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Research Article

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The effect of the problem-oriented project-based learning model assisted by artificial intelligence on students' problem-solving and communication skills

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ABSTRACT

The development of 21st-century education emphasizes the importance of problem-solving and communication skills. However, empirical evidence regarding the integration of artificial intelligence (AI) into problem-oriented project-based learning remains limited. This study aimed to examine the effect of a problem-oriented project-based learning model assisted by artificial intelligence on students' problem-solving and communication skills. A quasi-experimental method with a non-randomized pretest–posttest control group design was employed, involving three groups: an AI-assisted problem-oriented project-based learning group, a problem-oriented project-based learning group, and a regular learning group. The participants consisted of 90 eleventh-grade students from SMA Negeri 1 Singosari, Malang Regency, Indonesia, equally distributed across the three groups. Data were collected using a problem-solving skills test and a communication skills questionnaire and analyzed using Analysis of Covariance (ANCOVA). The results revealed a significant effect of the learning model on students' problem-solving skills ($p < 0.05$) and communication skills ($p < 0.05$). Students taught using the AI-assisted problem-oriented project-based learning model achieved significantly higher scores than those in the regular learning group, while the difference between the AI-assisted and non-assisted problem-oriented project-based learning groups was not statistically significant ($p > 0.05$). In conclusion, the problem-oriented project-based learning model assisted by artificial intelligence effectively enhances students' problem-solving and communication skills. These findings imply that integrating AI into project-based learning can serve as an effective instructional strategy to support the development of essential 21st-century skills in secondary education.

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INTRODUCTION

The fourth industrial revolution has transformed various aspects of social life. The demands of the 21st-century workforce are no longer the same as those of the previous century (Klingenberg et al., 2022). These changes require a response from the education sector to ensure that the skills students learn remain relevant in today's evolving world. One of the education sector's responses to the Fourth Industrial Revolution is the emergence of the Education 4.0 concept. There are four components that shape the vision of Education 4.0, such as competencies, the application of information and communication technology (ICT), teaching methods, and infrastructure. In terms of competencies, education must be directed towards developing skills needed in the 21st century, such as critical thinking, cooperation, collaboration, communication, creativity, and innovation (Miranda et al., 2021).

Another study conducted by Islam (2022) highlights decision-making skills, problem-solving skills, and information analysis skills as essential competencies to be developed. Problem-solving skills are not only useful in learning activities but also in everyday life. With strong problem-solving abilities, students are able to complete tasks and activities effectively. They are also better prepared and capable of achieving both personal and professional goals (Choudhar et al., 2022). Problem-solving skills involve coordinating all cognitive, metacognitive, and behavioral aspects when someone is faced with a complex or unfamiliar problem (Karyotaki & Drigas, 2016). According to Greenstein (2012), problem-solving skills include the ability to identify problems, apply problem-solving steps, identify possible solutions, evaluate those solutions, and defend the chosen solution. Additionally, these skills involve real-world application, inductive reasoning, and deductive reasoning.

Traditional teacher-centered learning methods are less supportive of the development of problem-solving skills (Arends, 2012). Therefore, Education 4.0 emphasizes collaborative, interactive, and cooperative learning approaches such as challenge-based learning, problem-based learning, learning by doing, and gamification-based learning (Miranda et al., 2021). The success of implementing these learning models heavily depends on the effectiveness of communication among students during discussions, idea sharing, and teamwork. Thus, communication skills become a key element in 21st-century education. Communication skills not only enable students to share information but also to actively contribute to social and academic interactions. Garay and Quintana (2019) define communication skills as social interaction skills that allow the expression of ideas, feelings, or emotions through both verbal and non-verbal language.

Communication skills are essential competencies that need to be taught to students and are considered a priority in the transformation of Education 4.0 (Miranda et al., 2021). The importance of communication skills is evidenced by their inclusion in various international agreements. P21 (Partnership for 21st Century Skills) places communication skills under the category of Information and Communication Technologies, emphasizing students' ability to use technology to communicate effectively. Meanwhile, ATC21S (Assessment and Teaching of 21st Century Skills) categorizes communication under "Ways to Work," focusing on collaboration and interaction within work contexts. UNESCO, in the "Learning to Do" category, emphasizes the importance of communication as part of practical and contextual learning (Garay & Quintana, 2019).

However, despite the strong emphasis on 21st-century skills in the Education 4.0 paradigm, significant challenges persist in senior high schools, particularly in developing students' communication and problem-solving skills. Several studies conducted in Indonesia have reported that high school students' problem-solving skills in biology remain at low to moderate levels. Putra and Astika (2023) found that students' average problem-solving skill score was 36.9, which falls into the moderate category, while

Palennari et al. (2022) reported that 65% of students demonstrated low and 12.72% very low problem-solving skills. In addition, previous studies indicate that students often experience difficulties in clearly expressing ideas, actively participating in discussions, and communicating problem-solving processes during science learning, particularly in collaborative learning environments (Lo & Hsieh, 2020). Preliminary observations conducted at SMA Negeri 1 Singosari, Malang Regency, indicated that students tended to demonstrate low levels of communication skills (M = 48.95) and problem-solving skills (M = 49.21). Furthermore, teachers reported challenges in implementing project or problem-based learning, including limited instructional time, difficulties in providing individual guidance, and students' limited ability to formulate investigative questions. These conditions indicate a gap between the expected competencies of Education 4.0 and actual learning practices in senior high schools, highlighting the need for an instructional model that effectively supports communication and problem-solving skills.

These skills can be enhanced if teachers use appropriate strategies, methods, models, approaches, and learning technologies. In a study conducted by Miranda et al. (2021), learning activities aligned with the goals of Education 4.0 are those that are based on collaboration and cooperation. One of the learning models that can be implemented is Problem-Oriented Project-Based Learning (POPBL). POPBL is a combination of project-based learning and problem-based learning that enables students to work independently in groups. Each group works on a project to solve contextual and complex problems. Project development is discussed continuously within the group under the guidance of a teacher or supervisor (Rongbutsri, 2017).

Yasin et al. (2011) divided the POPBL syntax into four main phases: 1) group formation, 2) problem formulation, 3) design and data collection, and 4) analysis and report writing. Meanwhile, Rongbutsri (2017) proposed a more detailed syntax consisting of seven learning steps: group formation, problem formulation, planning, data collection, analysis, problem-solving, reporting, and assessment preparation. Several other studies summarize these seven phases into four broader stages: 1) identifying and formulating problems, 2) organizing students for learning, 3) planning and carrying out the project, and 4) presenting results and evaluation (Hardyanto et al., 2024). The POPBL model has been studied by several researchers and has been empirically proven to enhance various 21st-century skills. The use of this model in biology subjects has effectively improved critical thinking and creative thinking skills (Suwistika et al., 2024). In addition, the POPBL model has also been shown to improve other competencies such as collaboration, digital literacy, inventive thinking, and effective communication (Filmi et al., 2024). The effectiveness of POPBL in enhancing 21st-century skills is supported by Jean Piaget's theory of cognitive development and Lev Vygotsky's sociocultural development theory. Both theories are grounded in the constructivist perspective, which views learners of all ages as active participants in acquiring information and constructing their own knowledge (Affandi & Tantra, 2022). Moreover, interaction with others stimulates the construction of new ideas and enhances students' intellectual development (Saleem et al., 2021).

One implication of Piaget's theory of cognitive development in education is the need to understand students' cognitive stages. High school students, who are typically over the age of 11, are generally in the formal operational stage. At this stage, they should be encouraged not only to acquire concrete knowledge but also to engage with more complex and abstract problems through activities such as discussion, problem-solving, and critical thinking (Schunk, 2020). The POPBL model not only encourages students to solve complex problems but also real and contextual ones. Additionally, POPBL promotes the occurrence of disequilibrium, which refers to a mismatch between reality and the cognitive schemas students possess (Schunk, 2020). Disequilibrium can occur at various stages of the POPBL process.

When students engage in exploration or investigation, they may encounter new knowledge, understandings, or perspectives that differ from what they previously held.

Alongside cognitive development theory, the POPBL model is also grounded in sociocultural theory. According to Lev Vygotsky, interaction with more knowledgeable others stimulates development and accelerates cognitive growth. A key concept in this theory is the Zone of Proximal Development (ZPD). The Zone of Proximal Development refers to the gap between a learner's actual level of development, as determined by independent problem-solving ability, and their potential level of development, which can be achieved through problem-solving with the guidance of adults or more capable peers. This concept has several implications for education, such as the need to build supportive social interactions in the classroom, implement collaborative learning, and provide scaffolding tailored to each student's needs. In addition, culturally relevant and contextualized activities should be integrated to increase the effectiveness of learning (Schunk, 2020).

The application of sociocultural theory in the POPBL model can be observed in each phase of the learning process. Students work collaboratively in small groups from the very first stage—orienting and formulating problems—through to the final stage of presenting results and evaluation. Collaborative group work supports positive peer interaction, which stimulates the construction of ideas and knowledge in line with sociocultural theory (Zhang, 2023). In addition to implementing innovative learning models, the use of emerging technologies is necessary to respond to the rapid advancement of digital technologies, especially artificial intelligence (AI). AI has been widely applied in education—across administration, teaching, and learning processes. AI-based platforms can be used to review and assess student assignments more effectively and efficiently, personalize learning content according to individual needs, and enhance students' learning experiences (Chen et al., 2020).

AI technologies implemented in primary and secondary education come in various forms, such as machine learning, intelligent tutors, chatbots, educational games, AI robots, and virtual reality-based devices (Martin et al., 2024). Among these technologies, chatbots are one of the most frequently used and applied in learning environments (Pack & Maloney, 2023). Martin et al. (2024) define a chatbot or chatterbot as a software application used to conduct online chat conversations via text or text-to-speech, serving as a substitute for direct human interaction. According to Shah (2023), chatbot-based AI can be applied in several activities within problem-based or project-based learning. First, it can be used to develop classroom activities. AI can quickly generate scenarios, project ideas, rubrics, and assignments. Second, AI can offer a more personalized project experience based on students' needs and interests. By providing the necessary input, AI can recommend relevant and desired project ideas. Third, AI can serve as a virtual mentor that offers guidance, support, and resources while students work through problems and complete project tasks.

The implementation of AI chatbots in problem- or project-based learning has been explored by several researchers. A study by Su & Yang (2022) found that AI-PBL (Artificial Intelligence–Problem Based Learning) helped most students enrich their learning experiences, foster problem-solving thinking, and improve their learning outcomes through interaction and guidance. In this study, AI supported learners in enhancing understanding, making decisions, and solving scientific problems they encounter in their daily lives. The use of AI, particularly ChatGPT, in biology problem-based learning has also been conducted by Faldi et al. (2024). ChatGPT was used to enhance teacher-student interactions, provide quick feedback, and personalize learning to meet students' individual needs. This action research study demonstrated improvements in students' cognitive abilities.

The integration of artificial intelligence, particularly AI chatbots, into the Problem-Oriented Project-Based Learning (POPBL) model is expected to enhance its effectiveness in developing students' 21st-century skills. Education 4.0 demands learning approaches that support higher-order thinking, communication, and problem-solving through the use of digital technologies. However, the implementation of problem-based and project-based learning in schools is often constrained by practical challenges. Meng et al. (2023) reported that teachers and students face difficulties such as limited instructional time, challenges in providing individualized guidance, students' limited ability to formulate investigative questions, and problems in managing complex projects. These constraints may reduce the optimal implementation of POPBL in classroom settings. In this context, artificial intelligence offers potential support by functioning as a virtual mentor that assists teachers and students in designing learning scenarios, accessing information, and analyzing data during problem-solving and project activities (Shah, 2023).

Previous studies have shown that Problem-Oriented Project-Based Learning (POPBL) is effective in fostering 21st-century skills, including critical thinking, collaboration, and creativity (Filmi et al., 2024; Suwistika et al., 2024). Nevertheless, several research gaps remain. In terms of research topic, most studies have examined POPBL or artificial intelligence as separate interventions, while empirical studies integrating AI into POPBL are still limited. Regarding research variables, prior studies have predominantly focused on cognitive learning outcomes, with less emphasis on 21st-century skills, particularly communication and problem-solving skills. In relation to research subjects, studies rarely target senior high school biology students, despite the abstract nature of biological concepts that require strong problem-solving abilities. Furthermore, limited studies have used validated performance-based instruments and inferential statistical analyses to examine the specific instructional effects of AI-assisted POPBL.

Based on these gaps, this study investigates the effect of Artificial Intelligence-assisted Problem-Oriented Project-Based Learning (POPBL-AI) on students' communication and problem-solving skills in senior high school biology learning. This study contributes to the literature in three ways: (1) by integrating AI chatbots as pedagogical support within the POPBL framework, (2) by focusing on communication and problem-solving skills as core 21st-century competencies rather than solely cognitive outcomes, and (3) by employing validated performance-based instruments and inferential statistical analysis. The findings are expected to provide empirical evidence and practical guidance for teachers in designing technology-integrated learning aligned with the demands of Education 4.0.

RESEARCH METHODS

The research was conducted at SMAN 1 Singosari, a senior high school located in Singosari District, Malang Regency, East Java. This school was chosen because it has a relatively large student population, consisting of 36 class groups. The study was carried out at the 11th-grade level, focusing on students majoring in biology. The total population consisted of 317 students (110 male and 207 female), distributed across nine classes. The research design used in this study is a non-randomized control-group pretest-posttest design (Leedy & Ormrod, 2018). The design used is illustrated in Table 1. To provide an overview of the research stages, the research procedure is illustrated in Figure 1.

Three classes were randomly selected from the nine 11th-grade classes. The academic abilities of the selected classes were tested for equivalence using a One-Way ANOVA. The data used for the analysis were the students' average report card scores from the previous semester. The report card score data for each class are presented in Table 2. The results of the ANOVA test with α = 0.05 showed a p-value of 0.229, which is greater than α = 0.05. These results indicate that the three classes used in the study did not differ significantly in terms of average academic ability (they were equivalent).

Table 1. Research Design

Class	Test	Treatment	Test
Experiment	O1	X1	O2
Positive Control	O1	X2	O2
Negative Control	O1	X3	O2

Information: X1=Artificial intelligence-assisted problem-oriented project-based learning (POPBL-AI) model, X2=Problem-oriented project-based learning model, O1=Pre-test, and O2=Post-test

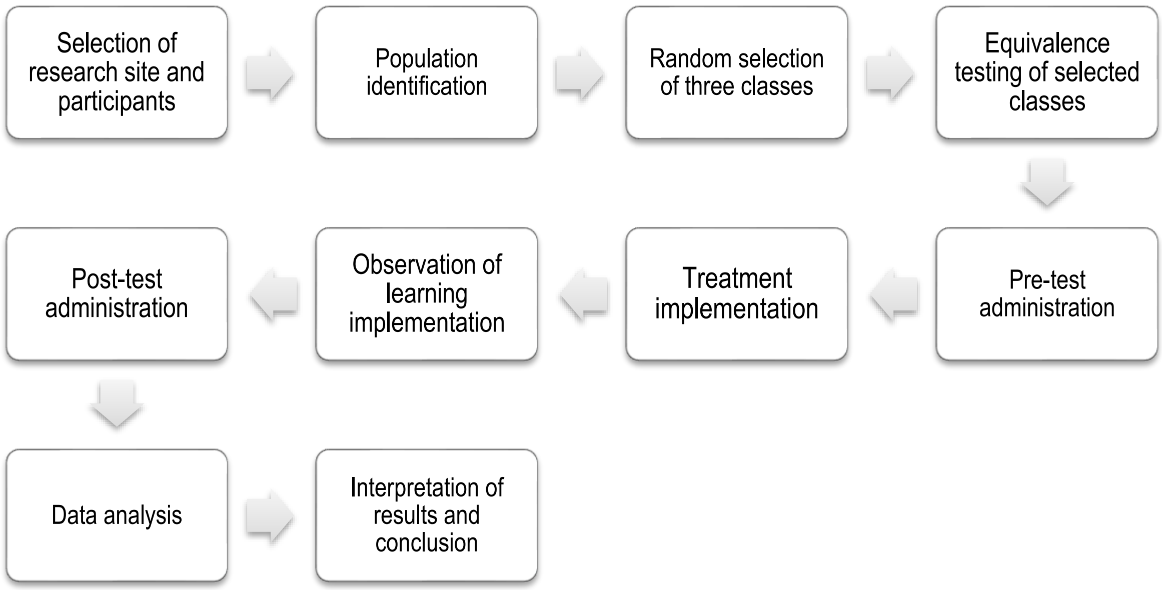

Figure 1. Flowchart of the Research Procedure

Table 2. Average Academic Scores of the Sample Classes

Class	Mean	Standard Deviation
A	87.2	0.89
B	87.1	1.13
C	86.8	1.35

The dependent variables in this study are problem-solving skills and communication skills. Problem-solving skills were measured using a test instrument in the form of essay questions. The test instrument was developed by the researcher based on the framework by Greenstein (2012). The aspects of problem-solving skills assessed include the ability to identify problems, apply problem-solving steps, identify multiple solutions, and evaluate solutions. The test blueprint for measuring problem-solving skills is presented in Table 3.

Table 3. Test Blueprint of the Problem-Solving Skills Test Instrument

Aspect	Indicator	Item Number(s)
Identifying the Problem	Able to describe a problem by including supporting details relevant to the given situation	1a, 1b
Applying Problem-Solving Steps	Able to apply all learned steps and strategies in solving the problem	2a, 2b

Aspect	Indicator	Item Number(s)
Identifying Multiple Solutions	Able to propose at least four possible solutions and clearly describe each one	3
Evaluating Solutions	Able to evaluate and analyze all possible options before selecting the most appropriate solution	4a, 4b

The scaled questionnaire used to measure communication skills was developed by the researcher based on the communication skill indicators proposed by Greenstein (2012). The questionnaire consists of 20 statements with five response options arranged using a Likert scale. For positively worded statements, the score weights are as follows: Strongly Agree (SA) = 5, Agree (A) = 4, Neutral (N) = 3, Disagree (D) = 2, Strongly Disagree (SD) = 1. Conversely, for negatively worded statements, the scoring is reversed: Strongly Agree (SA) = 1, Agree (A) = 2, Neutral (N) = 3, Disagree (D) = 4, Strongly Disagree (SD) = 5. The questionnaire development process began with the formulation of components and indicators, followed by the construction of descriptors or statement items. The score for each respondent was obtained by summing the scores of all statement items. Data collected from the Likert scale questionnaire are considered interval data (Gumanti et al., 2016).

The research instrument was validated by three experts: one education expert, one biology content expert, and one education practitioner. Once validated, the instrument was subjected to a limited trial to assess its feasibility based on validity and reliability. Based on the trial results, the problem-solving skills test instrument had a Cronbach's α value of 0.714, indicating acceptable reliability. This result shows that the problem-solving skills test instrument has sufficient reliability for use in research. The results of the validity test for the problem-solving skills test instrument are presented in Table 4.

Table 4. Validity Test Result of the Problem-Solving Skills Test Instrument

Item Number	Pearson's r	Description
1	0.54	Valid
2	0.60	Valid
3	0.79	Valid
4	0.55	Valid
5	0.50	Valid
6	0.60	Valid
7	0.66	Valid

Based on the data presented in Table 4, all items of the problem-solving skills test have Pearson's r values greater than 0.3. Therefore, it can be concluded that all items are valid. The problem-solving skills test instrument is considered suitable for use in this study. The communication skills questionnaire demonstrated a Cronbach's α value of 0.893, indicating a high level of reliability. This suggests that the instrument is sufficiently reliable for use in the study. The validity test results for the communication skills questionnaire are presented in Table 5.

Table 5. Validity Test Results of the Communication Skills Questionnaire

	Item Number 1-10			Item Number 11-20	
Item Number	Pearson's r	Description	Number	Pearson's r	Description
1	0.49	Valid	11	0.37	Valid
2	0.69	Valid	12	0.46	Valid
3	0.60	Valid	13	0.51	Valid
4	0.61	Valid	14	0.55	Valid
5	0.71	Valid	15	0.73	Valid
6	0.35	Valid	16	0.52	Valid

	Item Number 1-10			Item Number 11-20	
Item Number	Pearson's r	Description	Number	Pearson's r	Description
7	0.65	Valid	17	0.77	Valid
8	0.53	Valid	18	0.68	Valid
9	0.50	Valid	19	0.51	Valid
10	0.54	Valid	20	0.74	Valid

Based on the data presented in Table 5, all questionnaire items have a positive correlation with the total score. All items have Pearson's r values greater than 0.3, which allows for the conclusion that all questionnaire items are valid and can be used. All students from the three selected classes took a pre-test on communication skills and problem-solving skills. The pre-test was conducted within the same timeframe. The test was carried out in a single session lasting 90 minutes, with 60 minutes allocated for the problem-solving test and 30 minutes for completing the communication skills questionnaire. The treatment, using different learning models, was conducted over 30 teaching hours (45 minutes per hour), spanning five weeks. The learning period was the same for each class. Two observers were involved to observe the implementation of the learning model syntax used. The post-test was conducted in a single session after all phases of the learning process had been completed. The data were analyzed using Analysis of Covariance (ANCOVA). This test was chosen to control for differences in the initial ability of each student (Cohen et al., 2009). Before performing the hypothesis test, prerequisite tests were conducted, including normality of distribution, homogeneity of variances, linearity, and homogeneity of regression (Howell, 2010).

FINDING AND DISCUSSION

Normality testing was conducted using the Shapiro-Wilk test. The results of the normality test are presented in Table 6.

Table 6. Result of the Normality Test

Variable	Shapiro-wilk W	p-value
Problem-Solving Skills	0.98	0.21
Communication Skills	0.98	0.27

Based on the data in Table 6, both variables have p-values greater than $\alpha = 0.05$. Therefore, the null hypothesis is accepted. It can be concluded that the data for both variables are normally distributed. The data on problem-solving skills and communication skills meet the normality assumption for ANCOVA testing. Homogeneity of variances was tested using Levene's test. The results of the homogeneity test are presented in Table 7.

Table 7. Result of the Homogeneity of Variance Test

Variabel	F	df1	df2	p-value
Problem-Solving Skills	0.10	2	99	0.89
Communication Skills	0.01	2	101	0.98

Based on the data in Table 7, all three variables show homogeneity of variance test results with p-values greater than $\alpha = 0.05$, indicating that the null hypothesis is accepted. The variances of all three variables across the experimental groups do not differ significantly. Thus, the data for all three variables meet the homogeneity of variances assumption required for ANCOVA. Linearity testing was conducted to determine whether a linear relationship exists between the dependent variable (post-test) and the covariate (pre-test). The linearity test was performed using linear regression analysis. The results are presented in Table 8.

Table 8. Linearity Test Result

Variable	Predictor	Estimate	SE	T	p-value
Problem-Solving Skills	Intercept	32.44	5.33	6.09	<0.001
	Pre-test	0.29	0.07	4.16	<0.001
Communication Skills	Intercept	24.59	3.81	6.45	<0.001
	Pre-test	0.64	0.05	11.07	<0.001

The data in Table 8 show that the linear regression test results for each variable have p-values less than α = 0.05, indicating that the null hypothesis is rejected. This analysis suggests that the covariate, in the form of pre-test scores, has a linear relationship with post-test scores. These results satisfy the linearity assumption required for ANCOVA. The homogeneity of regression slopes test was conducted to determine whether the effect of the covariate is consistent across all experimental groups. The results are presented in Table 9.

Table 9. Result of the Homogeneity of Regression Slopes Test

Variable	df	F	p-value
Problem-Solving Skills	2	2.53	0.085
Communication Skills	2	1.65	0.197

The results of the homogeneity of regression slopes test showed that all variables had p-values greater than α = 0.05, indicating that the null hypothesis is accepted. This result suggests that the regression coefficients do not significantly differ across the experimental groups. Therefore, the data for both variables meet the homogeneity of regression assumption required for ANCOVA. The pre-test and post-test data on problem-solving skills are presented in Table 10. The data in Table 10 indicate that the POPBL-AI class had the highest average post-test score for problem-solving skills, with a mean of 80.4. Meanwhile, the POPBL class had a mean post-test score of 76, and the Regular class had the lowest average score of 59.5.

Table 10. Mean Scores of Pre-Test and Post-Test for Problem-Solving Skills

Group	N	Pre-Test		Post-Test	
		Mean	SD	Mean	SD
Experimental (POPBL-AI)	34	55.1	12.3	80.4	13.7
Positive Control (POPBL)	36	53.9	12.6	76	14.9
Negative Control (Regular)	32	53.1	13.8	59.5	13.2

The POPBL-AI class experienced an increase of 25.3 points. The other two classes also showed improvement, albeit with lower scores. The regular class showed an increase of 6.4 points, while the POPBL class improved by 22.1 points. A comparison of post-test scores for each aspect of problem-solving skills is presented in Figure 2.

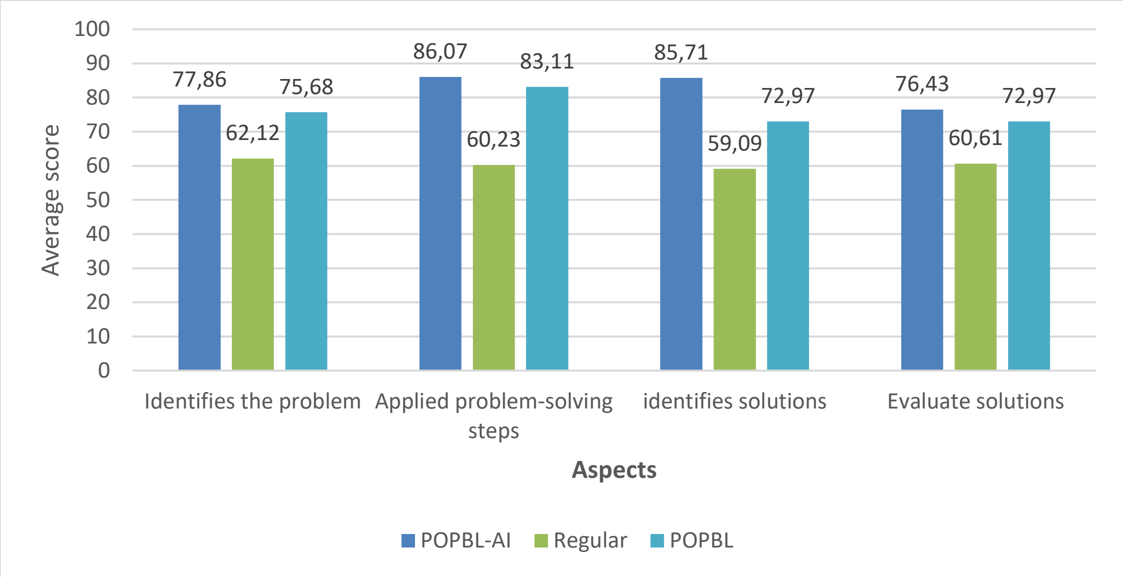

Figure 2 Comparison of Problem-Solving Skills Post-Test Scores for Each Aspect

The data in Figure 2 show that the POPBL-AI class outperformed the other classes across all measured aspects of problem-solving skills. The aspect with the highest mean score was applying problem-solving steps, with a score of 86.07. The aspect with the lowest mean score in the POPBL-AI class was evaluating solutions, with a score of 76.43. The effect of the POPBL-AI model on problem-solving skills was tested by comparing the post-test means of the experimental and control groups, while controlling for the pre-test as a covariate. The statistical test used was a one-way ANCOVA. The ANCOVA results are presented in Table 11.

Table 11. ANCOVA Results for Post-Test Scores in Problem-Solving Skills

	Sum of Squares	df	Mean Square	F	p
Learning Model	7352	2	3676	22.7	< .001
Pre-Test	3424	1	3424	21.1	< .001
Residuals	15901	98	162		

The data in Table 11 indicate that, after controlling for the covariate (pre-test scores), there was a statistically significant difference in the post-test mean scores of problem-solving skills among the experimental groups (p < .001). The results also show that the covariate (pre-test) had a significant effect on the post-test outcomes. The ANCOVA was followed by a post-hoc test to identify specific group differences. The results of the post-hoc test are presented in Table 12.

Table 12. Post-Hoc Test Results for Post-Test Problem-Solving Skills

Comparison						
Learning Model	Learning Model	Mean Difference	SE	df	t	ptukey
POPBL-AI	Regular	19.96	3.14	98.0	6.35	< .001
	POPBL	3.78	3.05	98.0	1.24	0.432
Regular	POPBL	-16.18	3.10	98.0	-5.23	< .001

Note. Comparisons are based on estimated marginal means

The results of the ANCOVA test on the post-test scores of problem-solving skills indicate a significant difference among the experimental groups (p-value < 0.001), after controlling for the pre-test scores as a covariate. The Tukey post-hoc test shows that the adjusted post-test mean of problem-solving skills in the POPBL-AI class is significantly different from that of the Regular model. Meanwhile, compared to the POPBL model, the adjusted mean score of the POPBL-AI model is 3.78 points higher. Although not statistically significant, this mean difference of 3.78 points indicates a potential practical effect of AI integration.

The POPBL-AI model outperforms the other groups across all four aspects of problem-solving skills measured, namely: (1) identifying problems, (2) applying problem-solving steps, (3) identifying various solutions, and (4) evaluating solutions (Greenstein, 2012). The superiority of the POPBL-AI model lies in its student-centered approach, incorporation of contextual and complex problem-solving activities, and more optimal use of technology. According to Arends (2012), problem-solving skills can improve when teachers implement more student-centered learning strategies. Furthermore, the use of technology helps students overcome difficulties in problem-solving, thereby enabling a more effective learning process (Celik, 2023). Integrating AI into problem-based learning has been proven to enhance students' problem-solving skills, particularly in the sciences. This is attributed to AI's role as adaptive scaffolding, enabling students to receive automatic feedback and adjust information based on their level of understanding (Govindasamy & Kwe, 2020).

Student-centered activities and the use of technology are embedded in every phase of the POPBL-AI model. In the first phase, which involves orienting students to the problem, students actively pose essential questions that are not directly answered by the teacher. Instead, they are encouraged to seek the answers independently and discuss them in groups. The teacher serves as a facilitator and corrector when misconceptions occur or when students face difficulties in understanding concepts. AI is used to accelerate the information-seeking process by providing personalized answers based on the students' level of understanding (Willis, 2024). The problem statements solved by each group are not provided by the teacher but are generated by the students themselves. Each student is responsible for proposing a problem statement, which may be enriched through AI suggestions or feedback. These statements are then discussed and selected within the group to determine the most appropriate one based on the criteria established by the teacher.

This activity encourages students not only to use AI as a tool but also to be critical of the information provided by AI. Students actively critique, discuss, and evaluate various proposed problem statements, rather than accepting AI-generated suggestions passively. Students who are more critical of AI are better able to filter relevant ideas and tailor them to their learning needs (Habib et al., 2024). The entire set of activities aims to develop students' skills in identifying problems. By posing and discussing essential questions, students are encouraged to gain a deeper understanding of the issues they are studying. Furthermore, problem formulation activities train them to determine the main focus of their problem-solving efforts, enhancing the effectiveness of the learning process.

In the second phase, organizing students for learning, students study essential concepts and carry out investigations. This phase trains their ability to apply problem-solving steps. Before conducting investigations, students must first formulate topics related to their problem statements. They also need to develop research questions and determine relevant learning resources. AI is utilized to provide suggestions on the material that needs to be studied. It is also used in developing research and interview questions when necessary. Students do not blindly follow AI suggestions but instead discuss and select the best options with their group. The integration of AI into problem-based learning has been shown to help students develop research and investigative strategies, including hypothesis formulation and the selection of appropriate research methods (Su, 2022). Moreover, students with higher AI literacy are better at formulating problem-solving strategies and adjusting their approaches to complex situations, making investigation and data analysis more effective (Promma et al., 2025).

In the third phase, designing and implementing the project, students use the data they have gathered to create solutions and determine the project theme. This activity develops their ability to identify various solutions. Each student may propose different solutions, which are then discussed and selected as the best by the group. AI assists in summarizing data and generating appropriate project ideas based on the information collected. AI is also used to provide feedback on the ideas that have been agreed upon by the group. In line with Habib et al. (2024), AI helps students brainstorm and broaden both the number and depth of ideas they generate. AI also supports logical thinking and the development of more structured solutions (Promma et al., 2025).

In the fourth phase, presenting and evaluating results, students practice defending the solutions they have proposed. They present these solutions in the form of project outputs, while students from other groups evaluate the solutions presented. This activity helps develop students' abilities to evaluate and defend their solutions. Before presenting their project results, students use AI to obtain feedback on their products. These suggestions are then used to make improvements. With the help of AI, students are able to better reflect on their solutions, reduce conceptual errors, and develop more logical arguments (Joksimovic et al., 2023; Suriano et al., 2025).

The strength of the POPBL-AI model in improving problem-solving skills lies in its emphasis on social interaction, real-world problem exploration, and reflection. These activities contribute to the development of critical thinking and problem-solving skills (Almulla, 2023). Based on Vygotsky's sociocultural theory, learning is more effective when students are in the zone of proximal development. In the POPBL-AI model, AI serves as adaptive scaffolding that helps students gradually develop their problem-solving abilities (Govindasamy & Kwe, 2020). The POPBL-AI model is also aligned with cognitive load theory, which suggests that excessive cognitive demand can hinder the learning process (Kirschner et al., 2018). The use of AI to reduce cognitive load is consistent with findings from Zahara et al. (2020), which indicate that reducing cognitive load in problem-based learning can enhance students' problem-solving skills. AI helps reduce intrinsic cognitive load by simplifying complex concepts and providing relevant examples. It also reduces extrinsic cognitive load by offering quick feedback and adaptive interaction in the learning process (Kirschner et al., 2018).

The pre-test and post-test data for communication skills are presented in Table 13. The data in this table show that the POPBL-AI class had the highest average post-test communication skills score (69.1), followed by the POPBL class (66.6), and then the Regular class (63.6).

Table 13. Mean Scores of Pre-Test and Post-Test for Communication Skills

Group	N	Pre-Test		Post-Test	
		Mean	SD	Mean	SD
Experimental (POPBL-AI)	35	66.7	8.42	69.1	7.72
Positive Control (POPBL)	34	63.9	9.76	66.6	7.00
Negative Control (Regular)	35	63.6	7.6	63.6	7.17

The POPBL-AI class experienced an increase in scores of 2.4 points (2.5%), and the POPBL class saw an increase of 2.7 points (4.2%). Meanwhile, the Regular class showed no improvement in communication skills scores. The post-test results of communication skills for each aspect are presented in Figure 3.

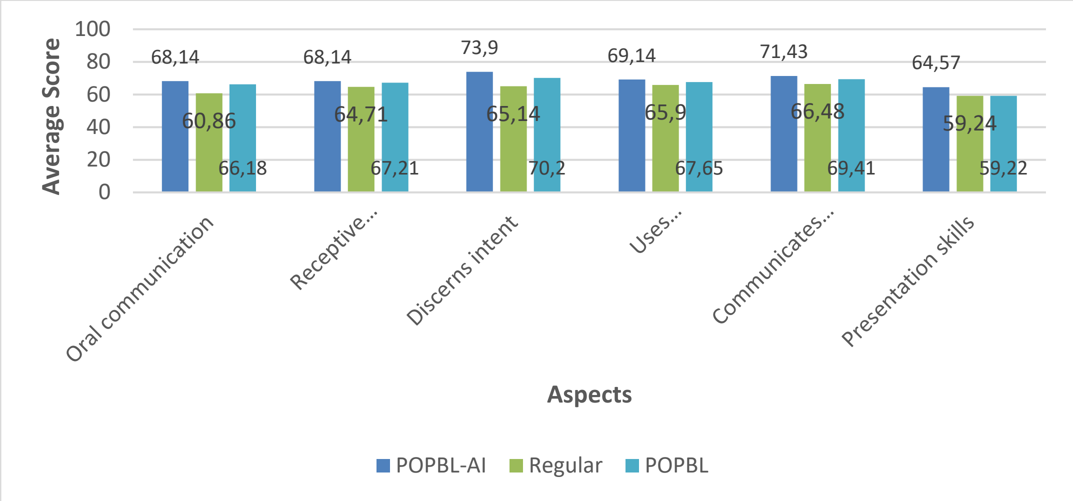

Figure 3. Comparison of Communication Skills Post-Test Scores for Each Aspect

The data in Figure 2 show that the POPBL-AI class had the highest average scores across all aspects of communication skills. The aspect with the highest average score in the POPBL-AI class was “understanding the intent/purpose of communication” with a score of 73.9. Meanwhile, the aspect with the lowest average score in the POPBL-AI class was “presentation skills” with a score of 64.57. The differences in the post-test means of communication skills between the experimental and control groups were analyzed using ANCOVA. The results are presented in Table 14.

Table 14. ANCOVA Result for Communication Skills Post-Test

	Sum of Squares	df	Mean Square	F	p
Learning Model	238	2	119.2	4.87	0.010
Pre-Test	2940	1	2939.5	119.98	< .001
Residuals	2450	100	24.5		

Based on the data in Table 14, the ANCOVA results for communication skills post-test scores showed a p-value = 0.010 < α = 0.05, indicating that the null hypothesis was rejected. This suggests that, after controlling for the covariate (pre-test), there was a statistically significant difference in communication skills post-test scores among the groups. Additionally, the data show that the pre-test had a significant effect on the communication skills post-test scores. The ANCOVA test was followed by a post-hoc test. The post-hoc results are presented in Table 15.

Table 15. Post-Hoc Test Result for Communication Skills Post-Test

Comparison							
Learning Model		Learning Model	Mean Difference	SE	df	t	ptukey
POPBL-AI	-	Regular	3.52	1.20	100	2.94	0.01
	-	POPBL	0.71	1.20	100	0.59	0.82
Regular	-	POPBL	-2.80	1.19	100	-2.35	0.05

Note. Comparisons are based on estimated marginal means

The ANCOVA results for the communication skills post-test scores indicated a significant difference among the treatment groups (p-value = 0.01), after controlling for the pre-test scores as a covariate. The Tukey post-hoc test revealed that the POPBL-AI class had the highest adjusted mean, with a statistically significant difference compared to the Regular class. Meanwhile, the POPBL-AI class scored 0.715 points higher than the POPBL class, although this difference was not statistically significant. This study measured seven aspects of communication skills, namely: (1) oral communication, (2) receptive communication, (3) understanding the purpose of communication, (4) using communication strategies, (5) clarity of communication for specific purposes, (6) effectiveness of communication in various contexts, and (7) interpersonal communication skills (Greenstein, 2012). The results showed that the POPBL-AI model outperformed both POPBL without AI and the Regular model in all aspects. The effectiveness of the POPBL-AI model in enhancing communication skills was supported by various collaborative activities that promoted discussions throughout each phase of the learning process.

According to Arends (2012), communication skills can be improved through discussion-based methods. Discussions provide opportunities for students to express ideas, listen to peers' opinions, respond appropriately, and ask high-quality questions. The POPBL-AI model explicitly integrates various forms of discussion at every stage of learning, thus providing students with more opportunities to develop their communication skills. In the first phase, students watched videos and read articles on the prevalence of smoking among adolescents, aiming to enhance receptive communication skills. Next, students posed essential questions, sought answers using AI, and discussed them in groups. Discussions did not occur immediately after posing questions, but only after students had first searched for answers independently with AI assistance. This approach aligns with the view of Krauss (2013), who stated that thinking individually before group discussion leads to more productive ideas than starting in groups from the outset.

Additionally, AI helped students develop ideas, improve the structure of their arguments, and enhance language clarity (Ciampa et al., 2023). When presenting the information they found, students practiced oral communication skills and applied communication strategies to ensure their messages were understood by group members. Meanwhile, students who were not speaking practiced receptive communication and developed an understanding of the speaker's communication purpose. In the second phase, students actively studied concepts related to their formulated problems. Reading from various sources supported receptive communication and contributed to improvements in oral communication skills. Reading not only enriched understanding but also helped students better organize and present information (Purba et al., 2023). Discussions in the second phase occurred when students divided investigation tasks. According to the collaborative cognitive load theory, collaborative learning can increase working memory capacity by distributing tasks among group members. This reduces individual cognitive load, allowing students to focus more on mastering the content and improving their communication skills (Kirschner et al., 2018).

In the third phase, students formulated solutions and determined project themes. AI was used to suggest potential project themes, which were then discussed in groups. Once a theme was selected, AI was also used to draft the project workflow. According to cognitive load theory, the use of AI helped reduce the cognitive burden, enabling students to concentrate more on communicating project progress rather than spending time manually planning workflows (Willis, 2024). Presentation skills were honed in the fourth phase, during which students presented their project outcomes and received evaluations. Each group presented their projects to the teacher and classmates, followed by a discussion session at the end of the presentation. This allowed students who were not presenting to stay actively engaged in practicing their oral communication skills.

During the presentation sessions, students also learned through observation. In line with Albert Bandura's Social Learning Theory, students do not only learn through direct experience but also through vicarious experiences—observing others in social contexts. Students with stronger communication skills served as models for their peers, allowing communication skills to gradually develop within the group (Chuang, 2021). Before presenting, students used AI to receive initial feedback on their product. After presenting, they received feedback from the teacher, not only regarding the content but also their communication performance. At the end of the learning process, students wrote reflections on their learning experiences. AI assisted in outlining their reflective essays, making it easier for them to articulate their thoughts. Lo and Hsieh (2020) emphasized that continuous feedback from instructors and self-reflection practices are essential elements in the development of effective communication skills.

Although communication skills improved, the post-test results showed that this improvement was lower than the gains in problem-solving skills. Greenstein (2012) stated that communication skills cannot be developed in a short time, but rather require years of practice to reach an optimal level. Therefore, teachers must consistently implement learning models that promote discussion, both among students and between students and teachers (Arends, 2012). Moreover, integrating AI into the learning process can help manage students' cognitive load by delivering content gradually and in alignment with their working memory capacity (Willis, 2024). With this approach, students not only understand the material more effectively but also have the space to develop their communication skills meaningfully.

The findings of this study are consistent with previous research reporting that the integration of artificial intelligence into problem-based or project-based learning can enhance students' learning outcomes (Azamatova et al., 2023; Su, 2022; Wan & Hu, 2022). In contrast to prior studies that primarily focused on cognitive achievement, this study extends existing evidence by demonstrating the contribution of AI-assisted POPBL to the development of 21st-century skills, particularly problem-solving and communication skills, among senior high school biology students. The results of the ANCOVA analysis indicate that students in the POPBL-AI class achieved significantly higher problem-solving and communication skills than those in the regular learning class. When compared with the POPBL class without AI assistance, the POPBL-AI class showed higher adjusted mean scores for both skills; however, these differences were not statistically significant. This finding suggests that the integration of AI in POPBL provides an added instructional support rather than fundamentally altering the effectiveness of the POPBL model itself. The non-significant difference may be attributed to the relatively short intervention duration and students' limited prior experience in utilizing AI as a learning scaffold. Nevertheless, the descriptive advantages observed indicate the potential of AI-assisted POPBL to further strengthen students' 21st-century skills when implemented more intensively.

CONCLUSION

This study demonstrates that the Problem-Oriented Project-Based Learning assisted by Artificial Intelligence (POPBL-AI) model has a statistically significant effect on enhancing students' communication and problem-solving skills compared to the regular learning model. The results of the ANCOVA analysis indicate significant differences among learning models for problem-solving skills ($F = 22.7$, $p < 0.001$) and communication skills ($F = 4.87$, $p = 0.010$) after controlling for students' initial abilities. Post-hoc analysis further shows that the POPBL-AI model resulted in significantly higher adjusted mean scores than the conventional learning model for both skills, while differences between the POPBL-AI and POPBL models without AI were not statistically significant. These findings suggest that artificial intelligence functions as an instructional support that strengthens the effectiveness of the POPBL model rather than replacing its core pedagogical principles. The integration of AI supports students by reducing cognitive load, providing automated feedback, and facilitating broader information exploration during collaborative problem-solving and project activities. In terms of implications, this study highlights the potential of AI-assisted POPBL as an alternative instructional approach for senior high school biology learning to foster 21st-century skills, particularly communication and problem-solving skills, when implemented through well-structured projects and sufficient learning duration.

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