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The Effect of STEM Integrated Project Based Learning Model on Students' Collaboration Skills in Atomic Structure

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Abstract

The objective of this research is to investigate the influence of the Project-Based Learning (PjBL) model, when integrated with the STEM approach, on students' collaborative abilities in the topic of atomic structure. The study is motivated by the persistent issue of low collaboration levels among chemistry learners, particularly when dealing with abstract subject matter. Employing a quantitative methodology with a quasi-experimental design—specifically the Non-Equivalent Control Group Design—the research was conducted with two tenth-grade classes at SMA Negeri 1 Suwawa, designating one as the experimental group and the other as the control group. Data were gathered through observation sheets that measured five aspects of collaboration: cooperation, responsibility, communication, adaptability, and compromise. The findings revealed a notable enhancement in collaborative skills within the experimental class following the application of the STEM-integrated PjBL model. The average final observation score for this group reached 76%, surpassing the control group's 61%. The N-Gain score for the experimental group fell within the medium category (0.48), whereas the control group's score was classified as low (0.17). Improvements were recorded across all collaboration indicators. Overall, the results suggest that the STEM-integrated PjBL model is effective in fostering collaboration skills and can be recommended as an alternative instructional approach for other chemistry topics to advance 21st-century skill development.

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1. INTRODUCTION

In the context of 21st-century education, the mastery of a series of core competencies known as the 4Cs is a crucial prerequisite for student success. These competencies include critical thinking, which enables learners to analyze information and solve problems effectively; collaboration skills that foster productive teamwork in various situations; communication skills that ensure the clear and coherent exchange of ideas; and creativity combined with innovation to produce new and valuable solutions in addressing ever-evolving challenges (Melinda, 2023). One of the most crucial skills is collaboration, in which students are expected to be able to work together effectively to complete tasks and solve problems in a learning context. Collaboration is a collective learning process carried out in groups, which includes discussions aimed at reconciling different perspectives and knowledge through suggestions, listening attentively, and respecting different opinions among students (Trisdiono et al., 2019). However, the reality on the ground shows that students' collaboration skills are still lacking or considered low (Octaviana et al., 2022). Research by (Nurwahidah et al., 2021) revealed that in group work activities, students tend not to divide roles evenly and only a few members are actively involved in completing tasks.

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This low collaborative ability becomes more complex when faced with abstract chemistry material, such as atomic structure. This material involves concepts that are difficult to visualize directly, such as electron configuration and atomic models. Research conducted by (Langitasari & Rogayah, 2021) shows that most students consider chemistry a difficult subject to learn. In line with this (Raini, 2020) found that 59.73% of students made mistakes in questions related to concepts and 74.91% in questions related to calculations involving atomic structure. This indicates a weak conceptual understanding among students. This weakness is exacerbated by conventional teaching approaches such as lectures, This condition leads to students becoming passive and minimally engaged in the learning process.

To overcome this challenge, an instructional approach that fosters active participation and collaborative problem-solving among learners is essential. One model that can be used is Project-Based Learning (PjBL), which is an innovative learning model that requires students to think creatively, critically, and interactively, producing a product based on a project that has been completed at the end of the learning process (Liah et al., 2024). Project-based learning (PjBL) encourages students to engage in activities that lead to the completion of a project involving in-depth investigation, critical thinking, diverse communication, and collaboration between students and teachers (Ihsan et al., 2024). In addition, one of the effective learning processes is by combining learning models and approaches. One approach that can be used is the STEM approach. STEM stands for Science, Technology, Engineering, and Mathematics, which encompasses the interconnection of these four disciplines in explaining the importance of principles, concepts, and methodologies in processes, useful systems, and the creation or production of products (Yuanita & Kurnia, 2019). The STEM approach encompasses theoretical exploration and practical learning, offering students direct hands-on experience during the educational process (Fathoni et al., 2020). The STEM approach offers numerous benefits, particularly the integration of various disciplines, making it highly efficient for developing 21st-century skills (Muttaqiin, 2023). According to (Putri et al., 2022), the STEM approach is effective in facilitating the development of 21st-century skills in students. The integration of STEM in PjBL can provide more complex challenges to students, so they need to think critically and collaborate more effectively (Febriani, 2023). Furthermore, the integration of the PjBL model with the STEM approach can also produce a more meaningful educational experience (Indriani, 2020).

Although the the project-based learning with STEM integration has been widely studied in the context of improving learning outcomes, studies that specifically examine its influence on students' collaboration skills, particularly in atomic structure material, are still very limited. Therefore, this study is important to fill this gap, with the main objective of evaluating the influence of the implementation of the the project-based learning with STEM integration on students' collaboration skills in understanding atomic structure material. This approach is anticipated to aid pupils in comprehending abstract concepts more deeply while developing 21st-century skills aligned with the demands of modern education.

2. METHOD

The methodology used in this work is quantitative and quasi-experimental, with a Non-Equivalent Control Group Design. In the second semester of the 2023–2024 academic year, the study was conducted at SMA Negeri 1 Suwawa in Bone Bolango Regency, Gorontalo Province.

The target of this study was tenth-grade students. The research subjects consisted of two classes, namely class X-F as the experimental class that was provided treatment utilizing the integrated STEM Project-Based Learning (PjBL) model, and class X-G as the control class that employed standard learning approaches.

The research procedure includes several stages: (1) planning learning tools and research instruments, (2) implementing learning in the experimental and control classes according to their respective treatments, (3) collecting data through observation sheets, and (4) analyzing data to see the effect of treatment on the variables studied.

The instrument used in this study was an observation sheet, which was developed based on five indicators of collaboration: cooperation, responsibility, communication, flexibility, and compromise (Trilling & Charles, 2009).

Normality and homogeneity tests are used to make sure parametric test requirements are met, t-tests are used to compare results between experimental and control classes, and N-gain scores are calculated to assess the efficacy of the integrated STEM Project-Based Learning model.

3. RESULTS AND DISCUSSION

3.1. Result

The research data include initial and final observation results, prerequisite test results, hypothesis test results, and N-gain results.

a. Initial and Final Observation Results of Collaboration Skills

The assessment of students' collaboration skills in this study used an observation sheet as an instrument. The researcher, assisted by an observer, observed the learning process of students before and after the implementation of the integrated STEM Project-Based Learning model. The initial observation results were the assessments obtained before the treatment, while the final observation results were the assessments obtained after the treatment. Based on the data obtained, the average scores of the initial and final observations in the control class and the experimental class are presented in Figure 1 below.

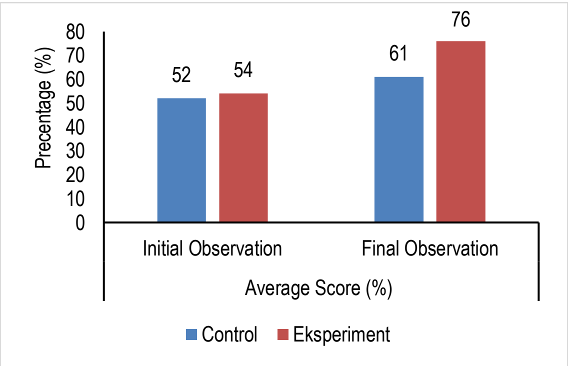

Figure 1. Diagram of Students' Collaboration Skills

Figure 1 illustrates that the experimental class's percentage of the average initial observation value was 54%, whereas the control class's percentage was 52%. Following treatment, it was discovered that the experimental class's percentage of the average final observation value rose in comparison to the control class using the STEM Integrated Project-Based Learning approach. Compared to the experimental class, which had a 76% average final observation score, the control group had a 61% average final observation score. Additionally, this indicates a notable rise in both classes' final observation scores compared to their initial observation scores.

Furthermore, the data from the initial and final observations based on the indicators of collaborative thinking skills in the control and experimental classes can be seen in Figure 2 below.

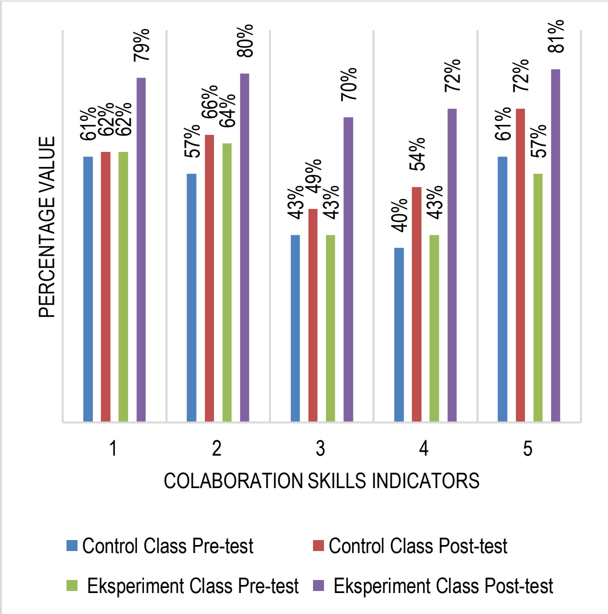

Figure 2. Diagram of Students' Collaboration Skills For Each Indicator

Description :

1 = Cooperation
2 = Responbility
3 = Compromise
4 = Communication
5 = Flexibility

Initial observations were conducted to assess students' collaborative thinking skills in each indicator before the intervention, and final observations were conducted to assess students' collaborative thinking skills in each indicator after the intervention. It is evident from Figure 2 that students' collaborative thinking abilities improved in both classes across all metrics.

b. Preliminary Test Results

The prerequisite test was conducted using the initial and final observation scores of collaboration skills from both the experimental and control classes. As part of the requirements, normality and homogeneity tests

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were carried out. The results of these prerequisite tests are presented below.

1) Normality Test

The normality test was used to determine whether or not the researcher's data was normally distributed (Kariadinata & Abdurahman, 2012). For the normality test, the Shapiro-Wilk test was used, and 0.05 was chosen as the significance criterion (α). The results of the researcher's Shapiro-Wilk test for the normality of the researcher's initial and final observations are displayed in Table 1 below:

Table 1. Results of Normality Testing for Collaboration Skills

Class	Saphiro Wilk		
	Statistic	df	sig
Initial observation of control	0,937	30	0,074
Initial observation of experiment	0,934	30	0,057
Final observation of control	0,959	30	0,191
Final Obsservation of experiment	0,954	30	0

Based on Table 1, the significance data of the initial observation and final observation show a significance value > 0.05, so it can be concluded that the initial observation and final observation data obtained are normally distributed.

2) Homogeneity Test

The next prerequisite test performed was the homogeneity test. The homogeneity test was conducted to determine whether the groups under study had homogeneous variance or not (Rustam, 2018). The Levene Statistic was used to conduct the homogeneity test in this investigation. Table 2 below displays the findings of the homogeneity test for the experimental and control classes:

Table 2. Results of Homogenity Testing for Collaboration Skills

Value	Levene Statistic	df1	df	sig
Initial Observation	Based on mean	1	58	0.617
	Based on median	1	58	0.689
	Based on median and with adjusted df	1	56.36	0.689
	Based on trimmed mean	1	58	0.654
Final Observation	Based on mean	1	58	0.112
	Based on median	1	58	0.234
	Based on median and with adjusted df	1	51.59	0.234
	Based on trimmed mean	1	58	0

Based on Table 2, the significance data obtained for the initial and final observations of the in the control and experimental classes was > 0.05, so it can be concluded that the initial and final observation data obtained were homogeneous.

c. Hypothesis Testing Results

Based on the results of the normality and homogeneity tests, the data were verified to be normally distributed and homogeneous, fulfilling the required assumptions for conducting further statistical analyses. Once these prerequisites were met, the research proceeded to the hypothesis testing stage using the t-test method. This statistical test serves to evaluate the reliability and accuracy of the research results, helping determine whether the proposed hypothesis should be accepted or rejected (Hikmawati, 2017). Hypothesis testing in this study was carried out using two approaches: the Paired-Samples t-test and the Independent-Samples t-test. The findings of these tests, as presented in Table 3, are outlined below:

Table 3. Results of the t-test for Collaboration Skills

t-test	sig
Paired-Sample t-test	0,000
Independent-Samples t-test	0,000

The data analysis in Table 3 indicates a significant gap between the pre-observation and post-observation scores of students' collaboration skills in the experimental group compared to the control group. The statistical test yielded a Sig. (2-tailed) value of 0.000, which is notably below the standard significance level of 0.05. This outcome serves as strong justification for rejecting the null hypothesis in favor of the alternative hypothesis. In other words, the integration of the STEM-based Project-Based Learning (PjBL) approach produces a measurable and statistically significant improvement in students' collaborative competencies. These findings highlight the effectiveness of this learning model as a pedagogical method for promoting teamwork and cooperative learning within classroom settings.

d. N-Gain Test Results

To evaluate the effectiveness of the STEM-integrated Project Based Learning (PjBL) model in the learning process, an N-Gain test was conducted to measure the extent of its influence (Hake, 1998). This test provides insight into how much students' collaboration skills improved after the learning intervention. The results of the N-Gain analysis, which specifically examine the development of teamwork abilities, are presented in Table 4 below.

Table 4. N-Gain Test Results for Collaboration Skills

Class	N-Gain Score	Category
Experimental	0,48	Medium
Control	0,17	Low

Figure 3 below displays the N-Gain test results for each indicator of students' collaboration abilities.

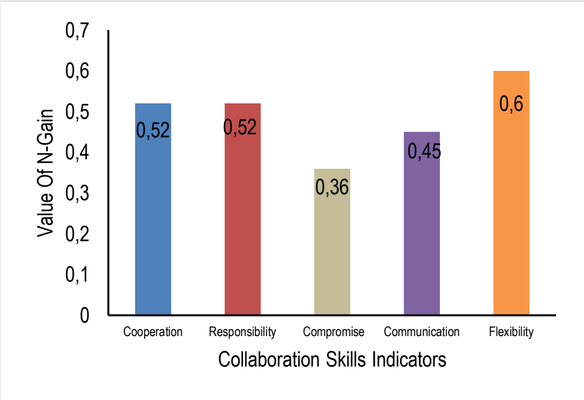

Figure 3. Diagram of N-Gain Test Results by each Indicator of Student Collaboration Skills

3.2. Discussion

Students' collaboration skills in this study were measured through five indicators, namely: cooperation, responsibility, compromise, communication, and flexibility. Initial observations were conducted before to the deployment of the integrated STEM project-based learning model, and final observations were conducted following the adoption of the model.

Figure 1 indicates that the two sample groups' levels of teamwork varied. Following treatment with the Integrated STEM Project Based Learning Model, students in the experimental class underwent modifications. With an average score of 54% on initial observation and 76% on final observation, the majority of students in the experimental class were able to improve their scores. This indicates that SMA Negeri 1 Suwawa students' teamwork is improved by the Integrated STEM Project-Based Learning Model, especially when it comes to atomic structure.

a. Cooperation

The first indicator of collaboration ability is cooperation. According to Figure 2, the control class's initial observation results on the cooperation indicator showed an average percentage of 61%, and the final observation's results showed an average percentage of 62%, an increase of just 1%. In contrast, the experimental class's initial observation results showed an average percentage of 62%, and the final observation's results showed 79%. Compared to the control class, the experimental class's cooperation indicator increased significantly more. This shows that the use of the Integrated STEM Project Based Learning model provides more space for students to interact with each other, complete group tasks, and share ideas and solutions together. Cooperation is trained in the second syntax of STEM PjBL, namely research, at which stage students begin to work in groups to gather information from various sources. Here, they learn how to divide tasks, listen to one another, and collectively integrate their findings. Collaboration is further strengthened during the discovery and application phases when students must design a project, including task distribution during the production of a product, tool, or model. All members must be actively involved so that the final result reflects collective work rather than individual work. A statement from (Winartiasih et al., 2023) supports this, explaining that the implementation of the Project Based Learning model involves the structured division of tasks among each group member, thereby encouraging active participation of all members in working together, providing space to express ideas, share knowledge, and help one another within the group.

b. Responsibility

The second indicator of collaboration skills is responsibility. Based on Figure 2, the initial observation results in the control class on the responsibility indicator show an average percentage of 57% and the results in the final observation show 66%, while The findings of the initial observation in the experimental class indicate an average percentage of 64%, whereas the results of the last observation indicate 80%. This is because the PjBL model has a distinctive characteristic where students are required to take responsibility for finding and managing the information they obtain (Purnomo & Ilyas, 2019). In addition, students are also responsible for completing various activities that support the success of the learning process, such as completing assigned tasks, maintaining discipline during learning activities, and obeying the applicable rules (Marlina et al., 2022).The responsibilities of students in STEM-integrated PjBL learning are integrated into the discovery syntax, where at this stage students are given the responsibility to design projects by developing concrete ideas based on the results of their previous research. This is followed by the application stage, where students' responsibilities are further developed, with each student given the responsibility to apply the designs they have created by directly designing, making, and testing the results of the product trials. Each student plays a crucial role in ensuring that the parts they work on proceed according to plan.

c. Compromise

The third indicator of collaboration skills is compromise. Based on Figure 2, the initial observation results in the control class on the compromise indicator show an average percentage of 43% and the results at the final observation show 49%, In contrast, the experimental class's average percentage at the initial observation was 43%, and at the last observation, it was 70%. A significant improvement in compromise skills indicates that students in the experimental class learned to express their opinions, respect differences of opinion, prioritize joint decisions, and negotiate to resolve minor conflicts during the project. Compromise was practiced in discovery syntax, especially when combining ideas into a single project design. Each student usually has their own ideas, and this is where students learn how to evaluate ideas objectively and decide on ideas in a fair manner. In the application stage, compromise is still necessary, especially when facing obstacles in implementing the design. Materials may not be available, tools may not work, or the design may be too complicated. In such situations, students must be able to agree on alternative solutions that are still effective. Compromise teaches the value of mutual respect and seeking the best solution collectively. This aligns with the statement by (Marita et al., 2023) who state that achieving indicators of compromise skills can be attained by accepting criticism and suggestions, making decisions together, and negotiating differences of opinion to achieve common goals.

d. Communication

The fourth indicator of collaboration skills is communication. Figure 2 illustrates that, The mean score for the communication indication in the control group was 40% in the initial observation and increased to 54% in the final observation. In contrast, the experimental class recorded an initial average of 43%, which rose to 72% in the final observation. Communication is an indicator that shows a significant increase in the experimental class. The integrated STEM Project Based Learning model strongly encourages students to actively express their ideas, listen to their peers' opinions, and practice presentation and discussion skills, both verbally and in writing. This is consistent with the assertion made by (Winartiasih et al., 2023) who stated that project based learning is considered to greatly support the communication process among group members, especially in conveying their respective responsibilities and communicating the findings of the project being worked on. This communication skill is honed through the discovery stage, because the entire project design process begins with discussion and the presentation of ideas. Each student must be able to express their opinions clearly, provide logical reasons, and listen to their friends' ideas. Communication is important to ensure that every decision made is truly a consensus and understood by all members. In addition, in terms of syntax communication, students' communication skills are further trained at this stage, where each student must be able to present the results of their tested projects in front of their friends and teachers. Each student can ask questions or share ideas based on their understanding of the concepts.

e. Flexibility

The fifth indicator of collaboration skills is flexibility. Based on Figure 2, the initial observation results in the control class for the flexibility indicator show an average percentage of 61% and the results at the final observation show 72%, while in the experimental class, the initial observation results show an average percentage of 57% and the results at the final observation show 81%. Flexibility increased rapidly in the experimental class because students had to be able to adapt to various situations while carrying out projects, facing challenges, working with various types of peers, and accepting changes or revisions to work strategies. This was practiced in the application syntax, where students worked together in teams to create projects. In this process, students were required to adapt to other members, divide tasks, and achieve common goals. Additionally, in the communication syntax, students interact with other team members to discuss project ideas and results, so they must be able to adapt to the communication styles and perspectives of other members. This aligns with the statement by (Trilling & Charles, 2009), which explains that indicators of collaboration skills are demonstrated through open attitudes, such as being willing to accept joint decisions, listening to criticism and suggestions, discussing differences of opinion, and being willing to work together to solve problems as a team.

The results of hypothesis testing using the Paired-Sample t-test in Table 3 indicate a significance level (α) of 0.05 and a two-tailed significance value of 0.000. Since this significance value is smaller than the predetermined α (0.000 < 0.05), the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. This suggests a measurable difference in the average collaboration skills of students taught using the STEM-integrated Project-Based Learning approach. Similar results are found in the Independent Samples t-test presented in Table 3, which also yields a two-tailed significance value of 0.000 at α = 0.05. For the same reason (0.000 < 0.05), H_0 is again rejected and H_1 is accepted. These results' consistency supports the idea that using the STEM-based Project-Based Learning model significantly improves students' ability to collaborate, especially when it comes to the atomic structure–nanotechnology issue.

The results of this study are consistent with previous studies conducted by (Aulia, 2023) and (Febriani, 2023) which claimed that students' teamwork skills were impacted by the use of project-based learning with STEM integration.

The effectiveness of project-based learning with STEM integration in enhancing students' cooperation skills was assessed using the N-Gain test. Furthermore, each of the collaboration indicators such as cooperation, responsibility, communication, flexibility, and compromise also recorded N-Gain values in the same category. These consistent results across all measured indicators indicate that the project-based learning with STEM integration has a considerable positive impact on improving students' collaborative abilities, demonstrating its potential as an effective instructional approach for fostering teamwork skills in educational settings.

4. CONCLUSION

Based on the results of the study and discussion, it can be concluded that there is an effect of the the project-based learning with STEM integration on students' collaboration skills in atomic structure material. This is indicated by the final observation results of collaboration skills, which showed an average of 76% for the experimental class, while the average for the control class was only 61%.

However, the implementation of the integrated STEM project-based learning (PjBL) model has limitations, namely that it requires a relatively long time. Therefore, teachers must be able to plan lessons well and use time effectively. To gain a more comprehensive understanding of the broader impact the project-based learning with STEM integration within the learning process, it is recommended that the application of this model be extended to various chemistry topics beyond atomic structure. Implementing the model across different subject areas would allow educators and researchers to examine its consistency, adaptability, and effectiveness in enhancing student engagement, collaboration, and mastery of 21st-century skills in diverse learning contexts.

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