Investigating the Impact of Project-Based Learning on Students' Analytical Thinking and Collaboration Skills

Ermia Hidayanti[1], Senam Senam[2], Saprizal Hadi Saputra [3], Rahmawati Rahmawati [4], Eka Junaidi [5]

[1345] University of Mataram, Mataram, Indonesia.
[2] Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
ermiahdyt@unram.ac.id

Abstract. This study aims to investigate the effects of Project-Based Learning (PjBL) on students' analytical thinking and collaboration skills in chemistry education, specifically focusing on electrolyte and non-electrolyte solutions. A quasi-experimental approach was used, employing a posttest-only design to assess the effectiveness of the intervention. The study involved 118 senior high school students, with an experimental group taught through Project-Based Learning (PjBL) and a control group taught using a scientific approach. Students' analytical thinking was assessed using the Electrolyte and Non-Electrolyte Solutions Analytical Thinking Test (ENSAT), while collaboration skills were evaluated with a modified Collaboration Self-Assessment Tool Rubric (CAST). Data on analytical thinking were analyzed using descriptive statistics and MANOVA, while data on collaboration skills were examined through percentage scores and MANOVA. The findings demonstrated that the experimental group exhibited markedly stronger analytical thinking than the control group across all assessed dimensions, namely differentiating, organizing, and attributing. The results of the MANOVA indicated a statistically significant multivariate effect of Project-Based Learning (PjBL) on the combined dependent variables. Further univariate analysis revealed that PjBL significantly improved students' analytical thinking but had no noticeable effect on their collaboration skills. These findings suggest that while PjBL is effective in enhancing analytical thinking in chemistry education, its impact on collaboration skills is limited.

Keywords: Project-Based Learning, analytical thinking, collaboration skills, chemistry learning, electrolyte and non-electrolyte solutions.

B. Z. Melani et al. (eds.), *Proceedings of the 7th International Conference on Education and Social Sciences (ICESS 2025)*, Advances in Social Science, Education and Humanities Research 1016,
https://doi.org/10.2991/978-2-38476-579-9_20

1 Introduction

Currently, education systems in developing countries are increasingly expected to provide students with the knowledge and skills needed for the demands of the twenty-first century [1]. The future world will increasingly depend on specialized knowledge and advanced cognitive skills as essential foundations for navigating complex social, scientific, and professional demands [2]. Education in the 21st century requires a learning process that emphasizes not just mastering content but also developing higher-order thinking and collaboration skills. Higher-order thinking skills include the abilities to analyze, evaluate, and create [3]. Recent literature reviews confirm that analytical thinking plays a crucial role in problem-solving, independent learning, and strengthening students' critical thinking skills. These skills highlight students' ability to apply their knowledge in meaningful ways within authentic, real-world contexts [4]. Human capital can be better positioned to adapt to rapid technological changes and leverage acquired knowledge to develop innovative technological advancements that are contextually relevant [5]. Analytical thinking is an important aspect of higher-order thinking skills [6]. Analytical thinking abilities are indispensable for students, as they enable them to distinguish among diverse components, organize relevant information, and discern the relationships that connect one element to another[7]. Analytical thinking abilities include differentiating, organizing, and attributing [2], [7]. At the same time, collaboration skills are a core competency because modern learning and the workplace demand that students communicate, share responsibilities, and complete tasks collaboratively [8].

However, classroom instruction is still frequently dominated by teacher-centered practices, which limit students' opportunities to analyze problems in depth and engage in meaningful collaboration. Moreover, learning environments that place excessive emphasis on memorization and single correct answers tend to reduce students' involvement in inquiry, discussion, and decision-making. A PISA 2022 reported that Indonesia's science score (383) was below the OECD average (485), and only around 34% of students reached at least Level 2, which refers to the ability to identify appropriate explanations for familiar scientific phenomena and evaluate simple conclusions based on data [9]. The main cause of these results is students' weak analytical thinking. Supporting research findings indicate that students who lack analytical thinking tend to have low academic success [10], [11], and experience uncertainty when confronted with the challenges of complex thinking in the 21st century [10]. However, a meta-analysis encompassing 66 empirical studies showed that Project-Based Learning (PjBL) is significantly more effective than conventional instruction in enhancing a wide range of educational outcomes, including thinking skills, affective dispositions, and student engagement. The study also confirmed that PjBL has a moderate positive impact on thinking skills and is strongly associated with problem-oriented activities, cooperative learning, and authentic tasks [11].

In the contemporary Indonesian curriculum, a constructivist orientation is strongly advocated to foster meaningful learning experiences. Among the instructional models grounded in this perspective, Project-Based Learning (PjBL) occupies a prominent position. As a constructivist pedagogical approach, PjBL enables students to develop a deeper and more enduring understanding of the subject matter through active exploration, construction, and application of ideas within authentic learning contexts [12]. Additionally, project-based learning is a student-centered teaching model that uses projects to facilitate learning [13]. Accordingly, students are able to attain the intended learning objectives through project-based activities, both independently and through interactive group discussions, as they actively construct and consolidate their own knowledge [14], [15]. In Project-Based Learning (PjBL), students actively engage in various learning activities that encourage creative thinking and meaningful participation in the learning process [16], participate in academic communication activities that promote cognitive and metacognitive skills while also boosting students' motivation.[18]. Successful projects are characterized by student engagement and a positive atmosphere [19]. Additionally, teaching project-based learning will be effective if teachers have a thorough understanding of both project-based learning and their subject matter. If teachers' knowledge of project-based learning is restricted to theory, they will struggle to apply it [20]. Although the Indonesian government has recommended project-based learning for chemistry instruction, its implementation in schools remains uneven. In practice, not all chemistry teachers possess a sufficient understanding of Project-Based Learning, particularly regarding its procedural stages and defining characteristics. Chemistry teaching often follows a traditional pattern where teachers first explain concepts and then conduct experiments using the available tools and materials in the school laboratory. Nevertheless, students tend to value Project-Based Learning more positively than conventional teaching approaches for several reasons, including its strong connection to scientific practices and real-world contexts, the open-ended nature of the problems explored, active engagement in investigative tasks, and the more meaningful, contextualized learning experiences it provides [21]. Consequently, implementing PjBL in the classroom presents a promising pedagogical approach to overcoming the previously mentioned challenges in chemistry education.

2 Research Method

2.1 Research Design

This study used a quasi-experimental design with a posttest-only approach to examine the impact of the independent variable on the dependent variable [22]. The experimental group was instructed using Project-Based Learning, while the control group received instruction based on the scientific approach outlined in the Indonesian national curriculum. Students' analytical thinking and collaboration skills were assessed after completing the instructional intervention.

2.2 Research Sample and Sampling Procedures

The sample was drawn using stratified random sampling from a population of students enrolled in 18 secondary schools across Yogyakarta Province, which were categorized as high-, middle-, or low-performing based on the 2018 national examination results. Schools in the high and middle categories were included because the study used a higher-order thinking skills test. From these categories, one high-category school and one middle-category school were randomly selected. An initial homogeneity analysis of Grade X students' prior knowledge, conducted using ANOVA, showed no significant differences between students in the two schools. Accordingly, a second-stage cluster random sampling technique was employed, two experimental groups and two control groups obtained. The final sample comprised 118 students, including 77 females and 41 males, of whom 62 were assigned to the experimental group and 56 to the control group.

2.3 Teaching Interventions

The intervention was conducted over five instructional sessions, each lasting 90 minutes. The experimental group received instruction through Project-Based Learning, while the control group was taught using a traditional scientific approach. In the experimental class, students collaborated in small groups of four to five members and engaged in learning activities organized according to the stages of Project-Based Learning. Following the framework proposed by the Lucas Foundation, the instructional process began with an essential question, followed by project planning, scheduling, monitoring student progress, and evaluating the outcomes.

The instructional sessions focused on four main topics: the theory of electrolyte and non-electrolyte solutions, electrical conductivity, compound dissociation reactions, and the practical applications of electrolyte solutions in everyday life. To enhance understanding, classroom activities were designed around real-life phenomena, such as power outages during floods, electric shock fishing, the role of electrolytes in the human body, and car batteries. These phenomena were incorporated into student worksheets that included guiding questions aimed at stimulating higher-order thinking. These questions served as a starting point for students to engage in a comprehensive sequence of project-based learning activities.

The learning materials, including lesson plans and student worksheets, were specifically developed based on principles of project-based learning and were designed to relate to real-life situations that students are familiar with. These materials were validated by three experts in chemistry and chemistry education. In contrast, the control group was taught using a scientific approach that included five stages: observing, questioning, gathering information, associating, and communicating. Table 1 outlines the differences in learning conditions between the experimental and control groups regarding electrolyte and non-electrolyte solutions.

Table 1. Outline of the lesson plan both experimental and control groups

Experimental group	**Control group**
Start with the essential question step. Students began the learning process by examining the phenomenon of flooding and relating it to the human body. They then formulated key questions concerning the factors that cause people to be electrocuted during floods, the substances present in water that are associated with bodily fluids, and the ways in which electrolyte solutions can be identified.	*Observing feature.* Students watched a video showing fish being caught using electric shock and listened to the teacher's explanation of the phenomenon. The teacher then posed several questions to stimulate and motivate students' thinking.
Design a plan for the project. Students worked collaboratively in groups to develop a project plan aimed at answering the proposed questions. The project involved designing and constructing a test apparatus for identifying electrolyte and non-electrolyte solutions.	*Asking feature.* Students formulated their own questions regarding the practice of catching fish using electric shock in relation to the topic of electrolyte and non-electrolyte solutions. They then developed hypotheses based on these questions within their groups of four to five members and recorded them in the student worksheet.
Create a schedule. Students developed a schedule for completing their project. In this schedule, they specified the tasks to be carried out on each date and documented the progress of each activity.	*Collecting feature.* Students in group looking for information about electrolyte and non-electrolyte solutions, electrolyte test equipment, and matter that will test the electrical conductivity. Students write the tools and material that they use to build electrolyte in students' worksheet.

Monitor the students and the progress of the project. While the project was in progress, students communicated the challenges they encountered to the teacher and made necessary modifications to their project. They explained the facts they observed and related them to relevant literature, while also documenting the progress of their project in the student worksheet.	*Associating feature.* Students formulated explanations and drew conclusions based on the results of the electrical conductivity tests conducted using the electrolyte and non-electrolyte testing apparatus they had developed.
Asses the outcome. Students presented their project results to the class, explaining the differences between strong electrolytes, weak electrolytes, and non-electrolytes based on the experimental data they collected during the project.	*Communicating feature.* The group of students confidently showcased their results to the entire class, demonstrating their hard work and dedication.

2.4 Instruments

The Electrolyte and Non-electrolyte Solution Analytical Thinking Test (E-NSAT) is an assessment tool that has been adopted to evaluate solutions containing electrolytes and non-electrolytes [23]. The instrument included 14 items related to electrolyte and non-electrolyte solutions, electrical conductivity, compound dissociation reactions, and the practical applications of electrolyte solutions in daily life. These items were developed from four daily-life contexts related to electrolytes and non-electrolytes: seawater components (items 1–4), experimental data on everyday compounds (items 5–9), battery operation (items 10–12), and the electrical conductivity of several substances, as well as salt regulation in the human body (items 13–14). The E-NSAT was developed based on three analytical thinking indicators proposed by Krathwohl (2002): differentiating (items 1, 3, 9–11, 13, and 14), organizing (items 4, 5, and 8), and attributing (items 2, 6, 7, and 12). The instrument was administered to a research sample of 116 students to assess its construct validity. The empirical results indicated that all items of the E-NSAT were valid, with a reliability coefficient of 0.71.

The Collaboration Self-Assessment Tool Rubric (CAST). This instrument [24] was designed to assess collaborative skills by emphasizing both intrapersonal and interpersonal dimensions that are closely related to effective collaboration. In its adapted form, the CAST consisted of 35 items distributed across two domains, namely intrapersonal and interpersonal skills. The instrument evaluated 11 aspects of collaboration. The interpersonal domain included five elements: contribution, group support, group dynamics, interaction among group members, and role flexibility. The intrapersonal domain covered six elements: motivation and engagement, quality of work, time management, readiness, reflection, and team learning. Each item was developed to capture students' self-assessment of their collaborative performance during the learning process. Before being used for data collection, the CAST questionnaire was piloted with 240 senior high school students. The item validity analysis showed that the Pearson product-moment correlation coefficients for all 35 items exceeded the critical value of 0.138, indicating that each item was valid and appropriate for measuring students' collaboration skills. In addition, the reliability test yielded a Cronbach's alpha of 0.898, indicating high internal consistency and meeting the exceedingly common minimum criteria for research instruments. Therefore, the collaboration questionnaire was considered reliable and suitable for repeated use in this study [25].

2.5 Data Analysis Techniques

The analytical thinking data were analyzed descriptively by examining the mean, minimum, maximum, and standard deviation. In contrast, the collaboration skills data were analyzed by calculating the percentage attainment to assess the extent of students' collaborative skills. Both data sets were then analyzed using MANOVA to evaluate the effect of Project-based Learning (PjBL) on two dependent variables: analytical thinking abilities and collaboration skills. This study utilized a quasi-experimental posttest-only design, comparing the posttest scores of the experimental and control groups. Before conducting MANOVA, we examined its underlying assumptions using Box's Test of Equality of Covariance Matrices and Levene's Test of Equality of Error Variances. Once these assumptions were satisfied, MANOVA was performed to determine the simultaneous effect of the treatment on both dependent variables. Additionally, to identify the effect on each variable separately, Tests of Between-Subjects Effects were conducted. The effect size was interpreted using Partial Eta Squared.

3 Result and Discussion

The analysis of students' analytical thinking data utilized descriptive statistics, which included the mean, minimum, maximum, and standard deviation, as shown in Table 1.

Table 2. Descriptive statistic of students' analytical thinking.

Variables/Indicator	Experimental Group				Control Group			
	Mean	**Min**	**Max**	**S.D.***	**Mean**	**Min**	**Max**	**S.D.***
Analytical Thinking	67.86	41.84	97.96	12.343	42.24	20.41	72.45	10.084
• *Differentiating*	74.78	40.48	100	13.46	49.78	11.91	76.19	13.82
• *Organizing*	62.21	10.71	100	19.58	34.44	0	71.43	17.16
• *Attributing*	63.07	28.57	96.43	15.41	38.46	0	78,57	17.16

*S.D: Standard Deviation

Table 1 shows that the experimental group achieved higher scores in analytical thinking compared to the control group. This trend is evident in both overall performance and across all measured indicators. The experimental group had an average score of 67.86 for overall analytical thinking, while the control group had an average score of 42.24. A similar pattern was found for each indicator: differentiating (74.78 vs. 49.78), organizing (62.21 vs. 34.44), and attributing (63.07 vs. 38.46). In addition, the experimental group consistently obtained higher maximum scores on all indicators. These findings indicate that students in the experimental group exhibited stronger analytical thinking performance than their counterparts in the control group.
Furthermore, students' collaboration skills were analyzed using percentage responses across each collaboration indicator, as shown in Figure 1.

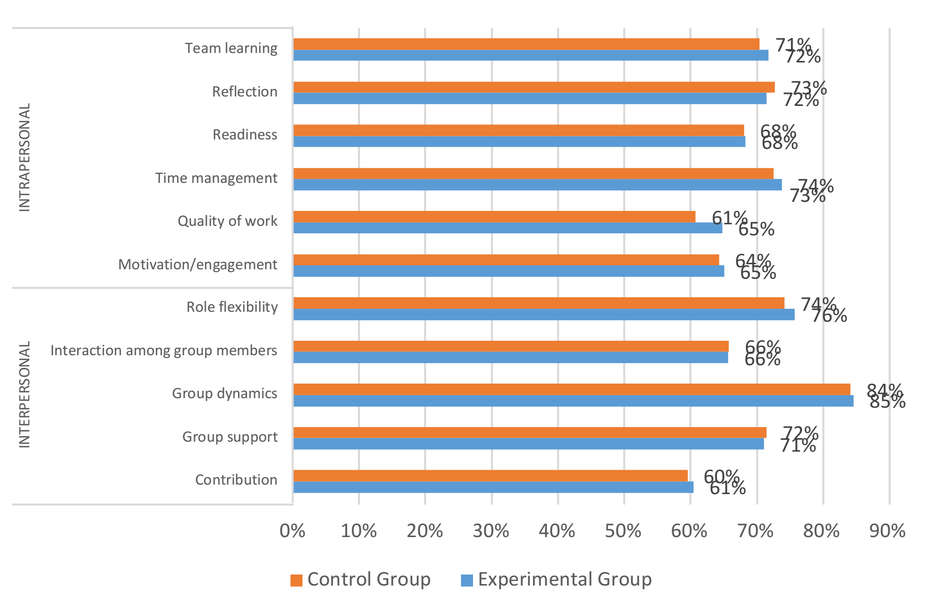

Fig. 1. Collaboration skills between two groups (PjBL group and scientific approach group) in every aspect.

Figure 1 presents the percentage scores of students' collaboration skills in the experimental and control groups, covering both interpersonal and intrapersonal domains. In general, the two groups showed relatively comparable percentages across all collaboration indicators. In the interpersonal domain, the experimental group showed slightly better performance than the control group across several areas: contribution (61% vs. 60%), group dynamics (85% vs. 84%), and role flexibility (76% vs. 74%). However, the control group had a marginally higher percentage of group support, at 72%, compared to 71%. The percentage for interaction among group members was the same in both groups (66%). In the intrapersonal domain, the experimental group obtained slightly higher percentages in motivation/engagement (65% vs. 64%), quality of work (65% vs. 61%), time management (74% vs. 73%), and team learning (72% vs. 71%). Meanwhile, the control group showed a slightly higher percentage in reflection (73% vs. 72%), whereas readiness was identical in both groups (68%). Overall, these data indicate that students' collaboration skills in both the experimental and control groups were quite similar, with only slight differences among the indicators.

Furthermore, the data were analyzed using MANOVA to examine the effect of Project-Based Learning (PjBL) on students' analytical thinking and collaboration skills. Prior to the multivariate analysis, the MANOVA assumptions were tested. The result of Box's Test of Equality of Covariance Matrices showed a significance value of 0.309, which was greater than 0.05, indicating that the covariance matrices were homogeneous across groups. In addition, Levene's Test of Equality of Error Variances showed significance values of 0.995 for collaboration skills and 0.101 for analytical thinking, both of which were higher than 0.05. These results indicate that the assumption of homogeneity of variance was satisfied, and therefore, the data were appropriate for MANOVA, as shown in Table 3 below.

Table 3. MANOVA test result.

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.989	5004.488[b]	2.000	115.000	.000	.989
	Wilks' Lambda	.011	5004.488[b]	2.000	115.000	.000	.989
	Hotelling's Trace	87.035	5004.488[b]	2.000	115.000	.000	.989
	Roy's Largest Root	87.035	5004.488[b]	2.000	115.000	.000	.989
Group	Pillai's Trace	.563	74.157[b]	2.000	115.000	.000	.563
	Wilks' Lambda	.437	74.157[b]	2.000	115.000	.000	.563
	Hotelling's Trace	1.290	74.157[b]	2.000	115.000	.000	.563
	Roy's Largest Root	1.290	74.157[b]	2.000	115.000	.000	.563

a. Design: Intercept + Group
b. Exact statistic

Table 2 demonstrates that the experimental group achieved higher descriptive scores than the control group in overall analytical thinking, as well as across all three indicators: differentiating, organizing, and attributing. Additionally, the experimental group reached higher maximum scores in all indicators, which reflects a stronger analytical performance following the implementation of Project-Based Learning (PjBL). These descriptive findings are consistent with the multivariate analysis. As presented in Table 3, the MANOVA test showed a significant group effect on the combined dependent variables, with Pillai's Trace = 0.563, Wilks' Lambda = 0.437, F = 74.157, and p = 0.000. The Partial Eta Squared = 0.563 indicates a large multivariate effect, meaning that the treatment made a substantial contribution to the combined variation in students' analytical thinking and collaboration skills. This confirms earlier evidence that PjBL positively impacts student learning outcomes, especially in higher-order thinking and active engagement [26]. The findings indicated that the use of project-based learning improved students' analytical thinking in chemistry. The phases of project-based learning focus on student-centered activities, while the teacher plays a vital role in facilitating and guiding students throughout the learning process [27]. The findings show that Project-Based Learning (PjBL) enhanced students' analytical thinking in chemistry. This outcome is logical as PjBL prioritizes student-centered learning, with the teacher acting as a facilitator who continuously supports students throughout the learning process [27]. By actively questioning, investigating, designing, and presenting, students gain a deeper understanding of the subject matter and build knowledge through their own ideas and experiences [28], [29]. At the beginning of the lesson, essential questions encouraged students to connect concepts, analyze contextual problems, and seek scientifically grounded explanations. Such activities trained the differentiating aspect of analytical thinking, as students had to identify relevant questions, distinguish appropriate materials, and determine suitable procedures for testing electrolyte and non-electrolyte solutions [30], [31].

Furthermore, during the project design and implementation stages, students were challenged to select tools and materials, classify substances, and establish relationships among concepts, thereby strengthening their organizing and attributing skills [32], [33], [34]. The process of arranging project schedules, developing test kits, monitoring progress, and preparing reports required students to structure information and determine how each component functioned within the project as a whole [35]. Although many students initially experienced confusion and repeated trial and error, these difficulties became part of the learning process and helped them refine their understanding through discussion, experimentation, and interaction with peers and teachers [11]. In the final stage, students presented their project results, explained the conductivity of tested materials, and justified their answers using chemical concepts and dissociation reactions. This presentation and discussion process further supported analytical thinking by requiring students to interpret evidence, defend conclusions, and respond to questions [36], [37]. Therefore, the significant MANOVA result for analytical thinking can be explained by the characteristics of PjBL itself, which provide meaningful, inquiry-based, and authentic learning experiences widely recognized as effective for developing higher-order thinking skills [38].

A closer look at the analytical thinking indicators suggests that PjBL's strongest contribution was cognitive rather than social. The higher score on the differentiating measure indicates that students in the experimental group were better able to distinguish relevant from irrelevant information in chemistry problems. The higher performance in organizing suggests that they were more capable of arranging evidence, concepts, and relationships into coherent explanations. Likewise, the better result in attributing implies that they were more successful in assigning meaning, identifying causes, and drawing interpretations from chemical phenomena. In chemistry learning, especially in topics such as electrolyte and non-electrolyte solutions, these processes are central because students must connect observable phenomena, symbolic representations, and conceptual reasoning. Research in chemistry education has similarly shown that PjBL and inquiry-oriented chemistry instruction can strengthen critical, analytical, and scientific reasoning by engaging students in contextual problem solving and evidence-based interpretation [39].

This interpretation is also supported by Indonesian studies in science and chemistry education. Recent national evidence shows that PjBL-based analytical chemistry materials enhance students' critical thinking and scientific literacy. Furthermore, PjBL in chemistry and science classes has been linked to improved higher-order thinking outcomes and stronger cognitive performance compared to conventional instruction. Similar findings were reported among pre-service chemistry teachers, in which project-based learning significantly improved critical thinking and self-efficacy. Since critical thinking and analytical thinking share core processes such as identifying evidence, relating concepts, and drawing justified conclusions, these studies reinforce the present finding that PjBL is effective in promoting students' analytical thinking [39].

In contrast, Figure 1 shows that the differences in collaboration skills between the experimental and control groups were relatively minor in both the interpersonal and intrapersonal domains. In the interpersonal domain, the experimental group demonstrated only a slight advantage in contribution, achieving 61% compared to the control group's 60%, group dynamics (85% vs. 84%), and role flexibility (76% vs. 74%), while both groups were equal in interaction among group members (66%). The control group was slightly higher in group support (72% vs. 71%). In the intrapersonal domain, the experimental group was only marginally higher in motivation/engagement (65% vs. 64%), quality of work (65% vs. 61%), time management (74% vs. 73%), and team learning (72% vs. 71%), whereas the control group was slightly higher in reflection (73% vs. 72%), and both groups were the same in readiness (68%). Overall, the collaboration profiles of the two groups were comparable.

The small descriptive gap in collaboration aligns with the statistical finding that multivariate significance was driven mainly by analytical thinking rather than collaboration. This pattern is reasonable because working in groups does not automatically produce high-quality collaboration. The literature on project-based learning has repeatedly emphasized that outcomes of collaboration depend on how group processes are structured, monitored, and scaffolded. Students may complete a project together, yet still show uneven participation, weak interaction quality, or limited shared regulation if roles, peer feedback, and reflective evaluation are not explicitly built into instruction. Studies on the quality of collaboration in PjBL have shown that effective collaboration is closely tied to interaction patterns, regulation, and the design of collaborative support rather than to group work alone [40].

Taken together, the findings show that PjBL was highly effective in improving analytical thinking, as reflected in consistently higher scores for differentiating, organizing, and attributing, and in a significant MANOVA with a large effect size. However, its effect on collaboration skills was limited, as shown by the relatively similar percentage responses across interpersonal and intrapersonal indicators. This overall pattern aligns with broader research indicating that PjBL is particularly effective at promoting deeper understanding, inquiry, and higher-order cognition, whereas gains in collaboration are more variable and strongly dependent on implementation quality, scaffolding, and assessment design [41].

Therefore, in the context of chemistry learning, PjBL appears to be a strong pedagogical approach for fostering analytical thinking, particularly when students are required to interpret contextual phenomena, analyze evidence, and connect concepts to everyday chemical situations. However, if the instructional goal also includes substantial improvement in collaboration skills, teachers should strengthen PjBL by incorporating structured team roles, process-oriented feedback, peer assessment, and guided reflection on group interactions. Such additions are important because the effectiveness of PjBL in social-skill development depends not only on the project itself but also on how collaboration is intentionally designed and supported throughout the learning process [42].

4 Conclusion

This study shows that Project-Based Learning (PjBL) is an effective teaching method for enhancing students' analytical thinking in chemistry, particularly regarding electrolyte and non-electrolyte solutions. Students in the experimental group attained notably higher analytical thinking scores than their counterparts in the control group, both overall and across the indicators of differentiating, organizing, and attributing. The

MANOVA results also confirmed that PjBL had a significant effect on analytical thinking. Although the experimental group demonstrated slightly higher percentages in various aspects of collaboration skills, the difference between the experimental and control groups was not statistically significant. This indicates that PjBL alone was not sufficient to produce a significant improvement in students' collaboration skills. Overall, the findings suggest that PjBL is a promising instructional approach for enhancing higher-order thinking in chemistry learning. Nevertheless, additional strategies, such as structured group roles, peer evaluation, and guided reflection, are needed to strengthen students' collaboration skills.

Acknowledgments. This research acknowledges the support of SMAN 1 Yogyakarta, SMAN 3 Yogyakarta, SMAN 1 Godean, and SMAN 1 Sayegan, particularly the students and teachers who participated. I would also like to express my deep gratitude to the Faculty of Teacher Training and Education at the University of Mataram for their financial support and for providing me with the opportunity to enhance my learning.

Disclosure of Interests. The authors state they have no competing financial interests or personal relationships that could influence the work reported in this article.

References

[1] Irwanto, E. Rohaeti, E. W. Lfx, and S. Suyanta, "The development of an integrated assessment instrument for measuring analytical thinking and science process skills," *AIP Conf. Proc.*, vol. 1847, 2017, doi: 10.1063/1.4983907.

[2] K. Kereluik, P. Mishra, C. Fahnoe, and L. Terry, "What Knowledge Is of Most Worth," *Journal of Digital Learning in Teacher Education*, vol. 29, no. 4, pp. 127–140, 2013, doi: 10.1080/21532974.2013.10784716.

[3] D. R. Krathwohl, "A Revision of Bloom's Taxonomy: An Overview. , 41(4), 212–218. doi:10.1207/s15430421tip4104_2," *Theory Pract.*, vol. 41, no. 4, pp. 212–218, 2002, doi: 10.1207/s15430421tip4104.

[4] L. C. Larson and T. N. Miller, "21st Century Skills: Prepare Students for the Future," *Kappa Delta Pi Record*, vol. 47, no. 3, pp. 121–123, 2011, doi: 10.1080/00228958.2011.10516575.

[5] T. J. Kennedy and M. R. L. Odell, "Engaging Students In STEM Education," *Science Education International*, vol. 25, no. 3, pp. 246–258, 2014.

[6] M. Hugerat and N. Kortam, "Improving higher order thinking skills among freshmen by teaching science through inquiry," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 10, no. 5, pp. 447–454, 2014, doi: 10.12973/eurasia.2014.1107a.

[7] R. P. B. Ramirez and M. S. Ganaden, "Creative activities and students' higher order thinking skills," *Education Quarterly*, vol. 66, no. December, pp. 22–33, 2008.

[8] M. Wang, M. E. E. Mohd Matore, and R. Rosli, "A systematic literature review on analytical thinking development in mathematics education: trends across time and countries," 2025, *Frontiers Media SA*. doi: 10.3389/fpsyg.2025.1523836.

[9] OECD, "Results in focus: What 15-year-olds know and what they can do with what they know," *PISA 2012*, 2012.

[10] C. Freed and R. Pena, "Minority Education and Analytical Thinking Skills : Traditionalizing Disempowerment Author (s): Craig Freed and Robert Peña Published by : University of North Carolina Press Stable URL : https://www.jstor.org/stable/40364369 Minority Education and Analy," vol. 85, no. 2, pp. 24–32, 2002.

[11] L. Zhang and Y. Ma, "A study of the impact of project-based learning on student learning effects: a meta-analysis study," 2023, *Frontiers Media SA*. doi: 10.3389/fpsyg.2023.1202728.

[12] P. C. Blumenfeld, R. W. Marx, E. Soloway, and J. Krajcik, "Learning with peers: From small group cooperation to collaborative communities," *Educational Researcher*, vol. 25, no. 8, pp. 37–39, 1996, doi: 10.3102/0013189X025008037.

[13] M. Holm, "Project-Based Instruction: A Review of the Literature on Effectiveness in Prekindergarten through 12th Grade Classrooms," *InSight: Rivier Academic Journal*, vol. 7, no. 2, 2011.

[14] S. J. Lou, Y. H. Liu, R. C. Shih, and K. H. Tseng, "The senior high school students' learning behavioral model of STEM in PBL," *Int. J. Technol. Des. Educ.*, vol. 21, no. 2, pp. 161–183, 2011, doi: 10.1007/s10798-010-9112-x.

[15] M. Boubouka and K. A. Papanikolaou, "Alternative assessment methods in technology enhanced project-based learning," *International Journal of Learning Technology*, vol. 8, no. 3, p. 263, 2013, doi: 10.1504/ijlt.2013.057063.

[16] S. M. Al-Balushi and S. S. Al-Aamri, "The effect of environmental science projects on students environmental knowledge and science attitudes," *International Research in Geographical and Environmental Education*, vol. 23, no. 3, pp. 213–227, 2014, doi: 10.1080/10382046.2014.927167.

[17] S. Boss and J. Krauss, *Reinventing project-based learning: youth field guide to real-world projects in the digital age*. USA: International Society for teaching in Education (ISTE), 2007.

[18] C. C. Meng, N. Idris, and L. K. Eu, "Secondary students' perceptions of assessments in science, technology, engineering, and mathematics (STEM)," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 10, no. 3, pp. 219–227, 2014, doi: 10.12973/eurasia.2014.1070a.

[19] A. Habók and J. Nagy, "In-service teachers' perceptions of project-based learning," *Springerplus*, vol. 5, no. 1, pp. 1–14, 2016, doi: 10.1186/s40064-016-1725-4.

[20] Ö. D. BAYSURA, S. ALTUN, and B. Y. TOY, "Perceptions of Teacher Candidates regarding Project-Based Learning," *Eurasian Journal of Educational Research*, vol. 16, no. 62, pp. 15–36, 2016, doi: 10.14689/ejer.2016.62.3.

[21] A. Hasni, F. Bousadra, V. Belletête, A. Benabdallah, M. C. Nicole, and N. Dumais, "Trends in research on project-based science and technology teaching and learning at K–12 levels: a systematic review," *Stud. Sci. Educ.*, vol. 52, no. 2, pp. 199–231, 2016, doi: 10.1080/03057267.2016.1226573.

[22] J. W. Creswell, *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*, 4th ed. United States of America: Pearson, 2012.

[23] E. Hidayanti and Senam, "Electrolyte and Non-Electrolyte Solutions: The Effectiveness of Project-based Learning on Students' Analytical Thinking Ability," in *Proceedings of*

the 9th International Conference on Research, Implementation, and Education of Mathematics and Sciences (ICRIEMS 2022), Atlantis Press, Oct. 2025, pp. 14–27. doi: 10.2991/978-2-38476-481-5_3.

[24] L. Hinyard, E. Toomey, K. Eliot, and A. Breitbach, "Student Perceptions of Collaboration Skills in an Interprofessional Context: Development and Initial Validation of the Self-Assessed Collaboration Skills Instrument," *Eval. Health Prof.*, vol. 42, no. 4, pp. 450–472, Dec. 2019, doi: 10.1177/0163278717752438.

[25] K. S. Taber, "The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education," *Res. Sci. Educ.*, vol. 48, no. 6, pp. 1273–1296, Dec. 2018, doi: 10.1007/s11165-016-9602-2.

[26] P. Guo, N. Saab, L. S. Post, and W. Admiraal, "A review of project-based learning in higher education: Student outcomes and measures," *Int. J. Educ. Res.*, vol. 102, p. 101586, 2020, doi: 10.1016/j.ijer.2020.101586.

[27] E. Paul D. and K. Donald P., *Strategies and models for teachers: Teaching content and thinking skills*. Boston: Allyn & Bacon, 2006.

[28] P. C. Krajcik, Joseph S. and Blumenfeld, "PBL_Article.pdf," 2005.

[29] Y. Çakici, "An Investigation of the Effect of Project-Based Learning Approach on Children's Achievement and Attitude in Science," *The Online Journal of Science and Technology*, vol. 3, no. 2, pp. 9–17, 2013.

[30] E. A. Mardiansyah, S. Saptono, and N. Setiawati, "The Enhancement of Senior High School Students ' Analytical Thinking Skills in Learning Excretory System Material with Quantum Learning Model," vol. 8, no. 1, pp. 79–87, 2019.

[31] I. Ikmah, S. Eko Nugroho, and Sutikno, "Analytical Thinking Skills of Vocational Students in Circular Motion Cases Article Info," *Phys. Comm*, vol. 2, no. 2, pp. 141–150, 2018.

[32] A.-I. Sitthipon, "Development of Teachers' Learning Management Emphasizing on Analytical Thinking in Thailand," *Procedia Soc. Behav. Sci.*, vol. 46, no. 1997, pp. 3339–3344, 2012, doi: 10.1016/j.sbspro.2012.06.063.

[33] A. de Graaf, H. Westbroek, and F. Janssen, "A Practical Approach to Differentiated Instruction: How Biology Teachers Redesigned Their Genetics and Ecology Lessons," *J. Sci. Teacher Educ.*, vol. 30, no. 1, pp. 6–23, 2019, doi: 10.1080/1046560X.2018.1523646.

[34] C. E. Purwanto, S. E. Nughoro, and Wiyanto, "Penerapan model pembelajaran guided discovery pada materi pemantulan cahaya untuk meningkatkan berpikir kritis," *Unnes Physic Education Journal*, vol. 1, no. 1, pp. 26–32, 2012.

[35] Suyatman, S. Saputro, W. Sunarno, and Sukarmin, "Of student analytical thinking skills in the natural sciences by implementing problem-based learning model," *Journal of Educational, Cultural and Psychological Studies*, vol. 2021, no. 23, pp. 89–111, 2021, doi: 10.7358/ecps-2021-023-suya.

[36] P. Chonkaew, B. Sukhummek, and C. Faikhamta, "Development of analytical thinking ability and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (STEM education) in the study of stoichiometry," *Chemistry Education Research and Practice*, vol. 17, no. 4, pp. 842–861, 2016, doi: 10.1039/c6rp00074f.

[37] I. Ayu, I. Wayan, and I. W. Muderawan, "Terhadap Pemahaman Konsep Kimia Dan Keterampilan," vol. 3, no. 2, 2013.

[38] M. Barak and Y. J. Dori, "Enhancing undergraduate students' chemistry understanding through project-based learning in an IT environment," *Sci. Educ.*, vol. 89, no. 1, pp. 117–139, 2005, doi: 10.1002/sce.20027.

[39] S. A. Sari, R. S. Dewi, K. Saputra, A. Kembaren, H. Hasibuan, and C. A. Talib, "INTEGRATION OF ANALYTICAL CHEMISTRY FLIPBOOKS BASED ON PROJECT-BASED LEARNING IN IMPROVING CRITICAL THINKING SKILLS AND SCIENTIFIC LITERACY TO SUPPORT SDG-4," *Jurnal Pendidikan IPA Indonesia*, vol. 14, no. 1, pp. 59–69, Mar. 2025, doi: 10.15294/jpii.v14i1.21038.

[40] D. Linda, A. W. M. Menno, and Y. I. W. Simanjuntak, "Analysis of Problems in Learners' Collaboration Ability towards Chemistry Learning: Systematic Literature Review," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 11, pp. 784–792, Nov. 2024, doi: 10.29303/jppipa.v10i11.7326.

[41] P. Guo, N. Saab, L. S. Post, and W. Admiraal, "A review of project-based learning in higher education: Student outcomes and measures," *Int. J. Educ. Res.*, vol. 102, Jan. 2020, doi: 10.1016/j.ijer.2020.101586.

[42] S. McLaughlin *et al.*, "Evaluating the Impact of Project-Based Learning in Supporting Students with the A-Level Chemistry Curriculum in Northern Ireland," *J. Chem. Educ.*, vol. 101, no. 2, pp. 537–546, Feb. 2024, doi: 10.1021/acs.jchemed.3c01184.