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Enhancing students' communication and collaboration skills through project-based learning in biology

Muhammad Isrul[1*], Andi Asmawati Azis[2], Nurhayati B.[2], Firdaus Daud[2], Muhiddin Palennari[2]

[1]Master's Program in Biology Education, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, Indonesia
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, Indonesia

[*]Corresponding author: isrulhusain01234@gmail.com

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ABSTRACT

Biology learning requires mastery of concepts as well as communication and collaboration skills relevant to the 21st century. This study aims to analyze the effect of implementing deep learning-based Project-Based Learning (PjBL) compared to deep learning-based Direct Instruction (DI) on students' communication and collaboration skills. The study employed a quasi-experimental method using a pretest-posttest nonequivalent control group design. The sample consisted of two 12th-grade classes at State High School 3 Makassar, selected through purposive sampling. The instruments consisted of validated questionnaires on communication and collaboration skills. Data were analyzed using ANCOVA at a significance level of 0.05. The results showed that the learning model had a significant effect on communication skills ($F=53.59$; $p<0.05$) and collaboration skills ($F=8.89$; $p<0.05$) after controlling for initial ability. The posttest average for communication in the PjBL class (84.81) was higher than that in the DI class (70.60), as was the case for collaboration (81.26 vs. 74.00). This study concludes that the deep learning-based PjBL model is more effective than the deep learning-based DI model in improving students' communication and collaboration skills in biotechnology learning.

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INTRODUCTION

Developments in the 21st century require education systems to focus not only on content mastery but also on the development of essential skills such as communication and collaboration

(Zekri et al., 2020). These two skills are key competencies for addressing complex global challenges, where individuals are required to collaborate across disciplines and communicate ideas effectively in various contexts. Communication skills encompass the ability to convey ideas clearly, logically, and persuasively, while collaboration skills emphasize the ability to work productively in teams to achieve shared goals (Dwiningrum, 2019; Zekri et al., 2020).

In line with these demands, current secondary education policies are beginning to steer learning toward a deep learning approach based on three core principles: mindful, meaningful, and joyful learning (Maharani, 2022; Suwandi et al., 2024). This learning approach aims to enable students to focus their learning on deep conceptual understanding, apply the knowledge they have gained in real-world contexts, and, finally, engage in self-reflection following the learning process (Hamruni, 2015; Siswati et al., 2020). This approach not only encourages students to memorize information but also to understand, analyze, and construct knowledge meaningfully through processes of exploration, reflection, and social interaction (Siswati et al., 2020).

In the context of biology education, particularly in biotechnology, the deep learning approach is highly relevant due to the complex, multidisciplinary, and contextual nature of the subject matter (Nurhidayati & Nurhidayati, 2017). Learning biotechnology requires students not only to understand concepts but also to integrate various types of knowledge, discuss ideas, and collaborate in designing solutions to real-world problems (wicaksono et al., 2020; Purnomo et al., 2022; Qurratu'ain et al., 2024). Modern biotechnology topics are also closely linked to controversial issues such as ethical and social concerns regarding the development of genetically modified organisms (GMOs), which require in-depth analysis and communication to raise public awareness of biotechnology issues (Brossard, 2019; Jimenez et al., 2022). Therefore, learning that is solely focused on rote memorization is no longer sufficient to achieve these objectives.

However, the reality on the ground shows that biology instruction is still dominated by a teacher-centered approach that tends to treat students as passive recipients of information (Azizah et al., 2018). The learning process is dominated by one-way communication, with teachers delivering content on biotechnology concepts without creating a learning environment that fosters students' communication and collaboration skills (Heni et al., 2018). This situation results in low levels of students' communication and collaboration skills, due to limited opportunities for discussion, exchanging ideas, and active group work (Sasmito et al., 2017). Several empirical studies also support this finding. Research by Mayani et al. (2023) indicates that high school students' communication skills remain inadequate, as evidenced by their ability to convey ideas both orally and in writing in biology classes. Meanwhile, research by Rahmi et al. (2023) indicates that 37.25% of students' collaboration skills remain in the moderate category, thus not yet reflecting optimal 21st-century skills. Furthermore, the implementation of the deep learning approach in teaching practice remains suboptimal and is often not integrated with appropriate instructional models (Suwandi et al., 2024).

One solution that, in theory, can have a tangible impact on these learning conditions and holds strong potential to support a deep learning approach is the implementation of the Project-Based Learning (PjBL) model (Maharani, 2022; Taufik et al., 2025). This model emphasizes learning through projects based on real-world problems that require students to conduct investigations, develop solutions, and produce outcomes. PjBL was chosen because, by its nature, it facilitates active student engagement, fosters intense social interaction, and provides space for students to construct knowledge independently and collaboratively (Darmawan et al., 2023; Heni et al., 2018; Ramadhani & Subiantoro, 2025; Riasty & Sari, 2024). Furthermore, when PjBL is integrated with a deep learning approach, the learning process focuses not only on project completion but also on the depth of conceptual understanding and the quality of interactions occurring throughout the process. This integration enables students not only to work in groups but also to engage in meaningful discussions, critique ideas, and reflect on their learning outcomes (Setiyaningsih & Subrata, 2023). Thus, learning becomes more focused on developing communication skills through the presentation of ideas and arguments, as well as collaboration skills through constructive interaction (Suriaman et al., 2024).

Theoretically, the integration of PjBL and the deep learning approach has the potential to have a more significant impact on the development of communication and collaboration skills compared to the separate implementation of these learning models. Communication skills develop through presentations, discussions, and scientific argumentation (Wakhudin et al., 2024), while collaboration skills are formed through teamwork involving coordination, active contribution, and respect for differing perspectives (Wakhudin et al., 2024). However, empirical studies specifically examining the integration of these two approaches in the context of biotechnology learning remain limited. Additionally, research measuring communication and collaboration skills often lacks a comprehensive approach. The use of a single type of instrument alone is insufficient to fully describe students' skills. Therefore, measurements involving various instruments, such as observation and questionnaires, are necessary to obtain a more accurate picture of students' skill development.

Based on the above discussion, this study aims to analyze the effectiveness of implementing Project-Based Learning combined with an immersive learning approach on students' communication and collaboration skills in biology, particularly in biotechnology. This research is expected to contribute to the development of learning strategies that align with educational policies and are effective in improving 21st-century skills.

RESEARCH METHODS

Research Design

This study is a quasi-experimental study using a pretest-posttest nonequivalent control group design. This design was chosen because the study was conducted in existing classes without full participant randomization. This study involved two groups: an experimental group and a control group. Both groups were taught using a deep learning-based approach, but implemented through different instructional models. The experimental group used a deep learning-based Project-Based Learning (PjBL) model, while the control group used a deep learning-based Direct Instruction model. The complete research design is presented in Table 1.

Table 1. *Research Design*

Group (Class)	Test	Treatment	Test
Experiment (XII.2)	O1	X1	O2
Control (XII.4)	O1	X0	O2

Information: X1=Project-Based learning model based on deep learning, X0=Direct learning model based on deep learning model, O1=Pre-test, and O2=Post-test.

Population and Samples

The study was conducted at Makassar State High School No. 3. The study population comprised all 12th-grade students in the Biology track, across five classes. The sample was selected using purposive sampling, with attention to the equivalence of academic characteristics, classroom conditions, and research needs. Class XII.2, consisting of 35 students, was designated as the experimental group, while Class XII.4, consisting of 36 students, served as the control group. The selection of sample classes was based on several criteria, namely a relatively homogeneous level of students' prior knowledge, a balanced number of students in each class, similar student characteristics, and an equal allocation of instructional time.

Instruments

The research instrument used a questionnaire to measure students' communication and collaboration skills, based on Greenstein (2012). The research instrument used was validated by two biology education experts from Makassar State University. Communication skills were measured based on six main indicators: oral communication, receptive communication, understanding the meaning of messages, use of communication strategies, the ability to convey information clearly according to the objective, as well as written communication and presentations. The communication questionnaire consisted of 12 items using a Likert scale (1–5) and was deemed highly valid, receiving an average validation score of 93.43 from the two education experts.

Collaboration skills were measured based on ten indicators covering the ability to work in a team, active participation, adaptation to individual differences, appreciation of members' contributions, role distribution, joint problem-solving, orientation toward group goals, responsibility, communication during discussions, and conflict resolution. The collaboration questionnaire consists of 10 items using a Likert scale (1–5) and was found to be highly valid, with an average validation score of 91.67 from two education experts.

Procedures

This study was conducted in several stages, namely a preliminary study, a literature review, the development of teaching materials, the implementation of the study, data analysis, and the preparation of a report and publication of the research results, as illustrated in Figure 1.

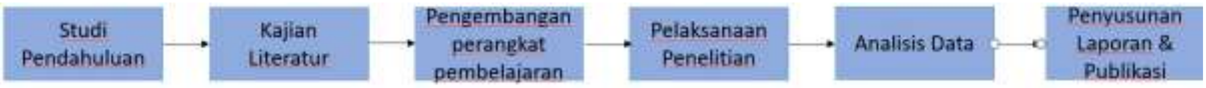

Figure 1. Research Procedure Flowchart

The preliminary study stage was conducted through observations of biology lessons in schools and interviews with subject teachers to identify problems and learning needs. Next, a literature review was conducted to establish the conceptual basis of the research. The subsequent stage involved the development of instructional materials and research instruments tailored to the deep learning approach and the learning model employed. Once all research instruments were ready, two research classes were selected—one as the control group and the other as the experimental group.

The study was conducted over three weeks, with a total of 5 class hours divided into two sessions per week. Before the intervention, both groups took a pretest to assess students' initial communication and collaboration skills. The experimental group received instruction using deep learning-based Project-Based Learning, while the control group used deep learning-based Direct Instruction. After the intervention, both groups were given a posttest to measure changes in student skills. The final stage included data analysis and interpretation, report writing, drawing conclusions, and publication of the research results.

Data Analysis

The research data were analyzed using descriptive and inferential statistics. Descriptive analysis was used to describe the pretest and posttest scores for students' communication and collaboration skills in the experimental and control groups. Before hypothesis testing, the data were first tested through prerequisite tests, namely normality tests, homogeneity tests, and other assumption tests relevant to covariance analysis, such as the linearity of the relationship between covariates and the dependent variable, as well as the homogeneity of regression slopes.

Next, the research hypotheses were tested using Analysis of Covariance (ANCOVA) at a significance level of 0.05. The use of ANCOVA aimed to test the effect of the learning model on posttest scores while controlling for differences in students' initial abilities via pretest scores. In this analysis, posttest scores for communication and collaboration skills were used as dependent variables, while the respective pretest scores for each skill were used as covariates. After all assumptions were met, two separate ANCOVA analyses were conducted, namely: (1) posttest communication skills with pretest communication skills as a covariate, and (2) posttest collaboration skills with pretest collaboration skills as a covariate.

RESULTS

The results of the descriptive analysis for each variable in each integrated learning model incorporating a deep learning approach are presented in Table 2.

Table 2. Descriptive Analysis of Communication Skills

Analysis	PjBL-Deep Learning		DI-Deep Learning	
	Pretest	Posttest	Pretest	Posttest
Mean	64.52	84.80	63.24	70.60
Std Deviation	3.76	3.61	3.62	10.48
N	35	36	35	36

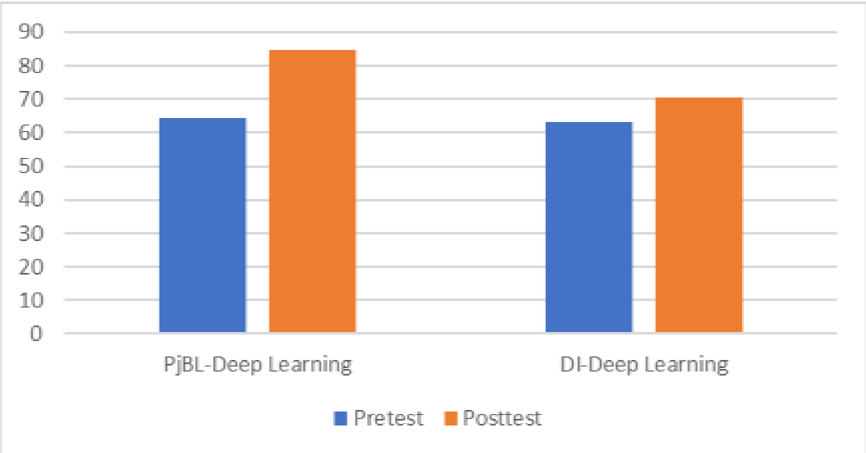

Figure 2. Comparison Chart of Descriptive Analysis Results for Communication Skills

The average initial communication skills in the PjBL class (M = 64.52) and the Direct Instruction class (M = 63.24) also showed relatively comparable levels. This indicates that there was no significant difference in the initial communication skills of the two groups. However, after the intervention, there was a very noticeable increase in the PjBL class (M = 84.81) compared to the Direct Instruction class (M = 70.60). This significant difference indicates that the Project-Based Learning model, based on a deep learning approach, has a stronger impact on improving students' communication skills. This is due to the characteristics of PjBL learning, which require students to actively discuss, present project results, and convey ideas and arguments both orally and in writing.

Table 3. Descriptive Analysis of Collaboration Skills

Analysis	PjBL-Deep Learning		DI-Deep Learning	
	Pretest	Posttest	Pretest	Posttest
Mean	60.57	81.25	61.66	74.00
Std Deviation	4.53	10.30	4.15	10.58
N	35	36	35	36

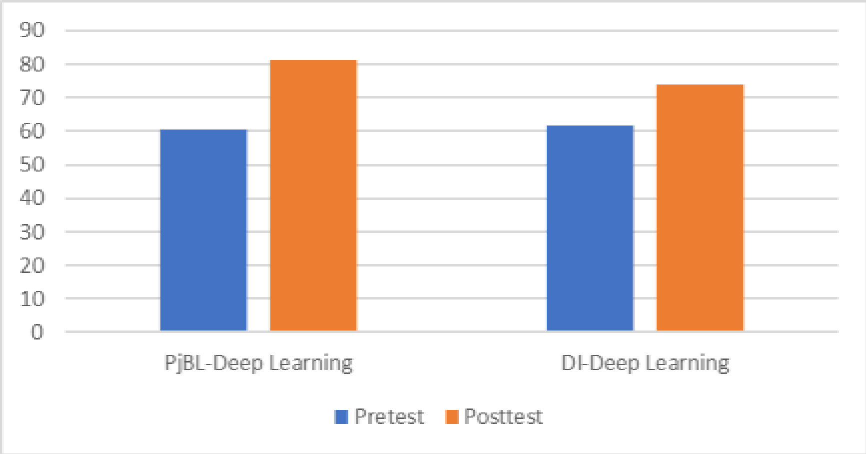

Figure 3. Comparison Chart of Descriptive Analysis Results for Collaboration Skills

The results of the descriptive analysis show that the average initial collaboration skills of students in the PjBL class (M = 60.57) and the Direct Instruction class (M = 61.67) were relatively comparable. This indicates that before the intervention, both groups had comparable collaboration skills. After the intervention, there was an increase in both groups; however, the increase in the PjBL class (M = 81.26) was higher than that in the Direct Instruction class (M = 74.00). This significant difference in the increase indicates that the Project-Based Learning model based on a deep learning approach is more effective in improving students' collaboration skills. This improvement can be explained by the fact that in PjBL, students are actively involved in group work, task division, and shared responsibility in completing projects, thereby encouraging all group members to participate collaboratively.

Table 4. Normality Test Results

Model		Sig
Communication Skill Posttest	PJBL-Deep Learning	0.30
	DI-Deep Learning	0.06
Collaboration skill posttest	PJBL-Deep Learning	0.25
	DI-Deep Learning	0.06

The results of the normality test using the Shapiro-Wilk test indicate that the posttest data for communication skills in the experimental group (Sig. = 0.306) and the control group (Sig. = 0.059), as well as the posttest data for collaboration skills in the experimental group (Sig. = 0.258) and the control group (Sig. = 0.060), are normally distributed (Sig. > 0.05).

Table 5. Homogeneity Test Results

	Model	Sig
Levene Test	Communication skill posttest	0.001
	Collaboration skill posttest	0.639

The results of the preliminary analysis tests indicate that the data are normally distributed based on the Shapiro-Wilk test (Sig. > 0.05). The Levene test for homogeneity of variances showed that the variances of the collaboration skills data were homogeneous (Sig. = 0.639 > 0.05), whereas those for communication skills were not homogeneous (Sig. = 0.001 < 0.05). Nevertheless, the analysis proceeded using ANCOVA because the sample sizes between groups were relatively balanced ($n_1 = 35$; $n_2 = 36$).

Table 6. Results of the ANCOVA Analysis of Communication Skills Variables

ANCOVA	F	Sig.
Communication skill pretest	0.52	0.47
Model	53.59	0.00

The ANCOVA analysis results indicate that the instructional model has a significant effect on students' communication skills after controlling for initial ability ($F = 53.591$; $p < 0.05$). Furthermore, the covariate of initial communication ability does not have a significant effect on posttest scores ($p = 0.471 > 0.05$). The coefficient of determination ($R^2 = 0.459$) indicates that the learning model contributes significantly to the variation in students' communication skills.

Table 7. Results of ANCOVA Analysis for Collaboration Skills Variables

ANCOVA	F	Sig.
Collaboration skill pretest	0.49	0.48
Model	8.89	0.004

The ANCOVA analysis results indicate that the instructional model has a significant effect on students' collaboration skills after controlling for initial ability ($F = 8.891$; $p < 0.05$). The covariate of initial collaboration skills does not have a significant effect on posttest scores ($p = 0.483 > 0.05$). The coefficient of determination ($R^2 = 0.117$) indicates that the learning model contributes to collaboration skills, albeit in the low to moderate range.

DISCUSSION

The results of the descriptive analysis indicate that the initial abilities of the students in both groups were relatively comparable. For the communication skills variable, the average score for the PjBL class was 64.52, and for the Direct Instruction class was 63.24. Meanwhile, for the collaboration skills variable, the average for the PjBL class was 60.57, and for the Direct Instruction class was 61.67. This very small difference indicates that both groups had comparable initial conditions before the treatment was administered. Thus, differences in posttest results can be more validly interpreted as a result of the application of the learning model, rather than due to differences in initial ability.

Data on the communication skills variable showed a greater improvement compared to collaboration. The average communication ability in the PjBL class increased to 84.81, while in the Direct Instruction class, it reached only 70.60. This significant difference indicates that PjBL, based on a deep learning approach, has a significant impact on students' communication abilities. This improvement is closely tied to the learning activities in PjBL, which require students to present ideas in group discussions, construct data-based arguments, present project results using the gallery walk method—which facilitates dynamic two-way interaction among students—and provide and receive feedback. Throughout the learning process, presentations, discussions, and reflections are an integral part of the learning framework. These activities directly develop students' scientific communication skills, both oral and written. However, the results of the homogeneity test indicate that the variance in the communication variable is not homogeneous. This suggests that improvements in communication skills are not evenly distributed across all students.

Regarding the variable of students' collaboration skills, after the intervention, there was an increase in collaboration skills in both groups. However, the increase in the class that used the Project-Based Learning (PjBL) model based on the deep learning approach ($M = 81.26$) was higher than that in the Direct Instruction class ($M = 74.00$). This difference in improvement indicates that PjBL is more effective in enhancing students' collaboration skills. This can be explained by the characteristics of the PjBL model, which emphasizes group work as the core of learning. In the experimental class, students were actively engaged in collaborative project planning, task distribution within groups, joint monitoring and evaluation, and collective problem-solving. These activities systematically encouraged every group member to participate, so that collaboration skills developed relatively evenly among students. This was also reinforced by the homogeneity test results, which showed that the variance in collaboration was homogeneous. This means that the improvement in collaboration skills occurred consistently among most students, not just in certain individuals.

This improvement in collaboration skills can be explained by the syntactic characteristics of PjBL, which place students at the center of learning. In the learning process, students are actively involved in planning, implementing, and evaluating projects in groups. Activities such as task division, group discussions, and shared responsibility in completing the project encourage every group member to contribute. This aligns with the statement by Azizah & Widjajanti (2019) that social interactions occurring during learning play a crucial role in developing collaborative skills evenly.

Unlike collaboration skills, improvements in communication skills exhibit a more varied pattern. Research findings indicate that the average communication skills in PjBL classes are significantly higher than those in Direct Instruction classes. This suggests that PjBL has a stronger impact on students' ability to convey ideas, engage in discussions, and present their work. This improvement is closely linked to the learning activities in PjBL, which provide ample opportunities for students to communicate. Group discussions, project presentations, and direct peer feedback among groups directly train students' scientific communication skills. This argument is supported by Dewi et al. (2020), who state that the deep learning approach applied in instruction encourages students to understand concepts deeply and connect them to real-world contexts, thereby making students more confident in expressing their ideas.

However, the results of the assumption tests indicate that the variance in communication skills is not homogeneous. This suggests that improvements in communication skills did not occur uniformly across all students. These differences are likely influenced by individual factors, such as self-confidence, willingness to express opinions, and each student's verbal ability. In other words, although PjBL provides an environment that supports communication, the extent to which students take advantage of these opportunities varies from one individual to another. Meanwhile, regarding collaboration skills, the homogeneous variance indicates that skill improvement occurs relatively evenly across all students. This is understandable because collaborative activities in PjBL are structured, with each student having a role and responsibility within the group. This structure ensures all students are engaged in the learning process, thereby reducing individual differences.

The results of the study indicate that there was an improvement in students' communication and collaboration skills following the implementation of a deep learning-based instructional model. This improvement was more significant in the class that used the Project-Based Learning (PjBL) model compared to the Direct Instruction class. Based on the results of the descriptive analysis, the initial abilities of students in both groups were relatively equivalent, both in communication and collaboration skills. This indicates that there were no significant differences in initial abilities between the two groups, so the changes observed in the posttest phase can be attributed to the instructional treatment provided.

The application of the deep learning approach in this study emphasizes mindful, meaningful, and joyful learning. This aligns with Trinova's (2012) research, which states that the deep learning approach encourages students not only to passively receive information but also to deeply understand concepts, connect knowledge to real-world contexts, and actively engage in the learning process. In this context, the learning model serves as a vehicle for implementing this approach, so that the effectiveness of learning is determined not only by the model but also by how the deep learning approach is integrated into each stage of learning.

In classes that use a deep learning-based PjBL model, students engage in a learning process that requires exploration, reflection, and the construction of knowledge—both independently and collaboratively. Activities such as project planning, group discussions, contextual problem-solving, and project presentations provide opportunities for students to develop communication and collaboration skills simultaneously. The deep learning approach reinforces this process by encouraging students to understand the meaning behind each activity, rather than merely completing tasks.

The research findings indicate that students' collaboration skills in PjBL classes are higher than those in Direct Instruction classes. This can be explained by the fact that in PjBL, collaboration is an inherent part of the learning process (Saenab, 2019). With the support of the deep learning approach, collaborative activities are not merely mechanical but also reflective and meaningful. Students do not merely work in groups but also understand the purpose of cooperation, value the contributions of group members, and develop shared responsibility in completing projects. Interestingly, the results of the homogeneity test indicate that the variance in collaborative skills is homogeneous. This suggests that the deep learning approach integrated into PjBL is able to foster relatively even engagement among all students. In other words, this approach successfully creates an inclusive learning environment where every student has an equal opportunity to contribute to collaborative activities.

The research findings indicate that students' collaboration skills in PjBL classes are higher than those in Direct Instruction classes. This can be explained by the fact that in PjBL, collaboration is an inherent part of the learning process (Saenab, 2019). With the support of the deep learning approach, collaborative activities are not merely mechanical but also reflective and meaningful. Students do not merely work in groups but also understand the purpose of cooperation, value the contributions of group members, and develop shared responsibility in completing projects. Interestingly, the results of the homogeneity test indicate that the variance in collaboration skills is homogeneous. This suggests that the deep learning approach integrated into PjBL is able to foster relatively even engagement among all students. In other words, this approach successfully creates an inclusive learning environment where every student has an equal opportunity to contribute to collaborative activities.

However, the non-homogeneous variance in communication skills indicates that improvements in communication ability are influenced by individual factors. Not all students are able to make optimal use of communication opportunities. This suggests that although the deep learning approach creates a supportive environment, internal factors such as self-confidence, the courage to speak up, and verbal ability still play a significant role in determining the final outcome. Nevertheless, in general, the implementation of PjBL has proven effective in improving students' communication and collaboration skills, as stated by Kumalaretna and Mulyono (2017) that PjBL can enhance students' mathematical communication skills and collaborative character, as evidenced by classical mastery and improved learning outcomes. Conversely, in deep learning-based Direct Instruction classes, although the same approach is applied, the limited interaction in the learning model results in fewer opportunities for communication and collaboration. This aligns with Mutohhari et al. (2021), who state that the deep learning approach requires a learning model that supports active and interactive activities to optimally impact 21st-century skills.

Thus, the results of this study indicate that the effectiveness of the deep learning approach is significantly influenced by the instructional model employed. The integration of the deep learning approach with the PjBL model proved to be more effective in enhancing communication and collaboration skills compared to the integration of the same approach within the Direct Instruction model. This underscores that meaningful and deep learning requires activity designs that enable students to be active, interact, and collaborate in constructing knowledge.

CONCLUSION

Based on the research findings and discussion, it can be concluded that both learning models are capable of improving students' communication and collaboration skills. The implementation of the deep learning-based Project-Based Learning (PjBL) model is more effective than the deep learning-based Direct Instruction (DI) model in improving students' communication and collaboration skills in biotechnology education. This effectiveness is demonstrated by the higher average posttest scores in the PjBL group and the significant ANCOVA test results for both skills. These findings confirm that the integration of the deep learning approach with active and collaborative learning models such as PjBL can create meaningful, reflective, and enjoyable learning experiences, thereby contributing optimally to the development of 21st-century skills. As a recommendation, biology teachers are advised to implement deep learning-based PjBL in a structured manner, and future researchers may test its effectiveness on different subject matter or educational levels while considering individual factors such as students' self-confidence and verbal abilities.

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