[Figure 1 about here]

The research was conducted on February 26, March 12, and April 09, 2025. Each cycle in this study was carried out in one meeting with a duration of 5 x 45 minutes. Before the learning began, an observer assessment rubric was prepared, which was used to assess the implementation of learning and the effectiveness of interaction in groups. There were two types of assessments used in this study, namely teacher observers, who assessed the implementation of deep learning based on problem-based learning (PBL) with a differentiated approach, carried out three times as much as the research time (see Table 2) and student collaboration ability observers, who observed the level of involvement and effectiveness of cooperation in groups, carried out three times as much as the research time (see Table 3).

The observation instrument was reviewed prior to implementation (see Table 2). The review process was conducted to ensure that the observation instrument aligned with the research objectives and assessment indicators. Validation of the observation instrument was determined through the alignment between the rubric indicators, learning objectives, and the conceptual framework of collaboration skills.

[Table 2 about here]

[Table 3 about here]

Stages of the Learning Cycle

Pre-Cycle

We conducted a pre-cycle process before the CAR cycle processes were implemented. In the pre-cycle phase, an initial analysis of the conventional learning conditions implemented by the teacher was conducted. Data on student engagement levels, interaction patterns between students within groups, and initial understanding of database concepts were collected at this stage. Observations made at this stage aimed to identify learning gaps and intervention needs for the learning cycle. A diagnostic assessment was also conducted at this stage to gauge initial understanding of the database material. We also conducted a survey regarding student learning styles and interest in learning methods during the pre-cycle phase.

Cycle 1

The first cycle was implemented on February 26, 2025 by implementing PBL without differentiation in Single Row

Subquery Multilevel SQL learning. Students were given exploratory challenges without the help of media or teaching materials from the teacher, so they had to find solutions independently in groups. The teacher prepared teaching materials such as teaching modules/RPP, LKPD, and teaching media, and compiled a problem-based learning scenario without differentiation. Observers recorded student engagement, learning effectiveness, and challenges that emerged. The evaluation results were used to assess the effectiveness of this method and became the basis for improvements in the next cycle. The assessment was carried out using the digital platform Quizizz and Google Form to support deep learning and measure students' understanding of SQL concepts.

Cycle 2

The second cycle was conducted on March 12, 2025. The second cycle was an improvement on the reflection of the first cycle with the material of Multiple Row Subquery Multilevel SQL. The teacher prepared teaching materials and designed problem-solving-based assignments with product variations according to students' learning styles. Students worked in heterogeneous groups to complete a multilevel SQL case study with product differentiation. Observers recorded student engagement, effectiveness of collaboration, and increased understanding of concepts. We conducted an evaluation to measure the effectiveness of this method in supporting in-depth learning and collaboration skills. Quizizz and Google Forms were used for the assessment phase, as in the first cycle.

Cycle 3

The second cycle was implemented on April 9, 2025. The third cycle was a refinement of learning in the second cycle. Students completed LKPD with an exploration-based approach. The material presented in the third cycle was JOIN Table. Observers noted the effectiveness of the new grouping in increasing student engagement and cooperation. Reflection was carried out to analyze the impact of implementing deep learning in PBL with differentiation on improving collaboration skills. The assessment continued to use Quizizz and Google Form to measure the development of student understanding.

Data Analysis

Questionnaire analysis was carried out using Likert Scale calculations with the following formula.

$$percentage = \frac{Total\ Scores\ Obtained}{maximum\ score} \times 100\%$$

The percentage values are classified into several categories, namely good, sufficient, lacking, and very lacking as shown in Table 4.

[Table 4 about here]

This study examines the relationship between the quality of PBL-based learning implementation by teachers and the development of students' collaboration skills during three cycles with Pearson correlation analysis through the Bivariate Correlation menu in SPSS. This analysis is used to measure the strength and direction of the linear relationship between two numeric variables, namely the average student collaboration ability and the average score of teacher learning suitability in implementing PBL in each cycle.

Although this study employed a Classroom Action Research design, Pearson correlation analysis was used to identify the trend of linear association between the quality of PBL implementation by teachers and students' collaboration scores across three cycles. The use of correlation in this context aimed to explore relationship patterns rather than test causal effects.

FINDINGS AND DISCUSSION

Pre-Cycle Results

Before the implementation of classroom action, an initial assessment was conducted to map the characteristics of students including learning styles and academic ability levels. The results of learning style identification are visualized in Figure 2, which shows that most students have a kinesthetic learning style of 44.12%, followed by a visual learning style of 35.29%, and an auditory learning style of 20.59%. These findings indicate that most students tend to gain better understanding through direct practice activities, physical movements, and motor involvement.

[Figure 2 about here]

In addition to learning style mapping, classification was also carried out based on academic ability levels, as shown in Table 5. Based on the results of the previous mid-term test, 17.6% were in the lower ability category, 44.1% were in the middle category, and 38.2% were in the upper group. This composition reflects that there is a diversity of competency levels in the class, with the largest proportion in the middle group. This diversity is an important basis for designing learning strategies that will be carried out.

[Table 5 about here]

First Cycle Results

In the first cycle, learning was carried out using the Problem-Based Learning (PBL) model without the application of a differentiated approach. All students worked in groups to complete SQL-based challenges without any variation in learning media, grouping processes based on learning styles, or adjustments to their individual needs. As a result, the learning process was still uniform and less responsive to the characteristics of the students. The assessment results as shown in Table 6 show that the average student collaboration ability only reached 30.22%, which is included in the poor category. In detail, student contributions in groups were recorded at 30.15%, time management 28.49%, problem solving 31.43%, teamwork

30.70%, and investigation techniques 29.96%. These values indicate low active student participation in the group work process, weak time planning, and minimal initiative in solving problems collaboratively.

[Table 6 about here]

In terms of learning implementation, the assessment of the suitability of teacher strategies with PBL principles also showed less than optimal results, with an average of only 46%. Table 7 shows the results of the questionnaire on the suitability of learning conducted by teachers with the PBL method. Several important indicators such as orientation to problems and organizing students to learn only scored 35% and 45% respectively, indicating a lack of initial direction and minimal structure in group formation and role division. On the other hand, indicators such as development of work results (55%) and learning evaluation (60%) began to show signs of improvement. However, the low level of teacher facilitation of the student investigation process has a direct impact on the lack of development of social interaction and cooperation between group members.

[Table 7 about here]

Based on these findings, reflection on the first cycle of learning emphasizes the need for improvement through the integration of differentiated approaches in the next cycle. Teachers need to design media and learning processes that are tailored to students' learning styles and implement heterogeneous grouping with more structured roles to increase the participation of each group member. In addition, strengthening guidance on the inquiry process and providing varied learning resources will be the focus in the implementation of the second cycle. These changes are expected to create a more inclusive, participatory learning environment and support the achievement of deep learning based on collaboration.

Second Cycle Results

In the second cycle, learning was carried out using the PBL model combined with a differentiated approach. The differentiation strategy applied was material differentiation, where the teacher provided various forms of teaching media such as modules in PDF format, learning videos, and presentations in PowerPoint format. These materials were designed to align with the learning style profiles of students that had been mapped in the pre-cycle stage. In addition, student grouping was also carried out using a differentiation approach based on two dimensions: homogeneous in learning style, and heterogeneous in cognitive ability. This strategy was chosen to facilitate intra-style learning comfort while encouraging mutual support between ability levels in one group.

This approach is based on previous findings stating that grouping based on learning style can increase engagement, grouping based on learning style can increase engagement, this view is supported by Muslim et al., who emphasized that accommodating visual, auditory, and kinesthetic learning styles increases student engagement and academic performance (Muslim et al., 2018). While heterogeneity in ability encourages peer tutoring and more even knowledge transfer. Peer tutoring thrives in heterogeneous groups because differences in ability encourage students to support each other in their learning journey. This collaboration encourages critical thinking and fosters a deeper understanding of the material through dialogue and discussion (Nicholson et al., 2021). Furthermore, heterogeneous grouping not only levels the playing field for students with different abilities but also fosters a collaborative learning environment where students engage in knowledge sharing (Matazu & Isma'il, 2024). Table 8 shows the results of students' collaboration skills in cycle 2. During the learning process, students were given problem-based Student Worksheets (LKPD) to work on in groups. The assessment results showed significant improvement compared to the first cycle. The average score for collaboration skills increased to 56.40%, in the sufficient category. Each indicator also showed even development, namely contribution (58.09%), time management (54.78%), problem-solving (56.07%), teamwork (55.88%), and investigative techniques (57.17%). This improvement reflects the positive impact of aligning learning strategies with student profiles and a more focused group work structure. This is consistent with the findings of Chou et al. (2023), who emphasized that differentiated learning can increase individual cooperation and responsibility in completing problem-based tasks.

[Table 8 about here]

Meanwhile, the analysis of teacher learning practice assessments showed a significant improvement, with an average score of 76% (see Table 9). The indicator for organizing students for learning achieved a high score of 80%, while problem orientation and inquiry guidance were each in the 70–75% range. The learning analysis and evaluation indicators experienced a jump, with a score of 95%. The analysis results in the second cycle showed strengthening in the final stage of the PBL process, which was previously suboptimal in the first cycle. These results are also in line with research conducted by Özdeniz et al. (2023). Özdeniz et al. (2023) showed that differentiation in PBL-based learning can increase the effectiveness of teacher facilitation and strengthen group interactions in active learning. Overall, the findings in the second cycle indicate that the integration of PBL with a differentiation approach has begun to create a more contextual, collaborative, and directed learning experience, both in terms of student engagement and the effectiveness of teacher learning management.

[Table 9 about here]

The implementation of learning in the second cycle showed improvements compared to the previous cycle, both in terms of student involvement in group work and teacher effectiveness in facilitating the problem-based learning process. The application of a differentiated approach through grouping students based on learning styles and the provision of diverse teaching media has created a more stable and collaborative group system.

However, the results of observations showed that there were unique dynamics in group interactions based on learning styles. Students with an auditory learning style tended to be able to convey discussion results verbally but often had difficulty in maintaining focus on the main objective of the problem being discussed. In contrast, students with a kinesthetic learning style tended to be able to focus and work systematically in solving problems but were less skilled in communicating the results of their thinking to other group members. This finding indicates that although the differentiation approach has increased participation, a more specific mentoring strategy is still needed to balance roles in the group based on the strengths and weaknesses of each learning style.

Reflections on cycle 2 demonstrate the importance of selecting more than one type of differentiation. Implementing content differentiation is not sufficient; research into process and product differentiation is needed. Teachers need to design activities that allow students with various learning styles to develop optimally in terms of cognitive and communication aspects. Subsequent learning cycles can further emphasize the balance between participation and effective communication in group work to further develop students' collaborative skills.

Third Cycle Results

In the third cycle, the implementation of PBL learning with a differentiated approach experienced significant improvements compared to previous cycles. Improvements were made by applying differentiation not only to the material aspect, but also to the learning product. The products produced by different students were adjusted to their learning styles, such as auditory making podcasts based on the results of the practice carried out, visual making interactive videos/ppts, while kinesthetic making live coding videos and clippings. The assessment results showed a very significant increase in students' collaboration skills, with an average percentage reaching 87.21%, which is in the good category (see Table 10). In detail, student contributions reached 87.68%, time management 85.48%, problem solving 87.13%, teamwork 88.79%, and investigation techniques 86.95%. Consistent improvements across indicators reflect that students have been able to work effectively in groups, divide roles well, and complete tasks with high focus and responsibility.

[Table 10 about here]

In terms of the implementation of learning by teachers, the assessment results also showed optimal effectiveness with an average score of 87%, all in the good category (see Table 11). Teachers showed very good abilities in orienting students to problems (85%), organizing learning (80%), guiding the investigation process (80%), and facilitating the development and presentation of work results (95%). This success shows that teachers have been able to internalize PBL principles in learning consistently and integrate differentiated approaches systematically in every stage of learning. This improvement is in line with the findings of Karina et al. (2024) which states that personalized collaborative learning can improve group performance in solving complex problems, as well as strengthen social interaction and individual responsibility.

[Table 11 about here]

Overall, the implementation of the third cycle successfully created an inclusive, collaborative, and adaptive learning ecosystem to the diversity of student characteristics. The combination of grouping strategies, media variations, and the provision of roles that are in accordance with learning styles have been proven to be able to optimize student involvement in the learning process. This confirms that the application of deep learning in problem-based learning through a differentiated approach can shape students' collaboration skills.

Based on the results of the three cycles above, **Figure 3** shows the conclusion of the results of the three-cycle skill collaboration.

[Figure 3 about here]

The Relationship Between Collaboration Ability and Teacher Teaching Methods

Data were analyzed descriptively to examine patterns of improvement across cycles. Pearson correlations were also used to examine the relationship between the quality of learning implementation and students' collaboration skills. However, this study was limited by the relatively small number of participants and the intervention's scope of only one classroom. Therefore, the correlation results are interpreted as supporting evidence, not conclusive.

In addition, methodological limitations in this study are (1) it only involved one class in one vocational school, (2) the intervention was conducted in an authentic classroom environment, so full control over external variables was not possible. (3) Observational data may be influenced by contextual and subjective factors, although efforts have been made to improve the validity of the instrument and consistency of assessment. Despite these limitations, the CAR cycle design, repeated observations, and reflective revisions across three cycles contributed to strengthening the internal validity of the study by allowing for continuous improvement and triangulated interpretation of classroom processes.

Table 12 shows the results of the correlation calculation between the quality of PBL-based learning implementation by teachers and students' collaboration skills. The results show a Pearson correlation value of $r = 0.953$ with a significance value of $p = 0.196$, indicating a very strong positive relationship between the two variables. The correlation calculation results indicate that improvements in the quality of PBL implementation by teachers tend to be followed by improvements in students' collaboration skills. However, a significance value that exceeds the threshold of 0.05 ($p > 0.05$) indicates that the relationship is not yet statistically significant, which may be due to the very limited amount of data (n indicators = 3). This finding still has strong practical meaning in the context of classroom action research. The high positive correlation provides support that efforts to improve the quality of teacher learning, especially in implementing the PBL approach consistently and in a differentiated manner, contribute significantly to strengthening the collaborative skills of vocational students.

These findings still have strong practical significance, as they demonstrate a consistent and directional pattern of improvement between teacher teaching quality and student collaboration skill development across each learning cycle. However, the limited

number of cycles and participants directly impacted the robustness of the inferential statistical analysis used. Therefore, correlational results should be interpreted more as indicating a trend in a positive relationship. Future studies may consider increasing the number of cycles and participants or using a control group design for more robust statistical analysis.

[Table 12 about here]

This study employed the Classroom Action Research (CAR) method, where the novelty of the methodology lies in the systematic application of differentiation in the dimensions of material, process, and product based on Problem-Based Learning, which has not been widely reported in previous PBL studies. Thus, this study provides conceptual and empirical added value in understanding how differentiated learning strategies can strengthen in-depth collaborative learning in a sustainable manner.

This study has several limitations, including the relatively short implementation time between cycles, which limited the time available for in-depth reflection, strategy adjustments, and reinforcement between cycles. Furthermore, the study only involved one class, making the findings difficult to generalize widely. This study also focused solely on developing collaboration skills as an indicator of 21st-century skills. Therefore, further research is recommended to involve a larger sample and explore its impact on other 21st-century skills. The integration of differentiation, PBL, and immersive learning approaches still has significant potential for development in improving student competency in the digital era.

CONCLUSIONS

Results

The results of this study indicate that the application of problem-based learning (PBL) combined with a differentiated approach through classroom action research can significantly improve the collaboration skills of vocational students. In the first cycle, learning was conducted without differentiation, indicating that student collaboration was at a low level. In the second and third cycles, which integrated differentiated materials, processes, and products, the results showed an increase in participation, social interaction, and teamwork effectiveness. These findings confirm that integrating the use of PBL with a differentiated approach for in-depth learning through adaptation to students' learning styles and cognitive levels is an effective strategy for cultivating 21st-century collaborative competencies in vocational education. The progressive improvement in teacher facilitation also illustrates the importance of the educator's role in designing an adaptive and inclusive learning environment that encourages reflection and inquiry.

Theoretical Contributions

This study contributes theoretically to the development of a differentiated learning model within a PBL framework by providing empirical evidence of its effectiveness in enhancing student collaboration. However, the Pearson correlation analysis between teacher implementation quality and collaboration skills yielded insignificant results, likely due to the limited number of observation cycles. Therefore, future research is recommended to include more cycles or additional sub-indicators to increase statistical robustness and further explore the impact of differentiated PBL on other 21st-century skills such as communication and creativity.

Practical Implications

This research practically demonstrates that vocational educators must design learning not only for academic achievement but also to foster collaborative competencies through contextual, structured, and differentiated strategies. Identifying and mapping students' learning profiles early on, as well as implementing various roles, media, and grouping formats, can strengthen engagement, problem-solving skills, and readiness for collaborative work in the ever-evolving demands of the Industry 4.0 era.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Table 1 / Gap Analysis.

Research Aspect	Previous Studies	This Study
Learning Model	PjBL with general differentiation strategies (Liu et al., 2025), intergenerational collaboration in the workplace (George et al., 2024), AR-based PBL (Chung et al., 2021)	PBL integrating differentiation and deep learning in terms of process, product, and student grouping
Differentiation Approach	Did not explicitly adjust learning products based on students' learning styles	Differentiation tailored to students' learning styles (auditory, visual, kinesthetic) and cognitive levels
Skill Focus	General collaboration and group participation (Liu et al., 2025; George et al., 2024)	Deep collaborative skills in vocational problem-based learning
Educational Context	Higher education, workplace, and technology-enhanced experiments (George et al., 2024; Chung et al., 2021)	Vocational secondary education (SMK) in Indonesia, aligned with the national vocational curriculum
Main Contribution	Has not thoroughly explored the integration of differentiation in PBL	Provides empirical evidence on the integration of differentiation in PBL to foster deep, collaborative learning

Table 2 / Assessment of the implementation of problem-based learning.

No	indicator
1	1. The teacher explains real problems that are relevant to student competencies
	2. The teacher provides stimulus through media or case studies
	3. The teacher encourages students to identify information needed to solve the problem
	4. The teacher facilitates initial discussions to understand the problem
	5. The teacher provides initial direction regarding problem-solving strategies
2	6. The teacher forms study groups according to project needs
	7. The teacher provides instructions regarding roles and tasks in the group
	8. The teacher provides guidance and learning resources for independent exploration
	9. The teacher helps students design problem-solving steps
	10. The teacher gives students the opportunity to develop group work strategies
3	11. The teacher guides students in collecting information from various sources
	12. The teacher guides students in analyzing and processing the data obtained
	13. The teacher provides challenges and critical questions to deepen understanding
	14. The teacher ensures that students can connect information with the problems faced
	15. The teacher provides support for students who experience difficulties in the investigation process
4	16. The teacher guides students in developing solutions based on the results of the investigation
	17. The teacher facilitates students in designing products or solution presentations
	18. The teacher ensures that students can present their work systematically
	19. The teacher provides opportunities for students to practice before presentation
	20. Teachers guide students in using technology or media in presentations
5	21. Teachers provide opportunities for students to present project results
	22. Teachers facilitate Q&A and discussion sessions
	23. Teachers provide feedback on the solutions presented
	24. Teachers invite students to reflect on the learning process
	25. Teachers and students prepare follow-up plans based on project evaluations

Table 3 / Assessment of students' collaboration skills by observers.

Indicator	Response
Contribution	Does not provide ideas and does not participate in group discussions, whether large or small.
	Rarely provides ideas and participates (only once) in group discussions, either large or small.
	Frequently provides ideas and participates (twice) in group discussions, either large or small.
	Very frequently provides ideas (more than twice) that are used as references in discussions. Often leads discussions and actively contributes.
Time	Does not complete the task, causing the group to extend the time limit.
Management	Completes the task but is more than 3 minutes late, causing the group to extend the time limit.
	Completes the task but is less than or equal to 3 minutes late, without causing the group to extend the time limit.
	Completes the task on time or before the deadline, never causing the group to extend the time limit.
Problem Solving	Makes no attempt to find or provide solutions and delegates all tasks to others.
	Rarely (only once) attempts to solve the problem and uses solutions initiated by others.
	Frequently (twice) attempts to solve the problem, though the solution is based on the development of others' ideas.
	Very frequently (more than twice) makes serious efforts to find and generate their own ideas in solving problems.
Teamwork	Does not listen to others' opinions, help others, or participate in group work.
	Rarely (only once) listens to others' opinions and helps others due to difficulties in group work.
	Frequently (twice) listens to others' opinions and helps others, but does not significantly ease the group's task.
	Very frequently listens to others' opinions and helps others, making group work easier and more effective.
Investigation	Does not seek out multiple sources (relies on only one source) and does not take notes.
Techniques	Rarely seeks out multiple sources (only focuses on two sources) and takes notes, but not in detail.
	Frequently seeks out multiple sources (three sources) and always takes notes, but not in detail.
	Very frequently seeks out multiple sources (more than three) and always takes detailed notes.

Table 4 / Classification of Collaboration Ability Scores (Putri et al., 2024).

Percentage (%)	Clasification
76 - 100	Good
51 - 75	Enough
26 - 50	Less
0 - 25	Very Less

Table 5 / Student Ability Level Groups.

Group	Number of Students
Bottom	6
Middle	15
Top	13

Table 6 / Students' Collaboration Skills Results in Cycle 1.

Indicator	Percentage (%)	Category
Contribution	30.15	Not enough
Time Management	28.49	Not enough
Problem Solving	31.43	Not enough
Teamwork	30.70	Not enough
Investigation Techniques	29.96	Not enough
Average	**30.22**	**Not enough**

Table 7 / Results of Teacher Learning Suitability with PBL Method Cycle 1.

Indicator	Percentage (%)	Category
Orienting students to problems	35	Not enough
Organizing students to learn	45	Not enough
Guiding individual and group investigations	35	Not enough
Developing and presenting work results	55	Enough
Analyzing and evaluating	60	Enough
Average	**46**	Not enough

Table 8 / Students' Collaboration Skills Results in Cycle 2.

Indicator	Percentage (%)	Category
Contribution	5.09	Enough
Time Management	54.78	Enough
Problem Solving	56.07	Enough
Teamwork	55.88	Enough
Investigation Techniques	57.17	Enough
Average	**56.40**	**Enough**

Table 9 / Results of the Suitability of Teacher Learning with the PBL Method Cycle 2.

Indicator	Percentage (%)	Category
Orienting students to problems	70	Enough
Organizing students to learn	80	Good
Guiding individual and group investigations	75	Enough
Developing and presenting work results	60	Enough
Analyzing and evaluating	95	Good
Average	**76**	Enough

Table 10 / Students' Collaboration Skills Results in Cycle 3.

Indicator	Percentage (%)	Category
Contribution	87,68	Good
Time Management	85,48	Good
Problem Solving	87,13	Good
Teamwork	88,79	Good
Investigation Techniques	86,95	Good
Average	**87,21**	**Good**

Table 11 / Results of the Suitability of Teacher Learning with the PBL Method Cycle 3.

Indicator	Percentage (%)	Category
Orienting students to problems	85	Good
Organizing students to learn	80	Good
Guiding individual and group investigations	80	Good
Developing and presenting work results	95	Good
Analyzing and evaluating	95	Good
Average	**87**	**Good**

Table 12/ Correlation of the Suitability of PBL Teaching with Collaboration Ability.

		Collaboration	Learning Path
Collaboration	**Pearson Correlation**	1	0.953
	Sig. (2-tailed)		0.196
	N	3	3
Learning Path	**Pearson Correlation**	0.953	1
	Sig. (2-tailed)	0.196	
	N	3	3

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Figure 1 / Research Flow Diagram.

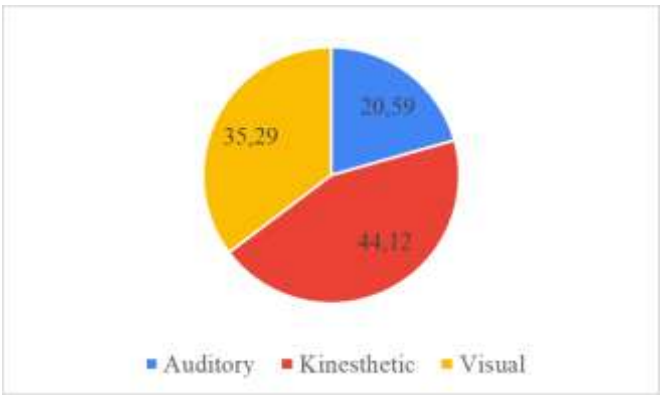

Figure 2 / Student Learning Styles.

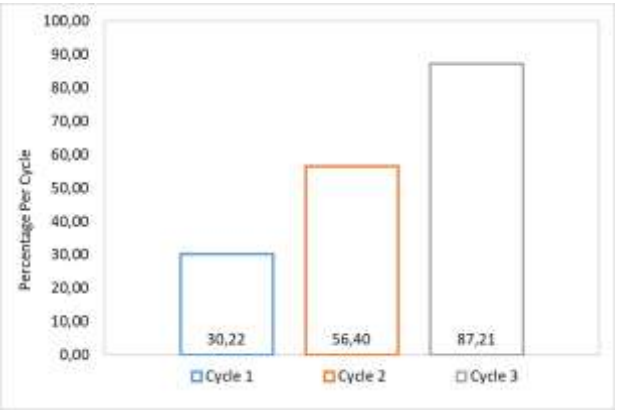

Figure 3 / Results of Improving Students' Collaboration Skills in Each Cycle.