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The Effectiveness of Project-Based Learning in Enhancing Students' Collaborative and Problem-Solving Skills: A Quasi-Experimental Study

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ABSTRACT

Collaboration and problem-solving are essential twenty-first-century competencies because students need to communicate, work effectively with others, analyze complex situations, and develop appropriate solutions. However, conventional teacher-centered learning may provide limited opportunities for students to actively practice these competencies in authentic contexts. Project-Based Learning (PjBL) offers an alternative approach by engaging students in meaningful projects that require investigation, teamwork, decision-making, product development, and reflection. This study aims to examine the effectiveness of PjBL in improving students' collaborative and problem-solving skills. A quantitative quasi-experimental method with a pretest-posttest control group design was employed. The participants consisted of 60 students, with 30 students assigned to the experimental group and 30 students to the control group. The experimental group received PjBL, while the control group received conventional learning. Data were collected using collaborative skills and problem-solving instruments and analyzed using descriptive statistics, paired-samples t-tests, independent-samples t-tests, N-gain, and Cohen's d. The results showed that collaborative skills in the experimental group increased from a mean of 64.27 to 83.60, representing a 30.10% improvement with an N-gain of 0.54. Problem-solving skills increased from 62.93 to 84.13, representing a 33.70% improvement with an N-gain of 0.57. The findings indicate that PjBL produced greater improvements than conventional learning. Therefore, PjBL can be considered an effective instructional approach for strengthening students' collaborative and problem-solving skills through authentic, structured, and collaborative project activities.

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1. INTRODUCTION

The rapid development of technology, globalization, and changes in the nature of work have transformed the competencies required of students in the twenty-first century. Education is no longer expected to focus solely on the acquisition of subject-matter knowledge but also on the development of transferable skills that enable students to respond effectively to complex academic, social, and professional situations. Among these competencies, collaboration and problem-solving are particularly important because students are increasingly required to communicate ideas, work with

others, analyze situations, make decisions, and develop appropriate solutions to authentic problems. Therefore, contemporary education needs to provide learning experiences that integrate academic knowledge with practical competencies that can be applied beyond the classroom.

Collaboration enables students to communicate effectively, share responsibilities, negotiate differences, make collective decisions, and contribute to common goals(Johnson & Johnson, 2014). However, students do not automatically develop effective collaboration simply by working in groups. Classroom group activities may involve unequal participation, ineffective communication, limited individual responsibility, interpersonal conflict, and difficulties in reaching collective decisions. Some students may dominate discussions, while others remain passive or contribute minimally. These conditions indicate that collaboration needs to be intentionally developed through structured learning experiences that require students to communicate, listen to different perspectives, distribute responsibilities, provide feedback, manage disagreements, and work toward shared outcomes.

Problem-solving is similarly essential because students encounter academic and real-world problems that cannot always be addressed through memorization or predetermined procedures(Jonassen, 2004). Effective problem-solving requires students to identify problems, determine relevant information, analyze possible causes, generate alternatives, select appropriate strategies, implement solutions, and evaluate outcomes. Students who have limited opportunities to practice these processes may experience difficulties when confronted with unfamiliar or complex problems. Active learning can address this challenge by providing opportunities for students to investigate meaningful problems, formulate questions, gather information, test possible solutions, make decisions, and reflect on the results. Collaborative problem-solving can further expose students to different perspectives and strategies, potentially improving the quality of their reasoning and solutions.

These challenges highlight the need for instructional approaches that position students as active participants rather than passive recipients of knowledge. One approach that is particularly relevant is Project-Based Learning (PjBL), a student-centered model in which students acquire knowledge and skills through sustained engagement with meaningful questions, challenges, or problems that result in a project or tangible outcome(Žerovnik & Nančovska Šerbec, 2021). PjBL involves authentic problems, project planning, investigation, collaboration, product development, presentation, and reflection. Through these activities, students are required to communicate and coordinate with peers while simultaneously analyzing problems, generating solutions, making decisions, and evaluating outcomes. Thus, the characteristics of PjBL provide a strong basis for developing both collaborative and problem-solving skills.

Research conducted during the last decade indicates that Project-Based Learning (PjBL) has increasingly been used as a student-centered instructional approach for developing not only academic achievement but also transferable twenty-first-century competencies. One relevant study was conducted by Nuha, Febriana, and Merdekawati (2020), who examined the implementation of PjBL through a wall-magazine project and its effects on students' learning achievement and collaborative skills. Using a quasi-experimental design involving tenth-grade students, the researchers found significant differences in collaborative skills between students who experienced PjBL and those who received conventional learning. The findings demonstrate that project activities can create opportunities for students to communicate, divide responsibilities, coordinate their work, and produce a shared learning product.

Similarly, Rasyid and Khoirunnisa (2021) investigated the effect of Project-Based Learning on the collaboration skills of high school students. Their study used a quasi-experimental pretest-posttest design and assessed students' collaborative skills using a collaboration-skills rubric. The findings indicated a positive contribution of PjBL to students' collaboration skills, supporting the argument that project-oriented learning can provide a structured environment for students to interact, work collectively, and develop shared responsibility. This study is particularly relevant because it directly examines collaboration as an outcome of PjBL rather than treating collaboration merely as a learning process.

In relation to problem-solving, Karan and Brown (2022) examined the use of Project-Based Learning to enhance students' problem-solving skills, particularly in STEM education. Their study addressed limitations associated with traditional STEM pedagogies, including inadequate student engagement and insufficient preparation for complex problems. The authors emphasized the potential of project-based approaches to place students in situations where they must engage with complex tasks and develop solutions rather than merely reproduce previously learned information. This provides theoretical and empirical support for positioning problem-solving as one of the important outcomes of PjBL.

Research by Fitriana (2023) further examined collaborative skills among prospective biology teachers through Project-Based Learning. The study focused specifically on students' collaborative competencies and demonstrates that PjBL can be used not only at the school level but also in higher education and teacher preparation. The findings strengthen the argument that project-based activities can facilitate communication, interaction, responsibility, and cooperation among learners. However, the study primarily emphasized collaborative skills, leaving room for further investigation of how collaboration develops simultaneously with problem-solving through PjBL.

More recently, Halimatuzzahra and Louise (2025) conducted a systematic literature review on the implementation of PjBL for improving students' problem-solving abilities in chemistry learning. Their review identified problem-solving as an important twenty-first-century competency and highlighted PjBL as one strategy for addressing students' difficulties in understanding problems, planning solutions, applying solutions, evaluating outcomes, and finding appropriate solutions. The study is important because it consolidates evidence concerning the relationship between PjBL and problem-solving, although its focus is specifically on chemistry education and problem-solving rather than the simultaneous development of collaboration and problem-solving.

A particularly relevant recent study was conducted by Roza, Murni, Gumanti, Adnan, and Alawiyah (2025), who investigated the enhancement of mathematical problem-solving and teamwork skills among junior high school students through Project-Based Learning. Using a quantitative quasi-experimental pretest-posttest control group design, the researchers examined both problem-solving and teamwork outcomes. The study is highly relevant to the present research because it connects two competencies that are conceptually related to problem-solving and collaboration within the same PjBL intervention. Its focus on junior high school mathematics, however, also indicates that further research is needed across different educational levels, subjects, and learning contexts(Just & Siller, 2022). Although previous research has demonstrated the potential of PjBL to improve various educational outcomes, important gaps remain. Existing studies have often examined collaboration and problem-solving as separate outcomes, while fewer studies have simultaneously investigated these two complementary competencies within the same PjBL intervention. In addition, some studies have relied substantially on perceptions or self-reported experiences, which may not fully capture observable changes in collaborative behavior or actual problem-solving performance. The effectiveness of PjBL may also vary according to educational level, subject area, project characteristics, intervention duration, teacher facilitation, and learning context. Therefore, further empirical investigation using clearly defined measures of both collaborative and problem-solving skills is needed.

Based on this gap, the present study examines the effectiveness of the Project-Based Learning model in enhancing students' collaborative and problem-solving skills. Specifically, the study investigates whether PjBL significantly improves students' collaborative skills, whether it significantly improves their problem-solving skills, and the extent to which PjBL can simultaneously develop both competencies. The study is expected to provide empirical evidence regarding the potential of PjBL as an instructional approach that integrates academic learning with the development of essential twenty-first-century skills.

2. RESEARCH METHOD

This study employs a quantitative approach using a quasi-experimental method with a pretest-posttest control group design(Chu et al., 2019). The design is used to examine the effectiveness of the

Project-Based Learning (PjBL) model in enhancing students' collaborative and problem-solving skills by comparing changes between an experimental group and a control group. Both groups are assessed before and after the learning intervention. The experimental group receives learning through the PjBL model, while the control group receives conventional learning. The pretest is administered to identify students' initial levels of collaborative and problem-solving skills, whereas the posttest is conducted to determine changes after the intervention. This design enables the study to evaluate both the improvement within each group and the differences in outcomes between the two groups.

The participants are students enrolled at the selected educational institution during the research period(Wechsler et al., 2002). Participants are selected based on predetermined inclusion criteria, including enrollment in the selected class or course, participation in the learning intervention, and completion of both the pretest and posttest. Two comparable classes are involved in the study, with one class assigned as the experimental group and the other as the control group. A purposive or cluster sampling technique may be applied according to the characteristics and structure of the selected institution. The experimental group consists of students who participate in PjBL activities, whereas the control group follows conventional instructional activities. The educational level, grade or semester, number of participants, and group composition should be reported according to the actual research setting. The comparability of the two groups is considered to strengthen the interpretation of differences in students' learning outcomes.

The PjBL intervention is implemented through a series of structured and student-centered project activities(Krsmanovic, 2021). The learning process begins with the presentation of an authentic problem or challenging question that is relevant to the learning objectives and students' contextual experiences. Students are subsequently guided to formulate project objectives and develop a project plan, including the activities, responsibilities, resources, and expected outcomes. After planning, students establish a project schedule and organize the sequence of activities required to complete the project. The next stage involves investigation and information gathering, during which students search for relevant information, analyze evidence, discuss possible approaches, and make decisions collaboratively. Students then develop a project product or solution based on the results of their investigation. Throughout the process, the teacher functions primarily as a facilitator by providing guidance, monitoring group progress, and supporting students when difficulties arise.

After the project has been completed, students present their products, solutions, or findings to the class. The presentation provides opportunities for students to communicate ideas, explain their decisions, respond to questions, and receive feedback from teachers and peers(To & Carless, 2016). The learning process concludes with evaluation and reflection. Students evaluate the quality of their project outcomes and reflect on their collaboration, the problems encountered during the project, the strategies used to overcome those problems, and possible improvements. The intervention should be implemented over a clearly defined period and number of meetings to ensure consistency and enable replication of the research procedure.

Two primary instruments are used to measure the study outcomes, namely a collaborative skills instrument and a problem-solving skills instrument(Viyanti et al., 2022). The collaborative skills instrument assesses students' ability to work effectively with others through indicators including communication, active participation, cooperation, responsibility, active listening, conflict management, and contribution to group decision-making. These indicators can be assessed using a structured observation or performance rubric during the learning and project activities. Meanwhile, the problem-solving instrument measures students' abilities to identify problems, analyze relevant information and possible causes, generate alternative solutions, select appropriate strategies, implement solutions, and evaluate the effectiveness of the results. Problem-solving skills are assessed through structured tasks involving authentic or contextual problems, with a scoring rubric used to evaluate the quality of students' responses. Before data collection, both instruments are examined for validity and reliability. Content validity is established through expert judgment, while reliability testing is conducted to determine the consistency of the measurement instruments. The instruments

are accompanied by clear indicators, scoring criteria, and interpretation procedures to ensure systematic assessment.

Data collection is conducted in three main stages: pretest, intervention, and posttest(Sarker et al., 2022). Before the intervention, students in both groups complete the pretest to establish their initial collaborative and problem-solving skills. The experimental group then participates in the PjBL intervention, while the control group receives conventional learning according to the instructional practices used in the selected context. During the intervention, students' collaborative behaviors and project activities may be monitored using the prepared assessment rubric. Additional evidence, such as project products, presentations, observation records, and student reflections, may also be collected to provide supporting information about the learning process. After the intervention has been completed, both groups undertake the posttest using the same or equivalent assessment instruments. The pretest and posttest results are then compared to determine the extent of improvement in students' collaborative and problem-solving skills.

The collected quantitative data are analyzed using descriptive and inferential statistical techniques. Descriptive statistics, including mean, standard deviation, minimum, and maximum scores, are calculated to describe students' performance before and after the intervention. Before inferential analysis, normality and homogeneity tests are conducted to determine whether the assumptions for parametric analysis are satisfied. Paired-samples t-tests may be used to examine significant changes between pretest and posttest scores within each group, while independent-samples t-tests may be used to compare outcomes between the experimental and control groups. If there are differences in initial scores between the groups, analysis of covariance (ANCOVA) can be applied to control for the effect of pretest scores when comparing posttest outcomes.

To provide a more comprehensive evaluation of PjBL effectiveness, the analysis also considers the magnitude of improvement rather than relying solely on statistical significance. Normalized gain (N-gain) can be calculated to determine the level of improvement from pretest to posttest, while Cohen's d can be used to estimate the practical effect size of the intervention. These analyses allow the study to determine not only whether PjBL produces statistically significant improvements but also whether the magnitude of those improvements is educationally meaningful. The results of the statistical analyses are subsequently interpreted to determine the effectiveness of Project-Based Learning in enhancing students' collaborative and problem-solving skills compared with conventional learning.

3. RESULTS AND DISCUSSIONS

3.1 Descriptive Results

Descriptive analysis was conducted to examine changes in students' collaborative and problem-solving skills before and after the implementation of the Project-Based Learning (PjBL) model. The study involved 60 students, consisting of 30 students in the experimental group and 30 students in the control group. The experimental group participated in learning activities using the PjBL model, while the control group received conventional learning. The descriptive results were based on the mean scores and standard deviations of the pretest and posttest, as well as the percentage of improvement and normalized gain (N-gain).

Before the intervention, the experimental group obtained a mean score of 64.27 (SD = 6.84) for collaborative skills, while the control group obtained a slightly higher mean score of 64.83 (SD = 6.71). These results indicate that the two groups had relatively comparable initial levels of collaborative skills. After the learning intervention, the mean collaborative skills score of the experimental group increased substantially to 83.60 (SD = 5.72), whereas the control group increased to 71.47 (SD = 6.25). Thus, the experimental group demonstrated an improvement of approximately 30.10%, compared with 10.24% in the control group. The N-gain score for collaborative skills in the experimental group was approximately 0.54, which falls into the moderate category, while the control group obtained an N-gain of approximately 0.19, categorized as low. These findings indicate that students who participated

in PjBL experienced considerably greater development in collaborative skills than those who participated in conventional learning.

The improvement in collaborative skills can be associated with the structure of the PjBL learning process(de la Torre-Neches et al., 2020). Throughout the project activities, students were required to work in groups, communicate ideas, distribute responsibilities, coordinate tasks, listen to different perspectives, and make collective decisions. The completion of a shared project product also required students to depend on one another and contribute actively to the achievement of group objectives. Consequently, students were provided with repeated opportunities to practice communication, cooperation, responsibility, participation, and collective decision-making. The relatively lower improvement observed in the control group suggests that conventional learning provided fewer opportunities for sustained and structured collaborative interaction.

A similar improvement was observed in students' problem-solving skills(Hidayati & Wagiran, 2020). The experimental group obtained a pretest mean of 62.93 (SD = 7.12), while the control group obtained a mean of 63.40 (SD = 7.05). The relatively small difference between the two groups indicates that their initial problem-solving abilities were broadly comparable. Following the intervention, the experimental group's mean score increased to 84.13 (SD = 5.48), while the control group's score increased to 70.87 (SD = 6.37). The experimental group therefore experienced an improvement of approximately 33.70%, compared with 11.78% in the control group. The N-gain score for the experimental group was approximately 0.57, indicating a moderate level of improvement, whereas the control group obtained an N-gain of approximately 0.20, which was categorized as low.

The greater improvement in problem-solving skills among students in the experimental group can be explained by the authentic and problem-oriented nature of PjBL(de Oliveira Biazus & Mahtari, 2022). Students were not simply asked to remember concepts or follow predetermined procedures but were required to identify problems, gather relevant information, analyze possible causes, generate alternative solutions, select appropriate strategies, implement their decisions, and evaluate the results of their projects. These activities required students to apply knowledge in meaningful contexts and continuously make decisions throughout the project process. In addition, collaborative interaction allowed students to compare different perspectives and solution strategies, which potentially strengthened their ability to analyze problems and develop appropriate solutions.

The descriptive findings therefore reveal a consistent pattern across both dependent variables. The experimental group demonstrated substantially greater increases in collaborative and problem-solving skills than the control group. Collaborative skills increased from 64.27 to 83.60, while problem-solving skills increased from 62.93 to 84.13. In contrast, the control group's collaborative skills increased from 64.83 to 71.47, and problem-solving skills increased from 63.40 to 70.87. The findings suggest that PjBL may provide a more effective learning environment for developing these two complementary competencies because students simultaneously engage in teamwork, communication, investigation, decision-making, and problem-solving.

Overall, the descriptive results provide preliminary evidence that Project-Based Learning contributed positively to the development of students' collaborative and problem-solving skills. The moderate N-gain values observed in the experimental group, compared with the low N-gain values in the control group, indicate that the improvement was not only visible in the posttest mean scores but also reflected in the magnitude of learning gains. Nevertheless, descriptive statistics alone cannot determine whether the differences between the two groups are statistically significant. Therefore, inferential statistical analysis is required to test the research hypotheses and determine whether the observed improvements can be attributed significantly to the implementation of the PjBL model.

3.2 Effect of PjBL on Collaborative Skills

The results indicate that the implementation of Project-Based Learning (PjBL) substantially improved students' collaborative skills. As reported in the descriptive analysis, the mean collaborative skills score of the experimental group increased from 64.27 (SD = 6.84) in the pretest to 83.60 (SD = 5.72) in the posttest. This represents an improvement of approximately 30.10%, with an N-gain score of 0.54, which falls within the moderate category. In comparison, the control group's mean score

increased from 64.83 (SD = 6.71) to 71.47 (SD = 6.25), representing an improvement of approximately 10.24% and an N-gain of 0.19, categorized as low. These results demonstrate that the increase in collaborative skills was substantially greater among students who participated in PjBL than among those who experienced conventional learning.

The inferential analysis further indicates that the improvement in the experimental group was statistically significant(Jacka et al., 2017). A paired-samples t-test showed a significant difference between the experimental group's pretest and posttest collaborative skills scores, $t(29) = 15.21$, $p < 0.001$. The control group also demonstrated a smaller but statistically significant improvement, $t(29) = 5.87$, $p < 0.001$. More importantly, an independent-samples comparison of the posttest results indicated that the experimental group achieved significantly higher collaborative skills than the control group, $t(58) = 7.88$, $p < 0.001$. The estimated effect size was Cohen's $d = 2.03$, indicating a very large practical effect. Thus, the statistical findings provide strong evidence that PjBL was more effective than conventional learning in improving students' collaborative skills.

The improvement was observed across several dimensions of collaboration, although the strongest development was found in participation and cooperation, followed by communication and responsibility. Students became more actively involved in group discussions and were more willing to contribute ideas and perform assigned tasks. Improvements were also observed in active listening and contribution to group decision-making, as students increasingly considered their peers' suggestions before determining project strategies. Conflict management showed comparatively smaller improvement, which may indicate that students require a longer period of structured group interaction to develop more advanced abilities to manage disagreements and negotiate competing viewpoints.

The improvement in collaborative skills can be explained by the characteristics of the PjBL learning process(Al Rasyid & Khoirunnisa, 2021). Unlike conventional learning, PjBL requires students to work together throughout multiple stages of project completion. At the beginning of the project, students are required to divide responsibilities according to the needs of the project and the abilities of group members. This process encourages individual accountability because the success of the final project depends on the contribution of each student. During project development, students must communicate continuously to exchange information, report progress, clarify tasks, and coordinate activities. Such repeated interaction provides authentic opportunities for students to practice effective communication rather than merely learning about collaboration theoretically.

PjBL also encourages students to negotiate decisions when selecting project topics, determining strategies, allocating resources, and addressing challenges encountered during project development. Differences in ideas require students to listen to alternative perspectives and reach decisions that are acceptable to the group. In addition, students must coordinate activities because different project components are interdependent. A delay or failure in one student's task can affect the progress of other group members, thereby encouraging students to monitor group progress and support one another. These conditions create a level of interdependence that is less frequently present in conventional teacher-centered instruction.

Another important mechanism is the requirement to solve group disagreements during the project process. When students encounter different opinions concerning project strategies or solutions, they are encouraged to discuss the alternatives and determine the most appropriate course of action. Through teacher facilitation, these situations become opportunities for students to develop negotiation, active listening, and conflict-management skills. Finally, the requirement to produce and present a shared product gives students a common goal toward which their individual contributions must be directed. The shared outcome reinforces cooperation and encourages students to recognize that successful project completion depends on collective rather than individual effort.

The substantially higher improvement observed in the experimental group therefore suggests that PjBL does not improve collaboration merely because students are placed into groups(Ibrahim & Rashid, 2022). Rather, its effectiveness appears to arise from the structured interaction, shared responsibility, authentic tasks, continuous communication, collective decision-making, and common project outcomes embedded within the learning process. The contrast between the experimental

group's 30.10% improvement and the control group's 10.24% improvement, together with the substantially higher N-gain of 0.54 compared with 0.19, supports the conclusion that PjBL provides a more intensive environment for practicing collaborative competencies.

These findings also have important pedagogical implications. Effective implementation of PjBL requires teachers to design projects that create genuine interdependence among students rather than simply assigning group work. Each student should have a meaningful responsibility, while project activities should require communication, coordination, joint decision-making, and collective problem-solving. Teacher facilitation is also important, particularly in helping students manage disagreements and reflect on the quality of their collaboration. Therefore, the findings suggest that PjBL can function as an effective instructional strategy for developing students' collaborative skills when project activities are carefully structured and supported throughout the learning process.

3.3 Effect of PjBL on Problem-Solving Skills

The results demonstrate that Project-Based Learning (PjBL) had a substantial positive effect on students' problem-solving skills. As presented in the descriptive analysis, the mean problem-solving score of the experimental group increased from 62.93 (SD = 7.12) in the pretest to 84.13 (SD = 5.48) in the posttest. This represents an improvement of approximately 33.70%, with an N-gain score of 0.57, which is categorized as moderate. In contrast, the control group increased from a pretest mean of 63.40 (SD = 7.05) to a posttest mean of 70.87 (SD = 6.37), representing an improvement of approximately 11.78% and an N-gain score of 0.20, categorized as low. The substantially greater improvement in the experimental group indicates that students who participated in PjBL experienced stronger development of problem-solving skills than students who participated in conventional learning.

The inferential analysis further supports the descriptive findings. A paired-samples t-test indicated a statistically significant improvement in problem-solving skills among students in the experimental group, $t(29) = 16.47$, $p < 0.001$(Azizi et al., 2022). The control group also showed a statistically significant increase, although the magnitude of improvement was considerably smaller, $t(29) = 6.14$, $p < 0.001$. More importantly, an independent-samples comparison of posttest scores showed that the experimental group achieved significantly higher problem-solving scores than the control group, $t(58) = 8.96$, $p < 0.001$. The estimated effect size was Cohen's $d = 2.31$, indicating a very large effect. These findings suggest that the improvement observed among students exposed to PjBL was not only statistically significant but also educationally substantial.

The improvement was evident across the major dimensions of problem-solving. The strongest development was observed in problem identification and information analysis, as students became more capable of recognizing the central issue, identifying relevant information, and distinguishing important evidence from less relevant information. Students also demonstrated substantial improvement in generating alternative solutions, indicating that they were increasingly able to consider more than one possible approach to a problem. The decision-making dimension also showed notable improvement, as students learned to compare alternatives and select solutions based on available evidence and project requirements. Improvements were further observed in solution implementation and evaluation, although these dimensions may require more sustained practice because they involve students' ability to translate decisions into actions and critically assess the effectiveness of the resulting outcomes.

The improvement in problem-solving skills can be explained by the authentic and open-ended nature of PjBL activities. In conventional learning, students may frequently encounter problems with predetermined procedures or expected answers. In contrast, PjBL places students in situations in which they must actively determine what the problem is, what information is required, which strategies may be appropriate, and how the success of a proposed solution should be evaluated. Consequently, students are encouraged to move beyond memorizing information toward a systematic problem-solving process consisting of problem identification, information analysis, alternative generation, decision-making, implementation, and evaluation.

At the first stage, problem identification, students are required to understand the authentic problem presented through the project and determine the specific issue that needs to be addressed.

This process encourages students to examine the situation carefully rather than immediately selecting an answer. At the second stage, information analysis, students gather relevant information from appropriate sources and evaluate how that information can contribute to understanding the problem. Because the information required to complete a project is not always directly provided by the teacher, students must actively search for, compare, and interpret information.

The third stage involves generating alternative solutions. Students work individually and collaboratively to develop several possible approaches rather than relying on a single predetermined answer(Kiraly, 2003). Group discussions allow students to compare perspectives and expand the range of possible solutions. The fourth stage, decision-making, requires students to evaluate available alternatives and select the strategy considered most appropriate based on evidence, feasibility, project objectives, and available resources. This process develops students' ability to justify decisions rather than simply provide answers.

The fifth stage is implementation, in which students transform their selected strategy into an actual project product or solution. Implementation provides students with opportunities to identify practical difficulties, revise their strategies, and adapt their actions when the initial plan does not produce the expected results. Finally, students engage in evaluation, where they assess the quality and effectiveness of their project outcomes. Reflection at this stage encourages students to identify weaknesses, consider alternative approaches, and determine how the solution could be improved.

The substantially greater improvement in the experimental group can therefore be attributed to the repeated opportunities to practice these problem-solving processes within meaningful project contexts(Fortus et al., 2005). Students are not merely asked to provide correct answers but are required to demonstrate how they understand a problem, how they obtain and use information, why they choose a particular solution, and how they evaluate the resulting outcome. This process makes problem-solving an integral component of learning rather than an isolated assessment activity.

The difference between the experimental and control groups further reinforces this interpretation. The experimental group demonstrated a 33.70% improvement and an N-gain of 0.57, whereas the control group demonstrated only an 11.78% improvement and an N-gain of 0.20. The much larger gain in the PjBL group, together with the very large effect size, indicates that project-based learning provides students with substantially greater opportunities to practice higher-level problem-solving processes. Therefore, PjBL can be considered an effective instructional approach for developing students' ability to identify, analyze, solve, implement, and evaluate solutions to authentic problems.

3.4 Comparison Between Collaborative and Problem-Solving Outcomes

The findings indicate that Project-Based Learning (PjBL) improved both students' collaborative and problem-solving skills. However, the magnitude of improvement was slightly greater for problem-solving skills than for collaborative skills. In the experimental group, the mean collaborative skills score increased from 64.27 (SD = 6.84) to 83.60 (SD = 5.72), representing an improvement of 30.10% and an N-gain of 0.54. Meanwhile, the mean problem-solving score increased from 62.93 (SD = 7.12) to 84.13 (SD = 5.48), representing an improvement of 33.70% and an N-gain of 0.57. Thus, although both outcomes demonstrated moderate improvement, the increase in problem-solving skills was slightly higher than the improvement in collaborative skills.

The difference in improvement suggests that PjBL may have a particularly strong influence on students' ability to address authentic and complex problems. The project activities required students to identify problems, gather and analyze information, generate possible solutions, make decisions, implement strategies, and evaluate project outcomes. These processes directly correspond to the indicators of problem-solving skills and were repeatedly practiced throughout the project(Jonassen, 2010). At the same time, students were required to complete these activities collaboratively, meaning that problem-solving occurred within a social and interactive learning environment. Consequently, the development of problem-solving skills was closely supported by students' collaborative interactions.

The findings also indicate that collaboration and problem-solving should not be viewed as completely independent competencies. During project implementation, students exchanged ideas,

discussed different interpretations of problems, and considered alternative strategies proposed by group members. Such interactions provided students with access to multiple perspectives that could help them understand problems more comprehensively. When students encountered difficulties, group discussions enabled them to compare possible solutions and determine the most appropriate course of action. Therefore, collaboration functioned as an important mechanism through which students could strengthen their problem-solving processes.

Conversely, the process of solving authentic project problems also created meaningful opportunities for students to develop collaboration(Nelson, 2013). Students could not complete complex projects effectively through individual effort alone because different project tasks required the coordination of multiple group members. Students had to divide responsibilities, communicate progress, provide assistance, negotiate decisions, and resolve disagreements. The need to achieve a shared project outcome encouraged students to become more accountable for their individual contributions while maintaining coordination with the group. In this sense, problem-solving activities provided an authentic context in which collaborative behaviors could be practiced and strengthened.

The comparison with the control group further supports this interpretation. Students in the control group demonstrated an improvement in collaborative skills from 64.83 to 71.47, equivalent to a 10.24% increase, while their problem-solving skills increased from 63.40 to 70.87, equivalent to an 11.78% increase. Although some improvement occurred under conventional learning, the gains were substantially lower than those observed in the experimental group. This difference suggests that conventional learning may provide some opportunities for students to develop these competencies, but it may not offer the same intensity of authentic interaction, investigation, decision-making, and shared responsibility provided by PjBL.

The relatively similar magnitude of improvement in the two outcomes within the experimental group also suggests that PjBL can provide an integrated learning environment for developing complementary twenty-first-century competencies(Davis, 2016). The collaborative skills N-gain of 0.54 and problem-solving N-gain of 0.57 are close in magnitude, indicating that the intervention supported both dimensions rather than improving only one. This is important because authentic problems in academic and real-world contexts frequently require individuals to combine independent reasoning with effective interaction with others. Students must be able to analyze a problem while simultaneously communicating their ideas, considering alternative perspectives, and coordinating actions with other people.

3.5 Comparison with Previous Research and Theoretical Perspectives

The findings of this study are broadly consistent with previous research showing that Project-Based Learning (PjBL) can strengthen students' collaborative competencies. Nuha, Febriana, and Merdekawati (2020), for example, found significant differences in collaborative skills between students taught through PjBL and those taught through conventional learning. Their findings can be explained by the fact that project activities require students to interact continuously, distribute responsibilities, exchange information, and work toward a common product. Similarly, Riyadi, Alimah, and Saptono (2020) reported that PjBL was effective in developing collaborative ability among senior high school students. The present study extends this evidence by showing that the experimental group's collaborative skills increased from 64.27 to 83.60, compared with an increase from 64.83 to 71.47 in the control group. The much larger improvement in the PjBL group can be understood through the repeated social demands embedded in project completion(Lee et al., 2015). Students cannot simply divide a task and work independently; they must communicate progress, coordinate activities, negotiate decisions, and integrate individual contributions into one shared product. Thus, collaboration becomes a necessary condition for completing the project rather than merely an additional classroom activity.

The findings concerning problem-solving skills are also supported by previous research. Karan and Brown (2022) emphasized the potential of project-based learning to address students' difficulties in dealing with complex problems, particularly by moving learning beyond traditional instructional strategies. In addition, Chusni (2023), through a meta-analysis of studies on PjBL and twenty-first-

century skills, reported a strong effect of project learning on problem-solving, with problem-solving outcomes showing an effect proportion of approximately 92% in the reviewed studies. These findings help explain why the present study found that problem-solving scores in the experimental group increased from 62.93 to 84.13, while the control group increased only from 63.40 to 70.87. The improvement is logically related to the structure of authentic projects because students must identify problems, analyze information, generate alternatives, make decisions, implement solutions, and evaluate their results(Larmer et al., 2015). PjBL therefore transforms problem-solving from an abstract competency into a repeated learning activity that students must actually perform.

The present findings are also consistent with the broader evidence that PjBL supports twenty-first-century skills. A recent umbrella review of meta-analyses found a generally positive direction of PjBL effects compared with traditional instruction across academic and higher-order outcomes, while also identifying small collaborative groups and technology integration as factors associated with stronger effects. This perspective is important because the current findings should not be interpreted as resulting simply from the use of "projects."(Engwall, 2003) Rather, the effectiveness of PjBL appears to depend on the quality of the learning environment created through the projects. In the present study, students were required to collaborate, investigate authentic problems, make decisions, develop products, and reflect on their results. These elements create repeated opportunities to exercise the competencies associated with twenty-first-century learning.

From the perspective of active learning, the findings can be explained by the shift from passive reception of information to active engagement with learning tasks(Chi & Wylie, 2014). Conventional instruction may allow students to acquire information efficiently, but it can provide fewer opportunities to apply that information in unfamiliar situations. PjBL requires students to actively search for information, discuss its relevance, test ideas, make decisions, and revise their work. The learning process therefore involves students in cognitive and social activities rather than positioning them primarily as recipients of teacher explanations. Research examining PjBL in external consultancy projects similarly emphasizes exposure to real-world problems, extended inquiry, communication, and interdisciplinary learning as important features of project-based experiences.

The findings can also be understood through experiential learning. PjBL gives students concrete experiences through which knowledge is applied, tested, and reconsidered. Students encounter a problem, attempt a solution, observe the consequences, receive feedback, and modify their approach. Consequently, learning occurs through a cycle of action and reflection rather than through conceptual explanation alone. The improvement in problem-solving from 62.93 to 84.13 is particularly compatible with this mechanism because students repeatedly experienced the consequences of their decisions during project development. Similarly, collaboration developed through actual group experiences in which students had to manage responsibilities, communication, disagreements, and shared outcomes.

The findings are further consistent with the constructivist learning perspective, which views students as active constructors of knowledge through interaction with their environment and with other learners. PjBL provides an environment in which students construct understanding by investigating meaningful problems and negotiating interpretations with peers. The teacher's role as facilitator also supports this process because students receive guidance without having every solution directly provided to them(Mascolo, 2009). Previous literature explicitly identifies PjBL as rooted in constructivist learning, emphasizing authentic experiences and active knowledge construction. Thus, the large improvement observed in the experimental group can be interpreted not simply as the result of increased activity, but as the consequence of a learning process in which students actively construct and apply knowledge.

The relationship between collaboration and problem-solving found in this study provides an additional contribution. Problem-solving improved slightly more strongly than collaboration, with an improvement of 33.70% and an N-gain of 0.57, compared with 30.10% and an N-gain of 0.54 for collaboration. This difference may occur because the project tasks directly required students to identify and resolve authentic problems, whereas effective collaboration developed progressively through

repeated group interaction. Nevertheless, the two outcomes appear interconnected. Students used collaboration as a means of exchanging ideas and evaluating alternative solutions, while the need to solve project problems created the social conditions requiring them to communicate, negotiate, coordinate, and share responsibilities. In other words, collaboration supported problem-solving, while authentic problem-solving simultaneously created opportunities to strengthen collaboration.

Overall, the consistency between the present findings and previous research can therefore be explained by a common educational mechanism: PjBL integrates authentic experience, active inquiry, social interaction, and higher-order thinking within one learning process. The findings are not merely consistent with previous studies because they use the same instructional model; they are consistent because the core features of PjBL directly correspond to the behaviors required by collaboration and problem-solving. At the same time, the present study adds value by examining these two competencies simultaneously, showing that PjBL can function as an integrated approach to developing complementary twenty-first-century skills rather than treating collaboration and problem-solving as separate learning outcomes.

4. CONCLUSION

This study concludes that the Project-Based Learning (PjBL) model was effective in improving students' collaborative and problem-solving skills compared with conventional learning. The experimental group demonstrated substantially greater improvements in both competencies, indicating that project-based learning can provide a meaningful learning environment for developing integrated twenty-first-century skills. In terms of collaborative skills, students who participated in PjBL showed an increase in their mean scores from 64.27 to 83.60, with an improvement of 30.10% and an N-gain of 0.54, categorized as moderate. The improvement was supported by project activities that required students to communicate, divide responsibilities, coordinate tasks, negotiate decisions, manage disagreements, and contribute to a shared product. These structured interactions provided students with continuous opportunities to practice collaboration in authentic learning situations. Regarding problem-solving skills, the experimental group improved from a mean score of 62.93 to 84.13, representing a 33.70% improvement and an N-gain of 0.57, also categorized as moderate. The project activities encouraged students to move through problem identification, information analysis, alternative generation, decision-making, implementation, and evaluation. The slightly greater improvement in problem-solving suggests that authentic project challenges provided particularly strong opportunities for students to practice higher-order thinking. The findings imply that PjBL is an appropriate pedagogical approach for developing integrated twenty-first-century competencies, particularly collaboration and problem-solving. However, its effectiveness depends on appropriate project design, meaningful student participation, effective teacher facilitation, and systematic assessment of learning processes and outcomes.

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