

IMPROVING STUDENT LEARNING OUTCOMES THROUGH A PROBLEM-BASED AND DIFFERENTIATED LEARNING APPROACH IN OBJECT-ORIENTED PROGRAMMING

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ABSTRACT

The quality of education determines a nation's ability to face the Industrial Revolution 4.0 era. Learning innovation towards a new paradigm is key to addressing educational challenges in this era. This study introduces an innovative learning model that integrates Problem-Based Learning (PBL) with a differentiated learning approach to improve student learning outcomes in Object-Oriented Programming (OOP). This study employs a quantitative method with a quasi-experimental design, specifically a non-equivalent pretest–posttest control group design. The research subjects consisted of 71 10th-grade students of the Software Engineering Expertise Program at SMKN 1 Cimahi, Indonesia. The results show that students who learned using PBL with a differentiated approach achieved higher and more equitable learning outcomes than those who used only the conventional PBL model. These findings indicate that a differentiated approach can effectively optimize the benefits of problem-based learning by adapting to students' diverse learning readiness. The novelty of this study lies in the combination of the PBL model and the differentiated approach in the context of vocational education, which provides an evidence-based model to improve the equity and quality of learning in the Industrial Revolution 4.0 era. Thus, this research makes a significant contribution to the development of adaptive and inclusive learning models to improve the equality of learning outcomes and student readiness to face the challenges of the Industrial Revolution 4.0.

Keywords: student achievement, problem-based learning, differentiated approach, object-oriented programming

I. INTRODUCTION

The quality of education can determine a country's success in facing the industrial revolution 4.0. The Industrial Revolution 4.0 requires higher education to adapt to produce

graduates who are competent, creative, and able to adapt in the digital era. Based on the results of the World Population Review 2023, educational systems and resources are also one of the factors that influence the level of population intelligence (Kamsari & Winarso, 2018; He et al., 2021). Learning innovation towards a new paradigm is expected to be able to solve problems entering the era of Industrial Revolution 4.0. Innovative learning activities create a class atmosphere that is not rigid and not monotonous (Mansyur, 2016). In addition, improving the quality of the education system can be done by developing a learning environment that leads to training students' problem-solving abilities (Smak, 2015; Nurtanto et al., 2020; Manurung et al., 2023).

Improving the quality of the education system can be done by developing a learning environment that leads to training students' problem-solving abilities (Smak, 2015; Nurtanto et al., 2020; Manurung et al., 2023). Problem-solving abilities have an impact on high-level thinking abilities, increasing students' critical and creative thinking processes (Sumartini, 2016). Problem-solving abilities can also improve learning outcomes because they are related to students' confidence in solving a problem (Utami and Wutsqa, 2017). Learning outcomes are one indicator that can be used to measure increases in intelligence and quality of education (Sari et al., 2019). It can be concluded that problem-solving skills are important for students to have because they influence learning outcomes which have an impact on the level of intelligence and the quality of the education system.

One learning model that is considered suitable for use is the problem-based learning model. Problem-Based Learning (PBL) is a learning model that allows students to be directly involved in learning and authentic problem-solving (Wahyu et al., 2017). In obtaining information and developing an understanding of topics, students learn how to construct problem frames, organize and investigate problems, collect and analyze data, organize facts, construct an argument regarding problem-solving, and work individually, or collaborate in problem-solving. PBL is learning that provides problems to students so that students can carry out active learning and the teacher only acts as a facilitator (Hmelo-Silver, 2004). Problems in PBL are used to engage students in curiosity about the learning being carried out.

Currently, there has been a lot of research using the PBL model to improve student learning outcomes, including the increasing understanding of the human excretory system (Sungur et al., 2006), mathematics (Malmia et al., 2019), critical thinking abilities (Anazifa, 2016; Suradika et al., 2023), learning outcomes in science learning (Gezim & others. However, previous studies have not examined the use of PBL to improve learning outcomes in programming subjects, particularly object-oriented programming, by integrating a differentiated learning approach.

The use of a differentiated approach to the problem-based learning model is used to optimize learning outcomes. Differentiated learning is a differentiated learning strategy that attempts to adapt the learning process in the classroom to meet the learning needs of everyone. Differentiated learning can improve the academic achievement of students who were previously less active in class and develop students' independent learning skills (Setyaningrum et al., 2023). The rationale for combining the Problem-Based Learning (PBL) model with a differentiated learning approach is explained because both have complementary characteristics

in achieving optimal learning objectives. PBL focuses on developing critical thinking, creativity, and problem-solving skills through direct student engagement in authentic situations, while differentiated learning focuses on adapting learning processes, content, and products to students' diverse readiness, interests, and learning profiles. Thus, a differentiated approach can strengthen the effectiveness of PBL in helping students with different ability levels to remain actively engaged and achieve maximum learning outcomes. The integration of these two approaches is expected to not only improve average learning outcomes but also minimize declines in student achievement, thereby creating more adaptive, inclusive, and equitable learning in vocational education environments. Therefore, this research aims to improve student learning outcomes, especially in object-oriented programming material using a problem-based learning system with a differentiated learning approach. It is hoped that this research can become a reference to improve the quality of learning to prepare students to face the era of Industrial Revolution 4.0.

II. LITERATURE REVIEW

Problem-Based Learning (PBL) and differentiated learning have complementary theoretical foundations for improving learning outcomes. PBL is based on constructivism theory, which emphasizes that knowledge is built through active and reflective learning experiences (Hmelo-Silver, 2004). Meanwhile, differentiated learning is rooted in humanistic learning theory and individual needs theory (Tomlinson, 2014), which emphasize the importance of considering differences in students' abilities, interests, and readiness to learn. The integration of these two approaches is expected to create an adaptive yet challenging learning environment, thus encouraging students to construct knowledge through problem-solving relevant to their ability levels. Thus, the theoretical framework of this study confirms that the combination of PBL and differentiated learning approaches can be an effective strategy for improving learning outcomes in object-oriented programming, which is the main objective of this study.

A. Problem-Based Learning

Problem-Based Learning (PBL) is a learning model that positions students as active subjects in the teaching and learning process, particularly through direct involvement in authentic problem-solving (Nuraini, 2017; Asri, 2024; Maftuh et al., 2023). In this process, students acquire information and build understanding of a specific topic by framing the problem, organizing and investigating the problem, collecting and analyzing data, categorizing facts, and formulating solution statements. This activity can be done individually or collaboratively. PBL presents problems to students to encourage active learning, while the educator acts as a facilitator (Wulandari, 2012; Dita et al., 2021; Rafiq et al., 2023). The problems presented serve to arouse students' curiosity about the learning material and are presented before students begin studying the related material. Based on this description, it can be concluded that PBL is a learning process that begins with the presentation of a problem to deepen existing knowledge and identify new knowledge needed to solve the problem. Students are also given the freedom to choose problems they find interesting to solve, thus encouraging their active involvement in the learning process..

According to Masrinah et al. (2019), the PBL model has the following main characteristics: (i) students are trained to formulate questions or problems; (ii) learning focuses on interdisciplinary connections; (iii) learning activities are based on an authentic inquiry process; (iv) the learning process produces a product or work that is then presented; and (v) learning encourages students to work together. The implementation of PBL generally includes five stages, namely: (i) providing problem orientation to students; (ii) organizing students to solve problems; (iii) carrying out the investigation process both independently and in groups; (iv) developing and presenting the results of problem solving; and (v) conducting analysis and evaluation of the problem-solving process (Nurlailly et al., 2019; Dita et al., 2021).

B. Differentiated Learning

Carol Ann Tomlinson is a leader in the field of differentiated learning and a professor of educational leadership, foundations, and policy at the University of Virginia. Tomlinson defines differentiated instruction as one that considers students' individual learning styles and readiness levels before designing lesson plans (Tomlinson, 2014). Research on the effectiveness of differentiated learning shows that this method benefits a wide range of students, from those with learning disabilities to those considered highly capable (Tomlinson, 2014).

Differentiated learning is an educational approach that aims to balance the individual needs of students and enhance their learning and motivation (Bal, 2016; Putranti & Maksum, 2024). Adjustments made include mapping students' learning needs, including their learning readiness, interests, and learning profiles, in an effort to improve learning outcomes. Differentiated approach modifies the educational and learning process to accommodate the diverse learning needs of students (Goyibova et al., 2025). Differentiated teaching allows educators to design learning strategies that suit the diversity of students' readiness, learning profiles, and interests (Kristiawan et al., 2025). This approach recognizes that each student has different needs and abilities and provides a variety of choices regarding subject matter, learning methods, and assessment techniques. The ultimate goal is to ensure each student can optimize their potential while maintaining motivation throughout the learning process.

According to Tomlinson (2014), educators can implement differentiated learning through four main components: (1) content differentiation, (2) process differentiation, (3) product differentiation, and (4) learning environment differentiation. Adiniyah and Utomo (2023) emphasize that these four aspects are the core of the differentiated learning approach. Content differentiation focuses on the knowledge, understanding, and skills that educators target for students to learn (Tomlinson, 2014). Process differentiation refers to grouping students based on their interests, readiness, and learning style profiles so that learning activities can be tailored to individual needs. Product differentiation reflects the extent to which students understand learning objectives, expressed through various forms of performance such as presentations, essays, or articles. Meanwhile, learning environment differentiation involves adjusting personal, social, and physical aspects of the classroom to create a supportive learning environment (Tomlinson, 2014; Adiniyah & Utomo, 2023).

C. Differences between Problem-Based Learning and Differentiated Approach

PBL and differentiated learning are two learning approaches that both center on students but have different focuses and implementation strategies. PBL emphasizes a learning process that begins with the presentation of authentic problems relevant to students' lives. Students are required to identify problems, collect and analyze information, and generate solutions through individual or collaborative work. The teacher acts as a facilitator, while students actively construct knowledge through investigation, discussion, and presentation of results (Nuraini, 2017; Rahyubi, 2012; Wulandari, 2012; Masrinah et al., 2019). The primary focus of PBL is the development of critical thinking skills, problem-solving, and interdisciplinary collaboration. In contrast, differentiated learning focuses on tailoring learning to individual student needs, including readiness, interests, and learning profiles. This approach modifies content, processes, products, and learning environments to ensure all learners have optimal access to learning (Tomlinson, 2014; Bal, 2016; Kristiawan et al., 2025). The primary goal is to provide equal opportunities for each learner to reach their full potential, considering differences in learning styles, levels of mastery of the material, and learning motivation.

The fundamental difference between the two lies in the learning focus. PBL focuses learning on real-world problems as triggers for the learning process, while differentiated learning focuses on adapting teaching strategies to suit individual learners' characteristics. PBL uses problems as a starting point for building skills and knowledge, while differentiated learning uses data on students' learning needs to tailor the learning experience. Although different, these two approaches can complement each other, with PBL providing a problem-based learning framework, while differentiated learning ensures each learner receives the support, they need throughout the learning process.

D. Previous Research

Previous research has shown that integrating PBL with a differentiated learning approach has a positive impact on various aspects of student learning outcomes, including cognitive, affective, and social skills. Several studies (Afelia et al., 2024; Permata et al., 2023; Anggraini, 2023) indicate improved collaboration skills, learning interest, and learning independence through grouping students based on learning styles (visual, auditory, and kinesthetic). Similar findings were reported by Atikah et al. (2024) and Rosyid et al. (2023), where mapping learning needs based on readiness, interests, and learning profiles increased students' activity and higher-order thinking skills. Furthermore, Elvani et al. (2024) demonstrated that the combination of PBL with differentiation was more effective in improving problem-solving skills than conventional methods, while Samawati et al. (2023) and Solihah et al. (2023) emphasized its contribution to student motivation, learning outcomes, and creativity. Several other international and national studies also support the effectiveness of implementing differentiated PBL in various subjects. A study by Bikić et al. (2016) revealed that problem-based content differentiation at three levels of complexity in analytical geometry learning significantly impacted exam results. On the other hand, Huda et al. (2023) showed that implementing content differentiation in PBL in geography improved students' discussion skills. Overall, the existing literature indicates that integrating PBL and differentiated learning

can accommodate diverse learning styles, ability levels, and student interests, thus creating a more inclusive learning environment oriented toward the development of 21st-century skills.

III. METHODOLOGY

This research uses quantitative research methods with a quasi-experimental research design in the form of a nonequivalent pretest-posttest control group design. The research procedure consists of three main stages, namely problem formulation, data collection, and data analysis. Figure 1 shows the research procedures used. This research used two groups of students, namely the experimental and control groups. The control group is a group of students who are given learning treatment in the form of implementing a problem-based object-oriented programming learning system. Meanwhile, the experimental group is a group of students who are given learning treatment in the form of implementing a problem-based object-oriented programming learning system through a differentiated learning approach.

In experimental classes, procedures are given in different ways based on students' learning styles. Visual, auditory, and kinesthetic are the learning methods used. To divide students into groups, aspects of testing their initial problem-solving abilities are also considered. Students' initial problem-solving abilities were grouped into three groups: lower, middle, and upper. This group was divided heterogeneously based on their initial abilities in problem-solving and homogeneously based on the learning styles of each student.

The validity and reliability of the instruments were established in a previously published (Rahman et al., 2024). Therefore, the current study refers to those validated and reliable instruments. This instrument was validated by two experts and piloted on 35 10th-grade vocational high school students and demonstrated strong validity and reliability, with 80 out of 100 items declared valid and reliable. The CT instrument covers four domains: abstraction, pattern recognition, decomposition, and algorithm design, and demonstrates appropriate levels of difficulty and discriminatory power.

A. Problem Analysis

Field observations show that in Object-Oriented Programming (OOP) learning, many students tend to only understand the terms and concepts commonly used in OOP materials but struggle to differentiate between OOP concepts themselves and the programming languages used to implement them. This results in students becoming less familiar with the OOP concepts they have learned when the programming language they use changes and struggling to apply them to new programming languages. This phenomenon aligns with the challenges of Computational Thinking (CT) skills in Indonesia. Data from the 2022 Programme for International Student Assessment (PISA) shows that although Indonesia's ranking improved by five to six places compared to the 2018 PISA, its reading, mathematics, and science scores declined by 12–13 points, remaining below the OECD average (Ministry of Education and Culture, 2023; OECD, 2023). In 2021, the OECD also expanded the definition of mathematical literacy to include the synergistic relationship between mathematical thinking and computational thinking (Ismawati et al., 2023), where computational literacy is considered essential to support abstraction, algorithmic thinking, decomposition, and generalization (Karalar & Alpaslan, 2021).

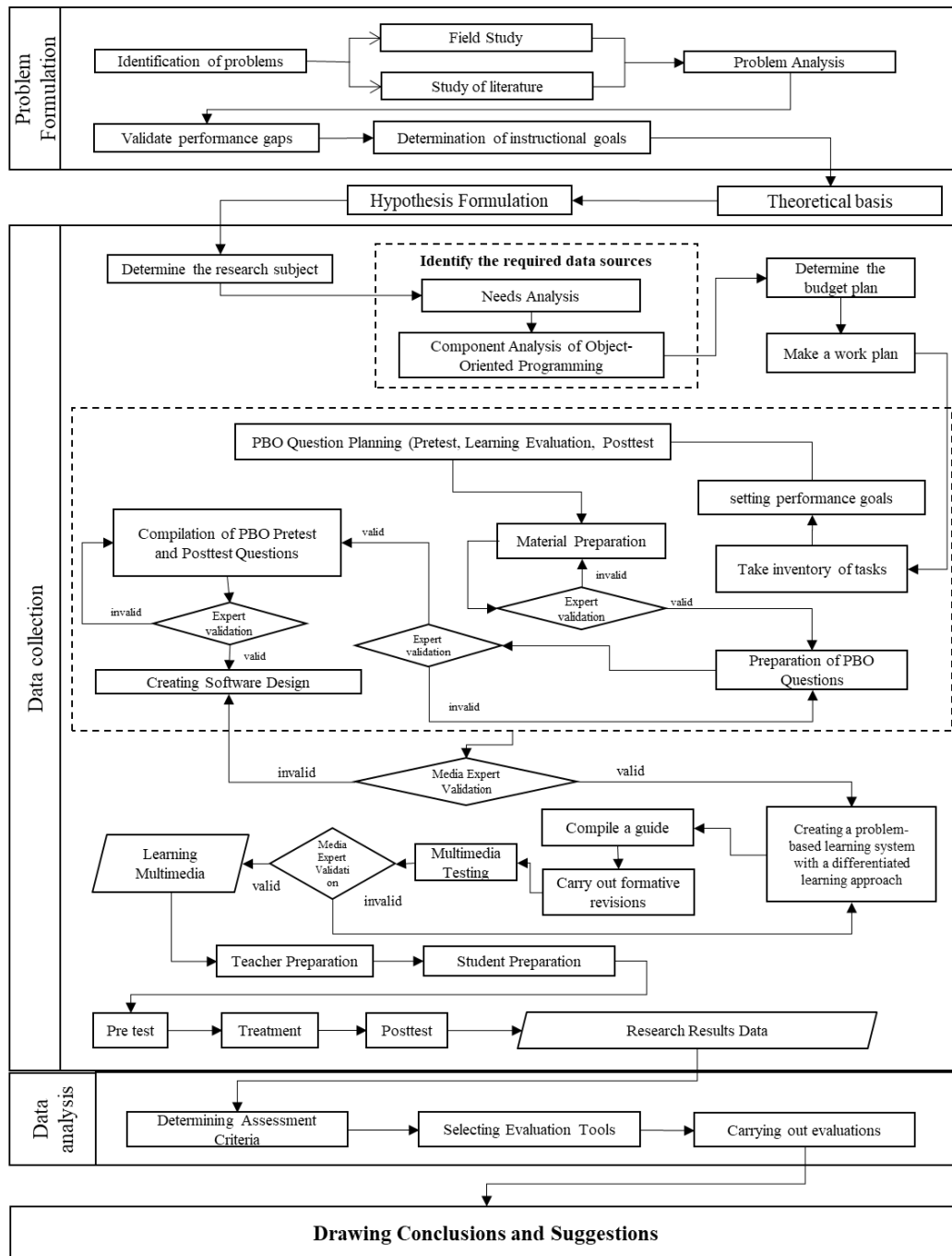


Figure 1. Research Procedure.

Indonesia has attempted to integrate computational literacy into the Independent Curriculum (2023) and the National Curriculum (2024) at all levels of education through the Informatics program. However, research shows that students' computational literacy skills at SMK Negeri 1 Cimahi remain low, with an average score of 65.43 particularly in the abstraction aspect (43.43) despite abstraction being a key skill for understanding OBE concepts across various programming languages (Al Husaeni et al., 2023). This low level of competence is further exacerbated by teacher-dominated learning practices, where teachers deliver material verbally, accompanied by examples of source code to be copied, without encouraging students to develop analytical, critical thinking, and problem-solving skills (Aldila & Mukhaiyar, 2020).

Various previous studies have shown that the PBL model can help improve CT skills by encouraging students to construct, organize, and investigate problems; collect and analyze data; compile facts; develop arguments; and solve problems individually and in groups (Reski et al., 2019; Surahman & Ulfa, 2020; Bai et al., 2021; Al Husaeni et al., 2023). However, the effectiveness of PBL is often suboptimal without strategies that address the diversity of students' learning needs. Siburian et al. (2019) and Septhiani (2022) emphasize the importance of teachers' ability to differentiate learning according to student characteristics to build confidence and independence in problem-solving. A differentiated learning approach allows teachers to accommodate students' learning styles, readiness levels, and interests, resulting in more effective learning interactions (Fauzi et al., 2023). Research by Simanjuntak et al. (2023) and Widana & Kusuma (2023) shows that grouping students based on learning styles (visual, auditory, kinesthetic) with differentiation of content, process, and product significantly improves learning outcomes compared to PBL alone.

Based on this background, this study proposes the development of a problem-based learning system with a differentiated learning approach. In this research, the problem formulation examines students' abilities to solve problems using the computational thinking (CT) approach in OOP subjects. The formulation of the problem in this research is how the use of a problem-based learning system with a differentiated learning approach affects student learning outcomes in object-oriented programming learning.

The general instructional objectives are formulated by referring to the learning outcomes of the independent curriculum used in Indonesia in the basics of software and game programming (DPLG) elements of OOP phase E at the vocational school level, namely "At the end of phase E students can carry out object-oriented programming by applying class, objects, methods, and packages, distinguishing various types of access modifiers, showing encapsulation, interfaces, inheritance, and polymorphism in simple software development projects."

B. Data Collection

The subjects of this study were 10th-grade students in the Software Engineering (RPL) Expertise Program at SMK Negeri 1 Cimahi, Indonesia. Vocational High Schools (SMK) are a form of vocational secondary education in Indonesia, equivalent to senior high school in the international education system (ISCED level 3). Vocational high schools have a three-year study period: grades 10, 11, and 12, with students generally aged 15–17. Vocational high school graduates are prepared to enter the workforce directly or continue their education to higher education.

Grade 10 was chosen because at this level, students are just entering the initial phase of their expertise program and have no prior experience studying Object-Oriented Programming (OOP). This is important to ensure that all participants have a relatively similar initial knowledge level (basic knowledge), thus minimizing bias due to differences in prior learning experiences. The inclusion criteria for this study were students who had never received formal learning about OOP, while students who had prior OOP experience or training were excluded. Two classes were selected as research samples, namely class XA with 35 students and class XB with 36 students, so that the total research subjects were 71 people. The selection of the two classes was carried out using a purposive sampling technique based on the availability of learning schedules and the suitability of student characteristics with the research objectives. Class XA was designated as the experimental class that received problem-based learning with a differentiated learning approach, while class XB became the control class that received problem-based learning without differentiation. This separation aims to facilitate the

measurement of learning outcomes and computational thinking skills between the two groups with different treatments.

The data collection process aligned with the research objective, which was to examine the effect of implementing PBL with a differentiated approach on Object-Oriented Programming (OOP) learning outcomes. This study also addressed ethical aspects by obtaining approval from the school and subject teachers, as well as verbal consent from students to participate. Student data was kept confidential and used solely for academic analysis.

C. Preparation of OOP Media and Teaching Materials

This research used the Merdeka Curriculum as the curriculum used during the research process. The preparation of OOP material is carried out by taking into account Learning Achievements (CP) in the OOP elements of DPLG phase E vocational school-level subjects found on the page <https://guru.kemdikbud.go.id/>. The OOP material prepared discusses several OOP sub-materials, namely classes, attributes, methods, objects, packages, special methods (constructor and destructor), encapsulation, and inheritance. Figure 2 shows the material module used in this research.

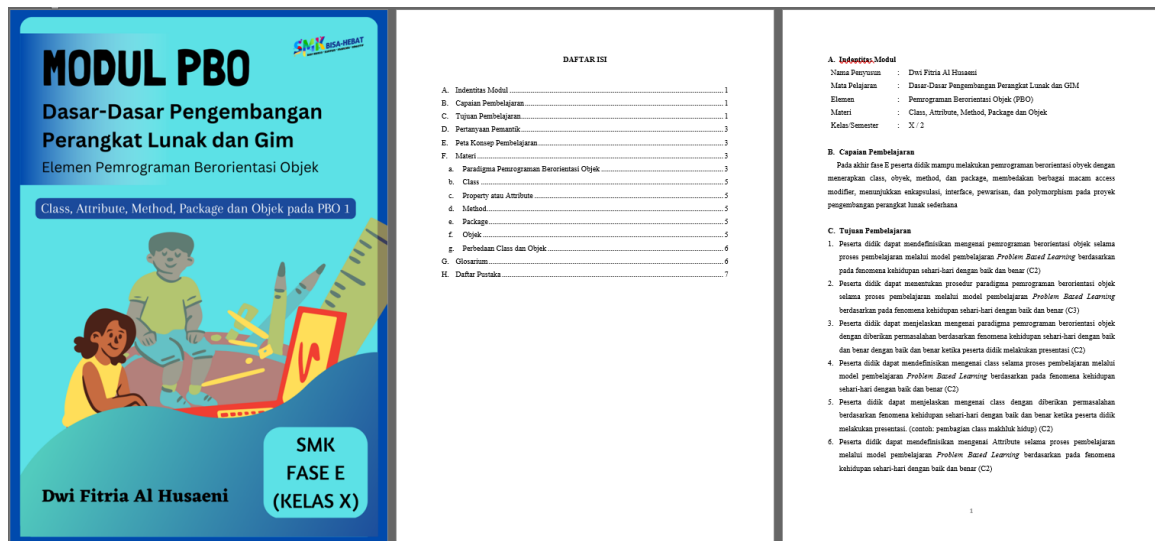


Figure 2. PDF View of Object-Oriented Programming Material.

Student Worksheets (as known as LKPD) are also prepared based on the PBL model learning steps by paying attention to the differentiated learning approach. There are four used in this research: LKPD 1 regarding classes, attributes, methods, packages, and objects in OOP, LKPD 2 regarding creating classes, attributes, methods, packages, and objects in OOP, LKPD 3 regarding special methods, and LKPD 4 regarding encapsulation and inheritance.

Figure 3 shows the LKPD display presented in the learning system. The LKPD presented in the learning system only contains steps or instructions for solving problems that must be carried out by students. Each completion step in the LKPD is adapted to the computational thinking or CT component. Meanwhile, the problems in the LKPD are presented in the form of learning media that is adapted to the learning style of the student group. This is done so that students can better understand the problems that must be resolved during the learning process by paying attention to the characteristics and asking students to learn.

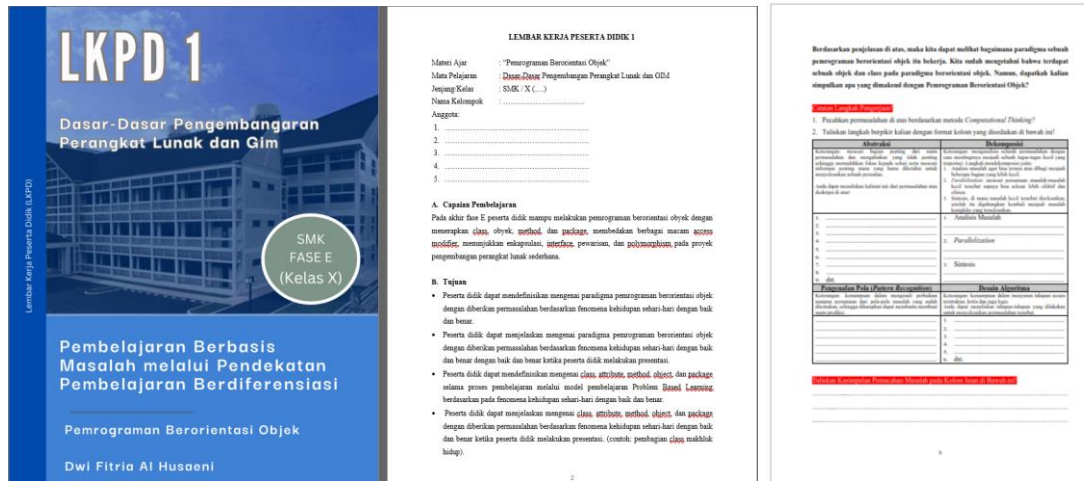


Figure 3. View of the LKPD PDF Answer Sheet.

The learning flow is designed and adapted to the PBL learning stages with a differentiated learning approach in the problem-based learning system with a differentiated learning approach. The learning system created is web-based. Figures 4a and 4b show an overview of the learning system page used in this research which presents problems based on the LKPD that has been prepared.

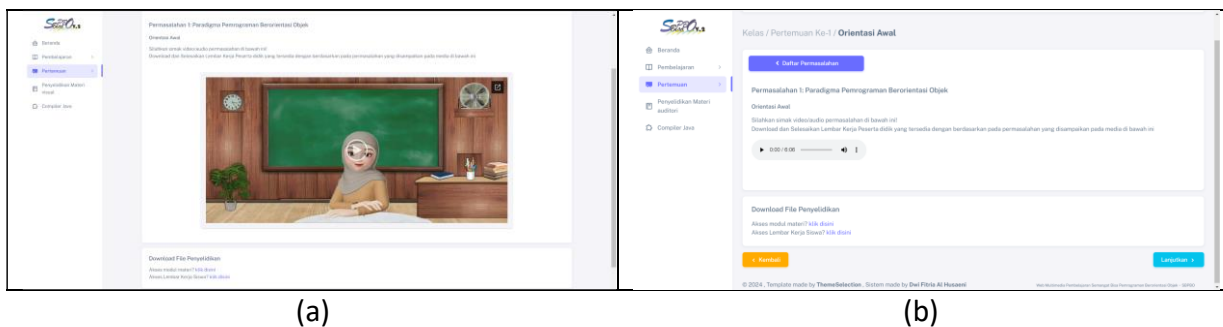


Figure 4. Problem orientation: (a) visual learning style; (b) auditory learning style.

D. Object Oriented Programming Instruments

The OOP instrument is divided into two parts, namely pretest and posttest questions. The OOP instrument used in this research was adapted from our previous research (Rahman et al., 2023). The number of OOP questions used is 80 multiple-choice questions, of which 40 are pretest and 40 posttest questions. The preparation of the OOP instrument is adjusted to the material indicators, cognitive level, and suitability of the questions to the CT components. The pretest and posttest instruments for the OOP material used in this study had a CT component composition weight of 27.5% abstraction questions, 27.5% pattern recognition questions, 22.5% decomposition questions, and 22.5% algorithm design questions. Each question item is adjusted to the desired CT component, but each problem can be changed in the context of the answer to another CT component. Examples of problem forms that use CT components to solve or answer a question used in this research are as follows:

- (i). Anita created 2 classes in the "Initial Registration" program, namely the Registration class and the Login class, in the Registration class there are attributes name, date of birth, and gender. Meanwhile, in the Login class, there are username and password attributes. Attributes in the Registration class can be accessed by the Login class, whereas attributes in the Login class can be accessed by the Registration class.
- (ii). Bayu created 3 classes in the PPDB program, namely the student class, the Parent class, and the school class. In the class, students create several attributes, namely name, gender, age, and address. Bayu determines that the attributes of the student class can be accessed by the Parent class and the school class even though these two classes are not inherited classes from the student class.

Based on the two conditions above, it can be seen that Anita and Bayu have the same pattern in determining access rights to the attribute class they will create, namely

- a. The example question above in the context of this research can be the basis for a question that can be solved with a **decomposition** component through the question "The simplified form of the problem below is appropriate regarding the problem faced by Anita and Bayu, namely....".
- b. The statement above can also be made into an **abstraction** component question in CT through questions that refer to finding true or false statements, or correcting unimportant information, such as the question "Based on the story above, choose the statement below that has the TRUEST value!"
- c. Students can solve the problem above with the **pattern recognition** component if the teacher presents questions that lead to finding similarities in the patterns of the two problems above so that a solution to the problem is found.
- d. The CT **algorithm design** component can be used in the problems above by instructing students to create programming programs or pseudocode based on the characteristics and specifications presented.

E. Process Implementation

The implementation stage is the stage for applying all learning components that have previously been prepared from the analysis to design stages to students. The learning implementation was carried out at SMK Negeri 1 Cimahi, Indonesia. The research implementation was carried out in four meetings, namely on the 6th, 13th, 16th, and 20th May 2024. Each meeting 5x45-minute sessions. The implementation phase was carried out through three main stages consisting of giving a pretest, learning actions, and giving a posttest as well as another stage, namely filling in the student response questionnaire. In this research, implementation was carried out in two different classes, namely the control class which treated learning through a problem-based learning system, and the experimental class which treated learning through a problem-based learning system with a differentiated learning approach.

Before the implementation process is implemented, we make initial preparations with teachers and students. In the teacher preparation stage, a meeting was held between the researcher and the teacher to discuss the suitability of the research with the subject at school, research class, research schedule, and time. Meanwhile, student preparation is carried out before carrying out the pretest, action, and posttest on the class used as the research sample. At the preparation stage, students are given direction regarding the implementation of research. Students are given information about how long the research will take and what will be done during the research process. This is done so that students prepare themselves and do not feel confused about the different learning methods used during the research process.

IV. RESULTS

A. Data Analysis of OOP Pretest Results

Table 1 shows the categorization of OOP pretest scores for control and experimental classes. Based on the data presented in Table 1, it is known that in the control class, there were 3 people included in the group with low initial OOP values, 25 people included in the group with medium initial OOP values, and 7 people included in the group with high initial OOP values. Meanwhile, in the experimental class, there were 8 people included in the group with low initial OOP values, 23 people included in the group with medium initial OOP values, and 5 people included in the group with high initial OOP values. This data shows that both the control class and the largest distribution experiment have an initial OOP capability of "Medium".

Table 1: Categorization of OOP Pretest Scores for Control and Experimental Classes.

No	Pretest Categorization	Control		Experiment	
		Total	Percentage	Total	Percentage
1	Low	3	8.57%	8	22.22%
2	Medium	25	71.43%	23	63.89%
3	High	7	20.00%	5	13.89%

Table 2 shows the results of the normality test for the OOP pretest scores of students in the control and experimental classes. Result Sig. Shapiro-Wilk normality test, the OOP pretest value for the control class was 0.143. Meanwhile, the Sig value. Shapiro-Wilk experimental class is 0.159. The results of the normality test for both classes showed that the Shapiro-Wilk score was > 0.05 , meaning that the OOP pretest score data in the control and experimental classes were normally distributed.

Table 2: OOP Pretest Normality Test Results for Control and Experimental Classes.

Class	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Control	0.179	35	0.006	0.953	35	0.143
Experiment	0.127	36	0.152	0.956	36	0.159

Table 3 shows the results of the homogeneity test of the OOP pretest scores of control and experimental class students. Homogeneity test results using SPSS Levene test calculations. The homogeneity test results show that the Sig. based on an average of $0.004 < 0.05$, meaning that the variance of the OOP pretest data for the control and experimental classes is not homogeneous.

The results of the OOP pretest normality and homogeneity tests in the control and experimental classes can be concluded that the data is normally distributed and not homogeneous. Therefore, the statistical test used to compare the averages of the two groups is the independent sample t-test.

Table 3: OOP Pretest Homogeneity Test Results for Control and Experimental Classes.

OOP Pretest Results	Levene Statistic	df1	df2	Sig.
Based on Mean	8.788	1	69	0.004
Based on Median	5.654	1	69	0.020
Based on Median and with adjusted df	5.654	1	52.692	0.021
Based on trimmed mean	8.189	1	69	0.006

B. Data Analysis of OOP Posttest Results

Table 4 shows the categorization of OOP posttest scores for control and experimental classes. Based on the data presented in Table 4, it is known that in the control class, there were 4 people included in the group with low initial OOP values, 23 people included in the group with medium initial OOP values, and 8 people included in the group with high initial OOP values. Meanwhile, in the experimental class, there were 7 people included in the group with low initial OOP values, 22 people included in the group with medium initial OOP values, and 7 people included in the group with high initial OOP values. This data shows that both the control class and the largest distribution experiment have an initial OOP capability of "Medium".

Table 4: Categorization of OOP Posttest Scores for Control and Experimental Classes.

No	Posttest Categorization	Control		Experiment	
		Total	Percentage	Jumlah	Total
1	Low	4	11.43%	7	19.44%
2	Medium	23	65.71%	22	61.11%
3	High	8	22.86%	7	19.44%

Table 5 shows the results of the normality test for the OOP posttest scores of students in the control and experimental classes. Result Sig. Shapiro-Wilk normality test, the control class OOP posttest value was 0.173. Meanwhile, the Sig value. Shapiro-Wilk experimental class is 0.174. The results of the normality test for both classes showed that the Shapiro-Wilk score was > 0.05 , meaning that the OOP posttest score data in the control and experimental classes were normally distributed.

Table 5: OOP Posttest Normality Test Results for Control and Experimental Classes.

Class	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Control	0,141	35	0,074	0,956	35	0,173
Experiment	0,116	36	.200*	0,957	36	0,174

Table 6 shows the results of the homogeneity test of OOP posttest scores for control and experimental class students. The homogeneity test results show that the Sig. based on the average using the Levene Test of $0.067 > 0.05$, meaning that the variance of the OOP posttest data for the control and experimental classes is homogeneous.

Table 6: OOP Pretest Homogeneity Test Results for Control and Experimental Classes.

OOP Posttest Results	Levene Statistic	df1	df2	Sig.
Based on Mean	3.458	1	69	0.067
Based on Median	3.689	1	69	0.059
Based on Median and with adjusted df	3.689	1	68.087	0.059
Based on trimmed mean	3.510	1	69	0.065

The results of the normality and homogeneity test of the OOP posttest in the control and experimental classes can be concluded that the data is normally and homogeneously distributed. Therefore, the statistical test used to compare the averages of the two groups is the independent sample t-test.

C. Comparison of Control and Experiment Class Means

Figure 5 shows the average OOP pretest and posttest scores in the control and experimental classes. Based on the data in Figure 5, it is known that the average value of the OOP problem-solving ability using the CT approach in the control and experimental classes has increased after being given learning actions. Figure 5 shows the pretest average for the control class is 45.71 and the experimental class is 41.60. The average value of students' abilities in solving OOP questions in the control class was greater than in the experimental class. However, the calculation of the independent sample t-test on the pretest results of the control and experimental classes was carried out to test the significance of the average difference between the initial OOP abilities of students in the two classes. Table 7 shows the results of the independent sample t-test OOP pretest for the control and experimental classes. The results of the t-test show that the significance value (2-tailed) of the OOP pretest in the control and experimental classes is $0.193 > 0.05$, meaning that there is no significant difference between the average initial ability of students in solving OOP questions with the CT approach in the control and experimental classes. So, it can be concluded that students in the control and experimental classes have the same initial OOP abilities based on the results of the independent sample t-test.

Figure 5 also shows a comparison of the OOP posttest results in the experimental and control classes. Based on the average OOP posttest data, it is known that the control class has an average OOP posttest score of 89.50, while the experimental class has an average OOP posttest score of 89.79. The experimental class had a higher average posttest score when compared to the control class. On the OOP posttest average value, an independent sample t-test was carried out to see the significance of the average difference. Table 8 shows the results of the independent sample t-test OOP posttest values for the control and experimental classes. The t test results show the significance value (2-tailed) of the CT posttest, namely $0.826 > 0.05$. The OOP posttest results show that although the experimental class has a higher average compared to the control class, it does not show a significant difference between the average OOP problem-solving ability and the CT approach of students in the control and experimental classes.

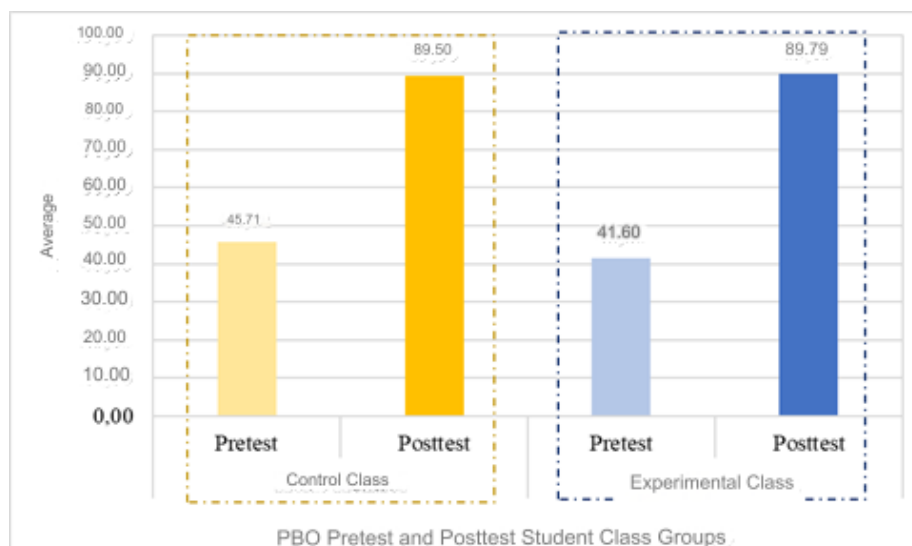


Figure 5. Average OOP Pretest and Posttest Scores.

Table 7: Independent Sample T-Test Results of OOP Pretest for Control and Experimental Classes.

t-test for Equality of Means					
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	1.329	69	0.188	4.11706	3.09889
Equal variances not assumed	1.319	53.151	0.193	4.11706	3.12206

Table 8. Independent Sample t-Test Posttest OOP Test Results for Control and Experimental Classes.

t-test for Equality of Means					
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	-0.221	69	0.826	-0.29167	1.32189
Equal variances not assumed	-0.221	65.674	0.825	-0.29167	1.31712

D. N-Gain Analysis

Figure 6 shows the results of the OOP pretest and posttest N-Gain analysis. Based on the results of N-Gain calculations in the control class, it is known that the average N-Gain value is 0.78 or 77.72% which is included in the “High” category with an effectiveness level of “Effective”. Meanwhile, the results of the pretest and posttest N-Gain calculations for the experimental class show an average N-Gain value of 0.83 or 82.55% which is included in the “High” category with an effectiveness interpretation of “Effective”.

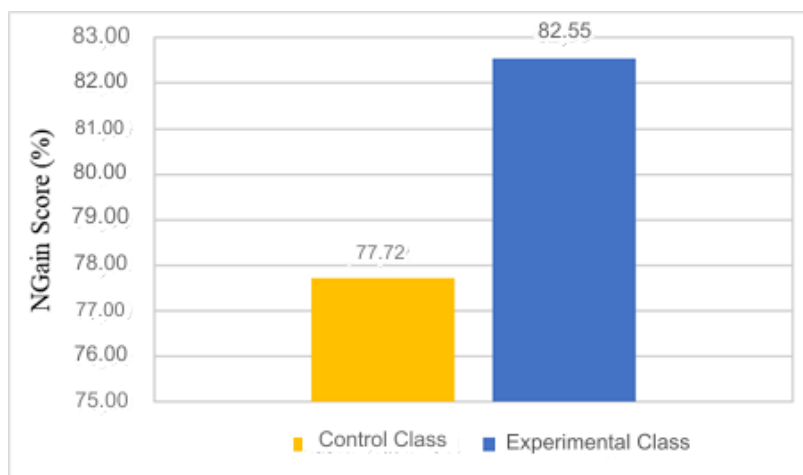


Figure 6. Percentage Results of N-Gain Pretest and Posttest OOP Values for Control and Experiment Classes.

Apart from that, as shown in Table 9, the minimum n-gain value for students in the control class is 0.20 or 20% with the category "Low" and the effectiveness interpretation is "Not Effective". Meanwhile, in the experimental class, the minimum n-gain value for students is 0.56 or 56.25%, which is included in the "Medium" category with an effectiveness interpretation of "Quite Effective". These results indicate that the use of a problem-based learning system with a differentiated approach is better for improving students' abilities in solving OOP problems created using the CT components approach than using a problem-based learning system alone.

Table 9: N-Gain Pretest and Posttest OOP Results for Control and Experimental Classes.

	Ngain Score	Ngain Score (%)	Category	Effectiveness Interpretation
Control Class				
Average	0.78	77.72	Tinggi	Effective
Minimal	0.20	20.00	Rendah	Ineffective
Maximum	0.96	95.65	Tinggi	Effective
Experiment Class				
Average	0.83	82.55	Tinggi	Effective
Minimal	0.56	56.25	Sedang	Effective enough
Maximum	1.00	100.00	Tinggi	Effective

V. DISCUSSION

The analysis of pretest and posttest scores for OOP showed that both the control and experimental classes achieved high levels of effectiveness in improving learning outcomes. The control class achieved an N-Gain score of 0.78 (category "High," effectiveness "Effective"). In contrast, the experimental class, which implemented PBL with a differentiated learning approach, achieved an N-Gain score of 0.83 (category "High," effectiveness "Effective"). Although both were effective, the implementation of PBL with differentiated

learning resulted in greater improvements. Furthermore, the minimum N-Gain score in the experimental class (0.56; category "Medium," effectiveness "Quite Effective") was significantly higher than that in the control class (0.20; category "Low," effectiveness "Ineffective"), indicating that improvements in student learning outcomes in the experimental class were more evenly distributed. These findings align with those of Widana and Kusuma (2023), who found that integrating PBL and differentiated learning significantly improved mathematics learning outcomes compared to PBL without differentiation. Differentiated learning supports grouping students based on learning styles, resulting in more effective learning interactions and improved learning outcomes (Fauzi et al., 2023; Taş & Minaz, 2024). Implementing differentiated learning environments can enhance students' self-efficacy, learning motivation, and problem-solving skills (Lai et al., 2020). Similarly, Krishan and Al-Rsa'i (2023) reported that differentiated teaching strategies significantly increased student motivation and participation.

In the context of vocational education, Lai et al. (2020) emphasized that tailored differentiation strategies for student profiles can increase learning engagement and academic achievement. Tomlinson (2014) also emphasized that adapting content, processes, and products to students' readiness, interests, and learning profiles will result in deeper learning and higher retention. Santangelo and Tomlinson (2012) added that differentiation provides equal access to learning, especially in highly diverse classrooms.

Research in computer science education supports these findings. Bai et al. (2021) found that PBL significantly improves computational thinking (CT) skills, while Al Husaeni et al. (2023) reported moderate to high N-Gain increases in PBL-based problem-solving (PBL) learning. However, as Subban (2006) noted, combining student-centered learning methods with differentiation strategies provides more sustainable and equitable results. Therefore, integrating PBL with differentiated learning can be considered a best practice for developing problem-solving skills, enhancing CT, and deepening mastery of PBL, while ensuring equitable learning outcomes in the classroom.

This study has several limitations, including a quasi-experimental design without randomization, which could potentially lead to bias. The study was limited to a single school with a small sample size, thus limiting the generalizability of the results. The short duration of the intervention also meant that long-term effects could not be measured. The measurement of learning outcomes also focused solely on cognitive aspects, without considering non-cognitive factors such as student motivation and engagement. Furthermore, although the instrument has been validated in previous studies, cross-context validity testing has not been conducted. Other factors, such as differences in ICT tools and the effectiveness of differentiated learning implementation, could also potentially influence the study results.

VI. CONCLUSION

The results of this study indicate that the application of a problem-based learning system with a differentiated learning approach can provide higher learning outcomes compared to the application of a problem-based learning system without differentiation. Theoretically, this finding reinforces the view that combining constructivist learning (PBL) with humanistic

and adaptive principles (differentiated learning) will produce a balanced model that supports active, personalized, and equitable learning. Practically, this model provides a viable strategy for vocational education by addressing diverse student characteristics through differentiation of content, processes, and learning products. This finding suggests that differentiated learning plays a crucial role in optimizing the effectiveness of PBL, not only in increasing average achievement but also in minimizing differences in achievement between students. By grouping students based on learning styles (visual, auditory, and kinesthetic) and adapting the content, processes, and learning products, students gain a learning experience tailored to their characteristics and needs. Therefore, the integration of PBL and differentiated learning can be recommended as an effective learning model for Object-Oriented Programming (OOP) subjects in vocational education. This model is not only relevant for improving mastery of PBO concepts and computational thinking skills, but it can also be an inclusive and adaptive learning strategy that promotes equitable learning outcomes. Further application to various subjects based on analytical and problem-solving skills will expand the benefits of this approach, thereby addressing the challenges of 21st-century education, which demands critical, creative, collaborative, and communicative competencies.

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