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The effectiveness of differentiated Problem-Based Learning (PBL) biology learning modules to improve student learning outcomes

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Abstract

This study aims to analyze the effectiveness of utilizing a differentiated biology learning module based on Problem Based Learning (PBL) on students' learning outcomes. The study employed an experimental method with a pretest–posttest control group design. The research sample consisted of 68 eleventh-grade students from a senior high school in Indonesia, divided into control class (n=34) and experimental class (n=34). The instrument in the form of essay questions had passed validity, reliability, discrimination index, difficulty level testing, and fulfilled analysis prerequisites including normality and homogeneity. The results showed that 5 items were valid (r > 0.254) and reliable (α = 0.804). The learning outcomes data were normally distributed (sig = 0.195 > 0.05) and homogeneous (sig = 0.661 > 0.01), indicating that the data were suitable for further analysis. The improvement of students' learning outcomes was measured using the N-Gain test. The experimental class obtained a mean N-Gain of 0.63, higher than the control class which obtained 0.51, both categorized as medium improvements. The module effectiveness test results showed a mean pretest score of 74 and posttest of 89, with an N-Gain of 0.62 (medium category), where 32% of students were in the highly significant improvement category and 67% were significant, indicating that the module was highly effective in improving learning outcomes. Based on learning styles, the highest improvement was found in kinesthetic learners (N-Gain = 0.69), followed by visual (0.64), and auditory learners (0.46), all within medium improvement criteria. This study concludes that the utilization of a differentiated biology learning module based on PBL effectively improves students' learning outcomes, particularly for students with visual and kinesthetic learning preferences. The study recommends the implementation of differentiated modules as a responsive learning innovation to accommodate diverse student learning characteristics.

Keywords: Differentiated biology learning module, Learning styles, Learning outcomes, Learning module effectiveness

Introduction

21st century skills require everyone to master the 4Cs, which are the means to achieve success in life in society. The 4Cs skills referred to are Communication, Collaboration, Critical Thinking and Problem Solving, and Creativity and Innovation (Thornhill-Miller et al., 2023). 4C is a soft skill that is far more useful in everyday implementation than mastering hard skills (Rehiara et al., 2024). In implementing education and teaching, in addition to teaching hard skills, soft skills must also be trained. Based on this information, learning about soft skills, especially the 4 C skills, is absolutely necessary in this era of the 4.0 industrial revolution in the 21st century (Ida Bagus Putu Arnyana, 2019).

The Merdeka Curriculum, which is currently being developed and updated, is a pedagogical framework that provides ample space for students to learn independently, calmly, and enjoyably, while promoting respect for individual talents and interests so that students do not feel pressured during the learning process (Rehiara et al., 2024). The essence of this curriculum is rooted in efforts to align educational practices with natural laws and the demands of the times, whereby each student is viewed as having unique potential that must be recognized and developed in a contextual, personalized and sustainable manner (Sharma, 2024). The Merdeka Curriculum places the diversity of aspirations and learning rhythms of students as the starting point for learning design, requiring curriculum flexibility, material enrichment, and a more authentic and competency-based assessment approach to support the holistic development of each individual (Trisnani et al., 2024).

The importance of education that accommodates differences in student potential to develop and optimize their competencies and character is a necessary orientation. This is intended to prepare students to face challenges in a dynamic future. In order to realize this dream, the revitalization of

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critical and equitable education is a necessity. One approach that can be used is differentiated learning (Studi et al., 2023). Biology education at secondary school level faces increasingly complex challenges, particularly in developing students' conceptual cognitive abilities and scientific thinking skills. Biology as a discipline has the characteristics of studying life processes that are factual, phenomenal, systemic, and based on empirical findings, thus requiring learning strategies that not only emphasize the transfer of information, but also the process of knowledge construction based on solving real problems (Caron, 1988; Nehm, 2019). In addition, the biology learning process emphasizes providing direct experiences to develop competencies in exploring and understanding the natural world scientifically. This is carried out through scientific inquiry to foster scientific thinking, working and behavior, and to communicate these as important aspects of life skills (Lederman & Lederman, 2011; Schwartz et al., 2004).

Students are required to be active in the learning process so that they can have a positive impact on their learning outcomes. If students themselves discover and process information related to the subject matter, this information will certainly be stored longer in their memory than if they only listen to the information conveyed by the teacher. There is so much subject matter that students must understand at school. This certainly becomes a consideration for teachers in varying their classroom teaching. In the concept Candrasekaran, (2014); Ramdani & Susilo, (2022) Biology is a subject that requires students to have logical, analytical, systematic, critical and creative thinking skills, as well as the ability to work together. Much of the material relates to everyday life. Therefore, teaching must use a variety of learning models that are appropriate to the subject matter. However, due to certain conditions in schools, not all biology material is taught using appropriate learning models. Teachers still act as the main source of learning, with students merely acting as recipients of information. Students are given little opportunity to explore and develop their potential, resulting in them being passive in the learning process. One solution offered is learning using the problem-based learning model.

Hung et al., (2008); Kwan, (2009) the purpose of Problem-Based Learning (PBL) is to enable students to acquire and construct knowledge efficiently, contextually, and holistically through active engagement in solving real-world problems. This approach uses authentic problems as the primary trigger for learning, so that students do not merely receive information but construct meaningful concepts and generalizations through experience and reflection is rooted in constructivism, which emphasizes the construction of knowledge by the learners themselves (Hendry et al., 1999) highlights the importance of social interaction in learning and supports the idea of experiential learning. Within the PBL framework, teachers act as facilitators who guide the inquiry and collaboration process (Ertmer & Glazewski, 2015) and contemporary research shows that PBL effectively improves critical thinking skills, problem-solving skills, and the transfer of knowledge to real-life situations. (Razak et al., 2022) making PBL a potential learning strategy for achieving contextual, integrated, and sustainable learning.

Philosophically Coulson & Harvey (2013) emphasizes experience-based learning and reflection, learning by doing, where students' active involvement in problem solving through direct experience develops meaningful knowledge. This approach forms the basis of Problem Based Learning, which positions problems as triggers, investigation as a process, and reflection as metacognitive reinforcement. PBL menekankan konstruksi pengetahuan dan peran interaksi sosial (Heo et al., 2010; Koh et al., 2010). PBL is an approach that can improve critical thinking skills, collaboration, and the transfer of knowledge to real-life contexts.

In terms of cognitive psychology, the principle of meaningful learning developed by Kalyuga, (2009) emphasises that new knowledge is easier to understand, remember, and transfer when it is logically connected to existing cognitive structures through the processes of subsumption and elaboration; in the context of PBL, prior knowledge activation occurs when students recognize elements of a problem, then repeatedly link hypotheses and evidence to their existing schemas. emphasizes that new knowledge is easier to understand, remember, and transfer when it is logically connected to existing cognitive structures through the processes of subsumption and elaboration; in the context of PBL, prior knowledge activation occurs when students recognise elements of a problem, then repeatedly link hypotheses and evidence to their existing schemas Axelrod, (1973) explains how information is organised in mental structures, while cognitive load by Doering & Veletsianos, (2007); van Nooijen et al., (2024) emphasises the importance of scaffolding to prevent overload when students analyse complex problems. In addition, the aspect of metacognition is reinforced in PBL through systematic reflection so that students not only develop solutions but also monitor and regulate their thinking processes to transfer knowledge to new situations.

Erbil, (2020) believe that students' abilities develop through social scaffolding, both from teachers and peers in a collaborative learning environment. In our view Howard & Miskowski, (2005) Module-based biology learning, scaffolding does not only occur verbally in class, but also permanently in the module text, which provides opportunities for students to learn independently during the investigation process. Teachers should use various teaching styles when delivering lessons so that students are able to digest and understand what is being conveyed. Teachers should be able to understand the various characteristics of students related to their learning profiles so that the learning delivered can be successful. The process of delivering learning by teachers who lack understanding of students' learning styles is the cause of meaningless learning in the classroom (Andriani & Nugraheni, 2024).

At the level of global education policy, Chadwick (2018) Describing scientific literacy as learning outcomes based on reasoning, the use of scientific evidence, understanding phenomena, and data-based decision making, as outlined in the assessment framework by the international educational organization OECD through the PISA 2018 Science Literacy Framework. This framework emphasizes that 21st-century science students need to be equipped with the ability to connect knowledge to real-world contexts, evaluate evidence, and solve scientific problems in an argumentative and reflective manner, all of which are key objectives of PBL (Wardani & Fiorintina, 2023). PBL is a student-centered pedagogy that uses collaborative problem solving as a means of building adaptive knowledge, critical thinking, independent learning, and collaboration, with educators acting as facilitators (Suryani & Syamsidah, 2018). The main characteristics of PBL are: 1) using problems as the starting point and focus of learning, 2) students learn in small collaborative groups, 3) students identify facts, develop hypotheses/ideas for solutions, and determine learning issues that need to be explored independently, 4) there is a process of Self-Directed Learning (SDL), which is independent learning guided by the need to solve problems, and 5) the role of the teacher is as a facilitator, not as the main provider of material. (Hake, 1998).

In line with the theoretical basis and assessment requirements, the development of differentiated PBL-based biology modules is important because it provides learning opportunities that facilitate differences in student learning characteristics, thereby making learning experiences and academic improvement more inclusive. Previous PBL studies Araz & Sungur, (2007); Günter, (2020); Syafii & Yasin, (2013) In general, it confirms the effectiveness of PBL in the field of science and PBL modules in improving students' academic performance, but it is still limited in the application of biology modules that explicitly incorporate learning style differentiation schemes in problem-based learning.

Therefore, this study examines the effectiveness of modules that not only follow PBL syntax but also provide different learning processing pathways (visual, auditory, kinesthetic) in helping students understand concepts, think scientifically, and solve biological problems meaningfully. The importance of education that accommodates differences in students' potential to develop and optimise their competencies and character is a necessary orientation. This is intended to prepare students to face challenges in a dynamic future. In order to realise this dream, the revitalisation of critical and equitable education is a necessity. One approach that can be used is differentiated learning.

Method

The research method used in this study was quantitative research. The research design used a quasi-experimental design with a nonequivalent control group design in the form of a pretest–posttest control group design (Thyer, 2012). This design was chosen because it is able to measure the effect of treatment by comparing the pretest and posttest results between the experimental group that was given differentiated biology learning based on Problem Based Learning (PBL) and the control group that was not given any treatment. The design of this study can be seen in Table below:

Table 01

Group	Pretest	Treatment	Post-test
Experiment (E)	Q1	X	Q2
Control (C)	Q3	–	Q4

Source: (Sugiono, 2018)

The data analysis technique used in this study was *Multivariate Analysis of Covariance* (*MANCOVA*) to determine the effect of differentiated *Problem Based Learning*-based biology learning modules on the learning outcomes of senior high school students (Shadish & Luellen, 2012). Hypothesis testing was conducted using the SPSS program application with the stipulation that if the sig. value was greater than the α value (0.05), then the hypothesis (Ha) was accepted. This research was conducted during the odd semester of the 2024-2025 academic year in class X MA. Muallimat NW Pancor, East Lombok Regency. The research subjects consisted of two classes, namely an experimental class of 34 students and a control class of 34 students.

The data collection technique used was a pre-test and post-test (Sullivan-Bolyai & Bova, 2014). The instrument used in this study consisted of five essay questions. A pre-test was conducted before the implementation of differentiated learning using a biology module based on Problem-Based Learning (PBL). Biology learning on the subject of Biodiversity was conducted over 6 meetings, where during the learning process, when students were working on the LKPD, it was adjusted to the students' learning styles. Students with similar learning styles were grouped together. The learning styles of students in the experimental class consisted of visual, auditory, and kinesthetic learning styles. After the learning process was completed, a post-test was conducted.

The pre-test and post-test scores were then analysed using the *Mancova* test to determine the effectiveness of learning using the *Problem Based Learning (PBL)* biology module in differentiating student learning outcomes. Before conducting the *Mancova* test, the researcher first conducted a prerequisite analysis test to determine whether the data obtained was normally distributed and homogeneous. The *Mancova* test was conducted using SPSS 25.0 software. To test the effectiveness of the learning module, manual calculations were also used, namely the N-Gain effectiveness formula. The normalised gain test (N-Gain) was conducted to determine the improvement in student achievement after the treatment was given. (Campbell & Stanley, 2015). N-gain is the ratio between the average gain obtained and the maximum possible average gain (Gain = post-test score – pre-test score). The average N-gain equation introduced by Hake (1998) is as follows:

$$N - Gain = \frac{Skor\ posts - pretes\ shoes}{maximum\ score - pretes\ shoes} x\ 100$$

The results of the normalised gain calculation are then interpreted based on the n-gain interpretation table according to (Hake, 1998).

Table 2. N-Gains scores

N-Gain	Criteria
> 0,7	Height
0,3 < X< 0,7	Currently
< 0,3	Low

Source: (Hake, 1998)

Result

The results obtained from the study to determine the effectiveness of differentiated *Problem Based Learning (PBL)* biology learning modules in improving student learning outcomes are as follows:

1.Prerequisite test analysis

a.Normality

Data normality testing is a statistical test used to determine whether the data in a sample is normally distributed or not. Normal distribution is a symmetrical data distribution (similar to a bell shape) where the data is centred around the mean (average). SPSS version 25.0 was used to perform the normality test, and the SPSS output is as follows

Table 3. Normality test results

No	Data Types	Statistics	df	sig	Note
1	Learning Outcomes	0,975	68	0,195	Data Normal

b.Homogeneity

Data homogeneity testing is a statistical test used to determine whether the variance of several data groups is homogeneous or uniform. To calculate data homogeneity, SPSS version 25.0, namely Box's M, is used. The SPSS output is as follows:

Table 4. Homogeneity test results

Uji	F	df1	df2	sig
Box's M	0,530	3	784080,000	0,661

Testing the homogeneity of variance and covariance matrices using SPSS, we read the table *Box's Test of Equality of Covariance Matrices* with the following criteria: If the sig value is > 0.01, the data is considered homogeneous, and if the sig value is 0.01, the data is considered non-homogeneous. From the table Box's Test of Equality of Covariance Matrices, we obtain a sign value of 0.661 > 0.01, which means the data is homogeneous.

Hypothesis test

The hypothesis in this study is that there is a difference in learning outcomes between students who use differentiated *Problem Based Learning* biology modules and students who do not use differentiated *Problem Based Learning* biology modules after controlling for students' prior knowledge. To analyse the data on student learning outcomes in the two groups, SPSS version 25.0 was used, with the results shown in the following table

Tabel 5. Tests of between-subjects effects

Source	Dependent Variable	Type III Sum of Square	df	Mean Square	F	Sig
Treatment	Learning Outcomes	263,659	1	263,659	16,569	,000

The effectiveness of differentiated *Problem Based Learning* (*PBL*) biology learning modules on student learning outcomes

The results of the effectiveness of the biology learning module based on *Problem Based Learning* (*PBL*) Differentiated learning outcomes for students can be seen in the table below:

Table 6. Results of the effectiveness test of the Differentiated PBL-based Biology Module on student learning outcomes after treatment

No	class	Number of Respondents	Average			
			Pre-Test	Post-Test	N-Gain	note
1	Experiment	34	74	89	0,63	Currently

Source: compiled by Researchers

The experimental class consisted of 34 respondents with an average pretest score of 74 and a posttest score of 89, indicating a significant improvement after the intervention. The N-Gain score of 0.63 indicates a moderate to high improvement category, reflecting the effectiveness of the differentiated PBL-based learning module in improving concept mastery. These findings confirm the success of group treatment and provide a basis for optimising implementation and continuous evaluation. Further analysis is needed to identify moderating factors and variations in individual responses.

Table 7. Learning outcome data based on student learning styles

No	Learning Style	Pre-test	Post-tes	N-Gain	Note
1	Visual	73,43	89,43	0,64	Currently
2	Auditori	73,14	85,14	0,46	currently
3	Kinesthetic	74,15	91,69	0,69	currently

Source: compiled by Researchers

Learning outcome data based on learning styles indicate that all student groups experienced moderate improvement. Kinesthetic learners achieved the highest N-Gain (0.69), followed by visual learners (0.64), while auditory learners ranked lowest (0.46). This difference indicates that the module design is more effective in supporting visual processing and practical activities than auditory stimuli. Overall, these findings confirm that differentiated modules can improve learning outcomes, although optimisation of auditory elements is still needed.

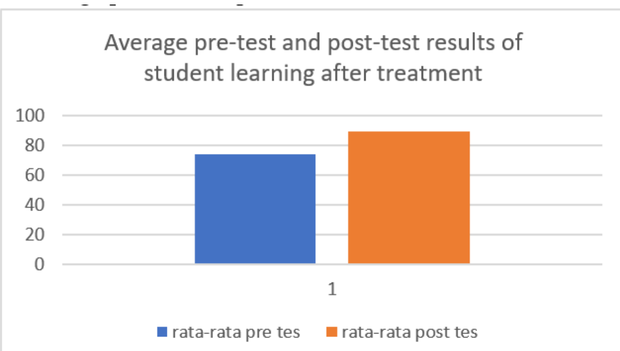

Figure 1. Average pre-test and post-test scores of students after receiving treatment

The figure above shows a comparison between the average pretest and posttest scores of students' learning outcomes after being given the learning treatment. The blue bar represents the average pretest score, which was around 73, reflecting the students' initial abilities before participating in the learning module or intervention. Meanwhile, the orange bar shows the average posttest score of **88**, which indicates an improvement in learning outcomes after the treatment. The increase in the average score indicates that the learning provided was able to significantly improve students' understanding and mastery of concepts. The considerable difference in scores between the pre-test and post-test also shows that the intervention

implemented was effective in improving students' cognitive achievements, both in terms of acquiring new knowledge and strengthening conceptual understanding. Overall, this graph illustrates the success of the learning process in encouraging the development of student learning outcomes.

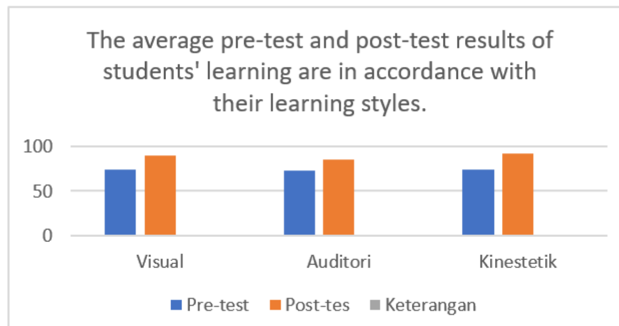

Figure 2. Average pre-test and post-test scores of students based on their learning styles

The image illustrates a comparison of the average pretest and posttest scores of students grouped according to visual, auditory, and kinesthetic learning styles to see the extent to which each group improved after participating in the learning process. In general, all learning style groups experienced an increase in scores on the posttest, but to varying degrees. Students with a kinesthetic learning style showed the highest improvement, indicating that learning involving hands-on activities, exploration, and practice greatly supports their understanding process. Meanwhile, the visual group also experienced a significant increase, indicating the effectiveness of using illustrations, diagrams, and other visual representations in the module. In contrast, the auditory group experienced the lowest increase compared to the other two groups, suggesting that auditory-based learning elements such as structured discussions or verbal narratives may not have been optimally provided in the learning design. Overall, this graph makes it clear that the module design is more in line with visual and kinesthetic needs, and suggests the need for further adjustments to accommodate auditory learners more effectively.

Discussion

Before testing the effectiveness of the module, the learning outcome evaluation instrument was validated using Pearson's correlation test. The results showed that five items (1, 2, 4, 6, 7) had a calculated *r* value exceeding the table *r* (0.254), thus declaring them valid and suitable for measuring students' cognitive learning outcomes. The SPSS 25.0 score also showed that the reliability of the instrument was in the high category with a Cronbach's Alpha of 0.804, indicating strong internal consistency. This condition is important because high reliability minimises measurement error, so that changes in student scores can be attributed to the learning treatment, rather than to instrument inconsistency.

The normality test (Kolmogorov-Smirnov) obtained a significance value of 0.195 > 0.05, indicating that the data was normally distributed. Furthermore, Box's M homogeneity test produced a significance value of 0.661 > 0.01, indicating that the variance between groups was homogeneous. Normality and homogeneity were fulfilled, indicating that the research data was stable and unbiased, and fulfilled the parametric assumptions, so that the comparison of learning outcomes between the control and experimental classes could be analysed validly without statistical violations.

Naro et al., (2023) Learning achievement is defined as the results achieved by learners based on specific criteria and reflecting behavioural changes that encompass cognitive, affective and psychomotor aspects. As the end result of a series of learning processes, this achievement is not an isolated phenomenon but rather the product of interactions between learning methods, assessment and learner experiences. Theoretically, this is in line with Bloom's taxonomy of educational objectives, which emphasises the cognitive dimension (Bloom et al., 1956), supplemented by Krathwohl's affective taxonomy in (Syrjälä et al., 1990) and Simpson's psychomotor taxonomy in (Begam & Tholappan, 2018) jointly explain the scope of behavioural changes that are assessed as achievements. From the perspective of learning psychology, behaviourism (Skinner, 1984) emphasising measurable behavioural change as an indicator of learning, whereas Piaget's constructivism in (Fosnot & Perry, 1996) viewing achievement as the result of knowledge construction rooted in students' experiences and mental activities. In addition, the role of formative assessment in improving the learning process as demonstrated by assessment for learning research (Black & Wiliam, 1998) emphasising that improved performance is a direct consequence of feedback and regulation of the learning process.

To test the hypothesis using the Tests of Between-Subjects Effects output in SPSS software, the focus of interpretation is placed on the Group row (treatment) and the Sig. column (p-value). Statistical decisions are made by comparing the significance value to the specified significance level ($\alpha = 0.05$): if the Sig. < 0.05, then there is statistical evidence to reject the null hypothesis and it can be concluded that there is a significant difference in effect between groups, Conversely, if the value is Sig. > 0.05, then there is insufficient evidence to reject the null hypothesis, and it can be said that there is no significant difference in effect. When reporting the results, the F value, degrees of freedom, p value (Sig.), and effect size should be included to provide a complete picture of the significance and magnitude of the treatment effect.

As seen in the Tests of Between-Subjects Effects table, the significance value in the learning outcomes row is 0.00 ($p < 0.05$), which indicates a significant difference in learning outcomes between students who used the differentiated Problem-Based Learning (PBL) biology module and students who followed conventional learning without the module. These results were obtained after controlling for differences in prior knowledge, so it can be concluded that learning with differentiated PBL modules has a significant effect on improving learning outcomes. These findings support the development of responsive teaching materials.

The effectiveness of the module was analysed by comparing the pretest, posttest, and N-Gain scores between the control and experimental classes. The results showed that the experimental class experienced a higher increase with a mean N-Gain of 0.63 compared to the control class of 0.51, although both were still in the moderate improvement category. However, the 0.12 difference in N-Gain scores indicates the *instructional impact* of the module used. This confirms that the differentiated PBL-based module design is able to provide greater cognitive benefits than the conventional learning used in the control class.

In addition, the results of individual N-Gain tests in the experimental class showed that 32% (11 students) experienced a highly significant improvement and 67% (23 students) experienced a significant improvement, with an overall average N-Gain of 0.62. The dominant proportion of significant improvement indicates that the module provided *learning acceleration* evenly across most students. This finding is important because effectiveness is not only characterised by the magnitude of the mean value, but also by the equitable learning impact of the intervention. Differentiated modules serve as flexible instructional scaffolds, enabling students with different initial ability levels to achieve meaningful gains.

The Problem-Based Learning approach in the module also contributes significantly to improving learning outcomes. PBL requires students to activate Higher Order Thinking Skills (HOTS) such as identifying biological problems, formulating hypotheses, searching for learning resources, and executing science-based solutions; these skills are in line with Bloom's revised taxonomy, which emphasises the skills of analysing, evaluating, and creating as indicators of higher-order thinking (Nkhoma et al., 2017; Pakpahan et al., 2021). Historically, PBL is rooted in Piaget's constructivism in (Muniandy, 2000) emphasises that knowledge is constructed through mental activity, as well as social constructivism (Palincsar, 2012) emphasises the role of interaction and scaffolding in the process of concept internalisation. When students engage in authentic problem situations, they build understanding through the inquiry process to reinforce meaningful learning and enable transfer learning to new contexts. Research Hmelo-Silver & DeSimone (2013) shows that PBL improves knowledge retention because students experience a deep, repetitive, and reflective learning process. The combination of these elements contributes to an increase in post-test scores because students' understanding is formed through stronger, more integrated, and more applicable concept construction.

The Problem-Based Learning (PBL) approach has been around for more than five decades since it was introduced into education programmes. In the early stages of its development, many curricula adopted PBL, and a number of early studies reported that PBL groups achieved higher academic scores than groups taught using conventional methods (Kaufman & Mann, 1999). Although many studies show advantages in application skills, retention, and higher-order thinking skills, recent reviews and meta-analyses, particularly in the field of cell biology in medical education, have found heterogeneity in results, methodological limitations, and variability in implementation, so it cannot be conclusively stated that PBL is always more effective than conventional methods (Xu et al., 2021).

This study also analysed learning outcomes based on students' learning styles (visual, auditory, kinesthetic). The results showed the highest N-Gain in kinesthetic learners (0.69), followed by visual learners (0.64) and auditory learners (0.46). This study also analysed learning outcomes based on students' learning styles (visual, auditory, kinesthetic). The results showed the highest N-Gain in kinesthetic learners (0.69), followed by visual learners (0.64) and auditory learners (0.46).

These findings can be interpreted through the characteristics of the module design developed, namely the dominance of visual representations such as infographics, illustrations of biological processes, charts, and conceptual diagrams, as well as kinesthetic activities in the form of problem solving, field exploration, and mini experiments that facilitate product-based learning. The low achievement of auditory learners indicates that auditory stimulus elements have not been adequately integrated, for example through structured narration or facilitated discussion, so that voice modality enrichment is needed to achieve modality inclusivity. The differentiation approach referred to in the module is also consistent with the principles of Universal Design for Learning, which requires the provision of multiple means of representation, engagement, and expression in order to meet heterogeneous learning needs (Kronberg et al., 1997), Thus, the learning style analysis serves as a starting point for more systematic pedagogical grouping and the development of learning scenarios that are responsive to variations in learning preferences. (Kronberg et al., 1997; Pashler et al., 2008).

This emphasises that differentiated modules must not only provide a variety of content formats, but the quality of stimuli for each learning preference must be balanced to avoid *style bias*, which is an imbalance in effectiveness due to the dominance of a particular learning modality. Nevertheless, the continued significant improvement across all learning styles indicates that differentiated PBL is able to respond to student learning diversity, while also providing a personalised learning pathway so that each student gains a learning experience tailored to their needs. This is in line with what was stated by (Naibaho, 2023) Differentiated learning is learning that fulfils, serves, and recognises the diversity of learners in learning according to their readiness, interests, and learning preferences. In principle, PBL emphasises improving and refining learning methods with the aim of reinforcing concepts in real-life situations, developing higher-order thinking skills and problem-solving skills, increasing student engagement in learning, developing decision-making skills, exploring information, and increasing confidence, responsibility, cooperation and communication (Anam & Wijaya, 2023; Andayani & Gunawan, 2025).

Differentiation provides learning opportunities for each student that are tailored to their individual abilities, interests and talents. Teachers must be able to apply learning methods that take into account the differences between students during the learning process, such as differentiating learning methods according to the content of the material, differentiating the learning process and differentiating the final learning outcomes. In addition, students are given the freedom to study in groups or individually (Ardyapramesti, 2023). The classification process for students is carried out in several ways, such as independent learning, collaborative learning in groups, and grouping according to student interests. Differentiated learning processes provide important benefits for both students and teachers.

For students, they receive learning services that suit their learning styles, fair treatment, and optimal guidance. For teachers, the application of differentiated learning processes helps them to understand students better, provide the best service, and develop students' potential optimally (Fauzi et al., 2023). This is also in line with research conducted by (Suwartiningsih, 2021) The implementation of differentiated learning can improve learning outcomes in science, specifically soil and sustainability, for Grade IXb students in the second semester at SMPN 4 Monta in the 2020/2021 academic year. This improvement in learning outcomes is demonstrated by a very high increase compared to the previous cycle, namely 28 students (96.55%) who have achieved the minimum competency standard, while 1 student (3.45%) has not yet achieved it, with an average score of 80.

The results of this study indicate that the Problem-Based Learning (PBL) module substantially improved learning outcomes at both the class and individual levels. This phenomenon can be interpreted within the framework of cognitive and social constructivism, whereby knowledge is actively constructed by learners through interaction with authentic problems Piaget (Von Glasersfeld, 1982). The implementation of PBL as a trigger for cognitive activities supports the formation of deep conceptual understanding and investigative skills, in line with the idea of meaningful learning (Gani & Wijaya, 2023); (Al-Thani & Ahmad, 2025) about subsuming new knowledge into existing cognitive structures. In addition, PBL's orientation towards developing higher-order thinking skills is reflected in the revised cognitive taxonomy (Bloom et al., 1956).

The contribution of differentiated learning to equal access and learning outcomes can be explained through the principle of differentiated instruction (Tomlinson, 2017). These findings prove that students with a dominant visual and kinesthetic learning style benefit more, indicating the dominance of visual-kinesthetic representation in module design; the implication is the need to optimise auditory representation, for example through structured narration or facilitated discussion as part of the strategy. However, with regard to claims of adjustment based on learning styles, it should be noted that there is evidence limiting the effectiveness of the "matching hypothesis." Therefore, the best practice is to apply multimodal scaffolding that is sensitive to cognitive load and supported by formative assessment mechanisms to ensure that performance improvements occur evenly among all students.

Conclusion

Based on research findings regarding the effectiveness of differentiated Problem-Based Learning (PBL) biology learning modules, it can be stated that these modules significantly improve the cognitive achievements of senior high school students. Empirical evidence shows that the average post-test score of the experimental class reached 89 compared to 86 in the control group, and the N -Gain value of 0.63 exceeded that of the control group, which was 0.51 (both were in the moderate improvement category), while the average individual N-Gain value of 0.62 reinforced the effectiveness at the personal level; the distribution of improvement also showed an equitable distribution of benefits, with 32% of students experiencing a very significant improvement and 67% experiencing a significant improvement. Based on research findings regarding the effectiveness of differentiated Problem-Based Learning (PBL) biology learning modules, it can be stated that these modules significantly improve the cognitive achievements of senior high school students. Empirical evidence shows that the average post-test score of the experimental class reached 89 compared to 86 in the control group, and the N -Gain value of 0.63 exceeded that of the control group, which was 0.51 (both were in the moderate improvement category), while the average individual N-Gain value of 0.62 reinforced the effectiveness at the personal level; the distribution of improvement also showed an equitable distribution of benefits, with 32% of students experiencing a very significant improvement and 67% experiencing a significant improvement. The practical implications of these findings call for the strengthening of the adoption of differentiated PBL modules as alternative teaching materials that are responsive to the diversity of students in biology learning. Its implementation should be accompanied by professional development programmes for educators to improve their capacity to facilitate problem-based learning and instructional differentiation skills. In addition, the redesign of the module needs to enrich the auditory representation channel so that the scope of learning modalities becomes more inclusive, while formative assessment mechanisms must be strengthened to monitor individual progress and provide diagnostic feedback and early intervention. At the policy level, the integration of this module into the curriculum and school supervision schemes needs to be considered to ensure the continuity and quality of implementation, including adequate resource support and implementation time. From a research and development perspective, further studies are needed to explore the sustainability of learning outcomes, cross-curricular and cross-level adaptation, and analysis of implementation factors that influence effectiveness so that pedagogical recommendations can be optimized systematically.

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