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Transforming Learning Independence in Future Science Teachers: The Powerful Impact of a Project-Based Collaborative Learning (PjBCL) Model

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ABSTRACT

This study examines the transformative impact of the project-based collaborative learning (PjBCL) model on the learning independence of prospective science teachers. As the educational paradigm shifts toward a learner-centered approach, efforts to foster independence and responsibility for learning in prospective educators are becoming increasingly important. This study employed a quasi-experimental design with a mixed-methods approach, involving 64 students from the science education study program who were enrolled in a course on developing science teaching materials. Students were divided into an experimental class and a control class. The experimental class participated in a series of project-based collaborative learning (PjBCL) activities, while the control class received regular instruction. Data on learning independence were collected through self-regulated learning (SRL) questionnaires, reflective journals, and classroom observations. The results showed a significant increase in the prospective teachers' ability to plan, coordinate, and implement their learning process independently in the experimental class. Furthermore, the collaborative nature of this model encouraged shared accountability, peer support, and active involvement of all students, which overall formed a more independent learning mindset. This study demonstrates the effectiveness of a project-based collaborative learning model in preparing prospective science teachers who are independent, reflective, and innovative.

Keywords: Learning Independence, Project-Based Collaborative Learning Model, Prospective Science Teachers.

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INTRODUCTION

21st-century education requires students to possess critical thinking, creative, collaborative, and communicative skills (4C) (Choli et al., 2024; Pramudyani et al., 2025). In line with these demands, prospective science teachers are expected not only to master scientific content but also to be able to learn independently and take responsibility for their learning process (Mashuri et al., 2022; Verma et al., 2023). Zimmerman & Schunk (2016) state that self-regulated learning allows individuals to actively direct, monitor, and evaluate their learning process. In the context of teacher education, this ability is crucial for future teachers to adapt to the development of science and technology (Agustin et al., 2018; Sung et al., 2016; Sutoyo et al., 2025; Treagust et al., 2015; Yoon & Cha, 2016; Zhai et al., 2024). This aligns with various expert opinions that, in addition to being equipped with specific content understanding, teachers must possess relevant pedagogical skills and technological mastery to support the learning process

(Almonacid-Fierro et al., 2023; Bramwell-Lalor, 2023; Doil & Pietzner, 2023; Magaji & Coombes, 2024; Mashuri et al., 2025; Palmer et al., 2015; Prachagool & Nuangchalerm, 2019; Wang et al., 2024).

Cultivating learning independence is an essential component and a key competency that should be developed during the education of teacher candidates. This is particularly important given the future role of teachers as adaptive and reflective facilitators of learning (Rubiyanti et al., 2020; Škugor & Tomaš, 2024). Learning independence is crucial for ensuring success in the educational process (Agnes-Ijeoma, 2023). Research indicates that self-regulated learning (SRL) plays a vital role in helping students achieve high academic performance and reach their learning objectives (Cho & Shen, 2017; Dent & Koenka, 2016; Essa, 2022; Greene & Azevedo, 2017; Hadwin et al., 2018; Jin et al., 2023; Kizilcec et al., 2017; Lai & Hwang, 2016; Panadero, 2017; Tersta et al., 2025; Wong, 2019). However, in practice, many students still exhibit low levels of learning independence, often relying heavily on instructors, lacking initiative in managing their own learning processes, and not being accustomed to independently reflecting on their academic achievements (Lee et al., 2022; Pilli et al., 2017; Rubiyanti et al., 2020; Yusuf, 2023). This situation highlights the necessity for interventions in learning models that can promote and foster independent learning (Broadbent & Poon, 2015).

One learning model believed to be effective in increasing the independent learning of prospective science teachers is the project-based collaborative learning (PjBCL) model. The project-based collaborative learning (PjBCL) model is an integration of collaborative learning (CL) with project-based learning (PjBL). Based on various previous studies and research, it is known that collaborative learning has been proven to improve students' communication skills, cooperation, motivation, science literacy, and technology literacy (Mashuri et al., 2024, 2025; Setiawan & Sugiyanto, 2020). In addition, project-based learning (PjBL), as the primary foundation of PjBCL, has been shown to improve outcomes in the learning process (Intan et al., 2025; Wahyudi et al., 2024). Based on the study by Anette Markula & Maija Aksela (2022), PjBL is effective because it emphasizes collaboration, technology use, and scientific practices, and can stimulate problem-centered learning with student reflection and scientific presentations. PjBL can also significantly improve students' enthusiastic learning attitudes, creativity, enjoyment of learning, competence development, and the quality of student project products (Latip & Supriatna, 2023). PjBL can also enhance 21st-century skills, such as problem-solving and critical thinking (Guo et al., 2020; Kokotsaki et al., 2016; Susanti et al., 2022).

Previous research on collaborative learning and PjBL has still focused on the separate implementation of PjBL and collaborative learning (Masdarini & Marsiti, 2024; Cahyani, 2021; Halim et al, 2023). Some other studies have applied more collaborative learning and PjBL to elementary or secondary school students (Rofik, 2023; Wahyuningrum et al., 2023; Wicaksono et al., 2021). Research integrating these two models through Project-Based Collaborative Learning (PjBCL) is still minimal, especially in the context of science teacher education. For example, research by Sung, Chang, and Liu (2016) discusses the integration of PjBL with technology to improve student learning outcomes; however, it has not specifically investigated learning independence in pre-service teachers. Meanwhile, research by Susanti et al. (2022) suggests that student collaboration in project-based learning has the potential to enhance self-regulated learning; however, this research remains exploratory and has not thoroughly examined the impact of the PjBCL model on learning independence. Additionally, most previous studies have focused more on cognitive learning outcomes or social skills, rather than learning independence as the primary outcome (Kokotsaki et al., 2016).

Through a review of previous studies, it was found that: 1) There is not much research specifically examining the impact of integrating PjBL and Collaborative Learning (PjBCL) on learning independence, particularly in science teacher candidates. 2) The development of PjBCL-based learning materials for science teacher candidates is still limited. 3) Research has been conducted more on elementary and secondary school students, not on teacher candidates at universities. 4) Previous research has focused more on cognitive learning outcomes and social skills, while the transformation of learning independence has not been sufficiently explored. Therefore, this research proposes a solution to overcome these various obstacles by developing

and implementing a Project-Based Collaborative Learning (PjBCL) model, which is expected to enhance the learning independence of prospective science teachers.

The theoretical framework underlying the PjBCL learning model is Self-Regulated Learning (SRL) (Agnes-Ijeoma, 2023; Broadbent & Poon, 2015; Cho & Shen, 2017; Dent & Koenka, 2016; Essa, 2022; Greene & Azevedo, 2017), Self-Determination Theory (Rahayu et al., 2022; Ryan & Deci, 2022; Wang et al., 2024), and Social Constructivism (Nithideechaiwarachok & Chano, 2024; Shah, 2019; Zhang & Hu, 2024). Based on the concept of Self-Regulated Learning (SRL), PjBCL provides students with the opportunity to plan, implement, integrate, and reflect on their learning (self-reflection). This allows for the systematic development of self-directed learning skills. This PjBCL model meets three basic psychological needs of students: autonomy, competence, and relatedness. This fosters intrinsic motivation and independence in students' learning during the learning process. In PjBCL, students build understanding through social interaction, scaffolding from peers and lecturers, so that knowledge develops through the process of negotiating meaning and shared experiences. This model places prospective teachers as the leading actors in building knowledge through relevant projects. Through collaboration, prospective teachers learn to support each other and exchange ideas, while through projects, they are challenged to manage their time, resources, and learning strategies independently. This study aims to examine the impact of implementing a project-based collaborative learning model on improving the learning independence of prospective science teacher students. Thus, the results of this research are expected to contribute to the development of more effective learning strategies for shaping future science teachers who are independent, reflective, and innovative.

METHOD

This study employed a mixed-methods approach with a quasi-experimental, nonequivalent control group design. This design involved two sample groups: an experimental class treated using a collaborative project-based learning model, and a control class following a regular learning model. This design was used to determine the effect of the learning model on the level of learning independence of prospective science teacher students. The population in this study consisted of all students in the science education study program at a state university in Indonesia. The sample consisted of 64 students taking the teaching materials development course, divided into two classes: an experimental class (32 students) and a control class (32 students). Sample selection was conducted using a saturated sampling method, based on class availability and equivalence of initial characteristics. The independent variable in this study was the collaborative project-based learning model, while the dependent variable was the level of learning independence among prospective science teacher students.

The main instrument in this study was a learning independence questionnaire developed based on the self-regulated learning (SLR) indicators according to Zimmerman (2002), which includes aspects of the forethought phase, performance phase, and self-reflection phase consisting of five main indicators, namely: 1) learning initiative, 2) active involvement in learning, 3) time and task management skills, 4) independent decision making, and 5) the ability to reflect on the learning process. The questionnaire used a 4-point Likert scale. Observations and reflective journals were also used as supporting data to understand the learning process and student behavior in collaborative learning. The questionnaire instrument has been tested for validity and reliability before use.

The research was conducted in three main stages, namely: 1) pretest, where both groups were given an initial test to measure the level of learning independence before treatment, 2) treatment, where the experimental group participated in project-based collaborative learning for 8 meetings, students worked in teams to complete real-world problem-based projects in the context of science, while the control group participated in learning with a lecture approach and individual assignments (regular), and 3) posttest, where both groups were given a questionnaire again to determine changes in their level of learning independence. Furthermore, the data were analyzed quantitatively using parametric statistical tests with the help of SPSS software. The paired sample t-test was used to determine the difference in pretest and posttest scores within each group. The independent sample t-test was used to determine the difference

in learning independence scores between the experimental and control groups. Significance was set at a 95% confidence level (α = 0.05).

RESULT AND DISCUSSION

A. Learning Independence Questionnaire

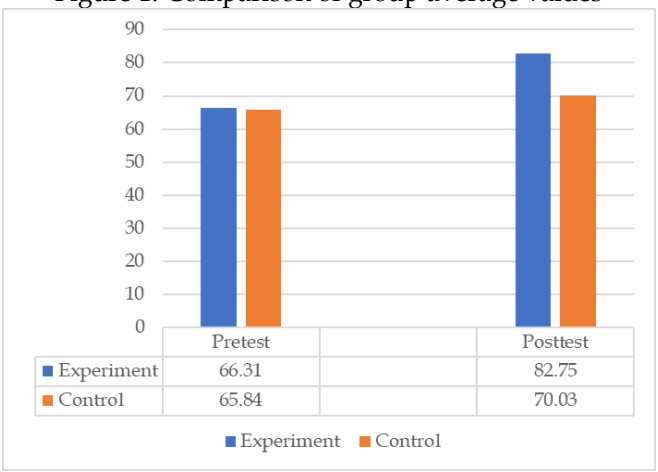
This study aims to determine the effect of the project-based collaborative learning (PjBCL) model on the learning independence of prospective science teachers. Data collection was conducted through pretests and posttests using a learning independence questionnaire in two groups: the experimental class and the control class. The mean scores and standard deviations based on the pretest and posttest results for both groups are presented in Table 1. Meanwhile, the changes in the average value of each class during the pretest and posttest are presented in Figure 1. The experimental group experienced a 16.44 point increase in learning independence scores, from 66.31 to 82.75. The control group also experienced an increase, but only from 65.84 to 70.03, representing a 4.19-point increase. This suggests that the project-based collaborative learning (PjBCL) model provided to the experimental group has a greater impact on increasing learning independence than conventional learning. The standard deviation of the experimental group decreased slightly from 5.24 to 4.89, indicating that the increase in learning independence was relatively evenly distributed among group members.

In contrast, the standard deviation in the control group increased from 4.97 to 5.12, indicating greater variation in scores between students, or uneven improvement. The higher average improvement and more stable distribution of scores in the experimental group reinforce the hypothesis that collaborative project-based learning is not only effective on average but also produces more consistent results across students. Meanwhile, conventional learning, while providing slight improvements, fails to facilitate the development of independent learning in an optimal and even manner.

Table 1. Sample mean and standard deviation

Class	N	Pretest		Posttest	
		Mean	SD	Mean	SD
Experiment	32	66.31	5.24	82.75	4.89
Control	32	65.84	4.97	70.03	5.12

Figure 1. Comparison of group average values



A paired sample t-test was conducted to determine whether there was a significant difference between the pretest and posttest scores in each group. The test results are as shown in Table 2. The test results indicate that a significant difference existed between the pretest and posttest scores in both the experimental and control classes ($p < 0.05$). However, the significantly higher t-value in the experimental group indicates a stronger improvement. The calculated t-value of 12.45 indicates a substantial difference between the pretest and posttest scores. The significance value (p-value) = 0.000, which means $p < 0.05$; therefore, statistically, there is a significant difference between the before and after treatment. This suggests that the

project-based collaborative learning model has a substantial impact on enhancing the learning independence of prospective science teacher students.

The t-value of 4.87 also indicates a significant increase, although it is lower than that of the experimental group. The p-value = 0.000 (<0.05) indicates a significant difference between the pretest and posttest scores; however, the increase was not as large as that of the experimental group. This suggests that conventional learning can still have an impact, albeit not as significant or effective as the project-based learning model. The second group experienced a statistically significant increase in learning independence, but the experimental group experienced a greater and stronger increase in effect (indicated by a much higher t-value). This finding confirms that the use of a collaborative project-based learning model is more effective in encouraging the transformation of learning independence compared to the conventional approach.

Table 2. Paired Sample t-test results

Class	t	Sig. (2-tailed)
Experiment	12.45	0.000
Control	4.87	0.000

The independent sample t-test was used to determine whether there was a significant difference between two unrelated groups: the experimental group (treated with a project-based collaborative learning model) and the control group (treated with conventional learning), after the treatment was administered (post-test). The results of the independent sample t-test are shown in Table 3. The average posttest score for student learning independence in the experimental group was 82.75, whereas in the control group, it was 70.03. The average difference of 12.72 points indicates that students who learned through a project-based collaborative model had a substantially higher level of learning independence. The t-value is 9.32, which is a high value indicating a very strong difference between the groups. The significance value (p-value) = 0.000, which means $p < 0.05$, indicating a statistically significant difference between the experimental and control groups in the posttest scores for learning independence. This difference proves that the project-based collaborative learning model is significantly more effective than the conventional model in improving learning independence. These results also strengthen the effectiveness of the project-based learning model in fostering active engagement, personal responsibility, and reflective skills in prospective science teachers. There were significant differences between the experimental and control groups. This suggests that the implementation of a collaborative project-based learning model has a significant positive impact on enhancing student learning independence. Therefore, the results of this study support the implementation of the collaborative PjBL model as a relevant strategy for developing independent and competent future teachers.

Table 3. Independent sample t-test results

Class	Mean	t	Sig. (2-tailed)
Experiment	82.75	9.32	0.000
Control	70.03		

The results of the study indicate a significant difference in the level of learning independence between prospective science teachers who participated in a collaborative project-based learning model and those who participated in conventional learning. This is demonstrated through the results of the paired sample t-test and independent sample t-test, where the experimental group experienced a higher and more even increase in average scores compared to the control group. In more detail, the average score for learning independence in the experimental group increased from 66.31 to 82.75, whereas in the control group, it increased from 65.84 to 70.03. The standard deviation in the experimental group also decreased, indicating that the increase occurred relatively evenly among group members. The results of the independent sample t-test with a significance value of 0.000 and a t-count of 9.32 strengthen the finding that the difference is statistically significant.

These findings support the view that project-based collaborative learning (PjBL) models can effectively enhance students' learning independence. This aligns with the theory of self-regulated learning (Zimmerman, 2002), which emphasizes that independent learning is formed through three important phases: planning (forethought), implementation (performance), and self-reflection (self-reflection). In the context of PjBL, students are actively involved in developing project plans, collaborating on tasks, and evaluating the results of group work and individual contributions. This entire process encourages students to manage their time, develop strategies, solve problems, and develop their independent thinking.

Furthermore, from the perspective of Self-Determination Theory (Deci & Ryan, 1985), collaborative project-based learning can fulfill students' basic psychological needs, namely autonomy, competence, and social connectedness. Students are given the freedom to manage the learning process, experience success through project completion, and receive support through team interactions. These three aspects have been shown to increase intrinsic motivation, which is a key prerequisite for developing independent learning.

This model also aligns with the principles of social constructivism (Vygotsky, 1978), which emphasizes that knowledge is actively constructed through social interaction and the interpretation of experiences. In collaborative learning, students learn not only from the project assignments they undertake, but also from the exchange of ideas, negotiations, and collaborative problem-solving. These interactions create a challenging yet supportive learning environment, encouraging students to learn independently and take ownership of their learning. Therefore, the collaborative project-based learning model impacts not only learning outcomes but also character development and long-term learning abilities. The findings of this study provide an important insight for education teachers, emphasizing the importance of implementing innovative and participatory learning strategies to develop independent, reflective, and prepared prospective teachers who are ready to face the complexities of modern education.

B. Reflective Journal of Prospective Science Teachers

Student reflective journals are an important source of qualitative data in assessing how students respond to learning not only cognitively, but also affectively and metacognitively. As part of the learning process, students in the experimental group were asked to write reflective journals at the end of each learning session. The components that prospective teachers were required to write in their reflective journals for each learning activity were what they learned, how they felt during the learning process, and reflections or improvements for future learning. The analysis of the prospective teachers' reflective journals revealed four important aspects related to their learning independence.

1) Increased Awareness of Learning Responsibilities

Most students stated that involvement in project groups made them more aware of the importance of each member's role and responsibility. They felt the need to complete assignments on time and not rely on other members. Student reflections indicated that the project-based learning model fostered self-awareness of individual responsibility in the learning process. Unlike conventional learning, which tends to be one-way, projects that require concrete contributions from each group member encourage students to be independent of the lecturer or teammates. Project-based learning creates an environment of accountability, where the failure of one individual can impact the overall performance time. This makes students realize the importance of their active role, in line with the principle of ownership of learning in self-directed learning. One prospective teacher wrote:

> "*I learned not to wait for the lecturer to constantly process things. I had to take the initiative to seek information and complete my part so that the group project could be completed*." (Prospective Science Teacher (PST) 7, Week 3 Reflection).

The student's expression indicates that their approach to learning has shifted from being passive and relying on the teacher to being active and learning independently. This future instructor knows that the success of the group project depends significantly on how much each person contributes and how much they take the lead. This statement means that students are learning to take responsibility for themselves and to learn independently. These are two key

parts of professional education, especially for prospective teachers who will later instruct pupils.

Students have learned to adapt to the project-based learning paradigm, which requires them to be active participants and possess problem-solving and teamwork skills. This is shown by the fact that they are no longer always waiting for orders from the teacher. Students are beginning to realize that learning is not just about acquiring information; it is also about discovering and building knowledge independently. Adult learners (andragogy) are those who are willing to take the initiative to find information and finish their work on a project. This is a skill that is very important in the workplace, especially in education.

2) Formation of Time Management and Independent Learning Habits

Students noted that problem-based projects required them to organize their study schedules, independently read sources, and collectively discuss their findings. This fostered structured study habits. Students stated that they learned to manage their time, set priorities, and independently seek resources to complete project tasks. This is an important indicator of self-management skills, which are part of self-regulated learning (Zimmerman, 2002). The open-ended and complex nature of project activities provided students with the opportunity to develop personal learning strategies, including organizing study schedules, seeking additional resources, and initiating progress on assignments independently. In other words, projects served as a vehicle for ongoing autonomy in learning. One prospective teacher wrote:

> "*At first, I was confused about where to start. But over time, I got used to planning my work steps and managing time for independent research before group discussions*." (PST 12, Week 4 Reflection).

This expression reflects the process by which students adapt to learning methods that require independence and personal planning. Initially, students experienced confusion, indicating challenges in the transition from a more structured learning model directed by the lecturer to a more independent one. This confusion is natural because students may have been more accustomed to following instructions than to independently designing work stages. However, over time, students successfully developed the ability to create their work steps and manage their time effectively, enabling them to conduct research before group discussions. This indicates the development of self-management skills, learning initiative, and planning skills. The ability to design a workflow and manage time effectively is crucial, not only in the context of learning but also in professional life, especially for future teachers who will need to design lessons and manage their time efficiently.

This change can occur due to the characteristics of project-based learning or independent tasks, which provide students with space to experience the learning process directly and learn from their experiences (experiential learning). When students are faced with challenges without detailed instructions, they are "forced" to find solutions, design strategies, and manage resources on their own. By frequently encountering situations like this, students gradually learn to overcome initial confusion by developing structured thinking habits and taking initiative.

Additionally, the experience of conducting independent research before the group discussion allows students to delve deeply into the information, enabling them to make more meaningful contributions during the discussion. This process also builds confidence, as students feel more prepared and understand the material that will be discussed. Over time, the trial-and-error process of time management and work organization strengthens adaptability and flexibility, two essential competencies in the educational world. Thus, the student's expression describes an authentic learning process, where initial challenges become the trigger for developing self-directed learning skills and personal planning, which are crucial for future teachers in facing the dynamics and complexities of their future tasks.

3) Increased Reflective Ability and Self-Awareness

Through guidance and reflective instruction from lecturers, students begin to analyze their strengths and weaknesses in the learning process, becoming aware of their progress from week to week. The process of writing a weekly journal allows students to reflect on their learning process. Many of them notice changes in learning behavior, such as transitioning from

a passive to a more active and proactive approach. This aligns with the self-reflection phase of the independent learning cycle, where individuals evaluate the effectiveness of their learning strategies and plan future improvements. This reflective practice not only fosters metacognition but also helps students develop their identity as learners, which is crucial in the long term, especially in the teaching profession, where continuous learning is demanded. One prospective teacher wrote:

> "*I realized that I'd been too passive. But after being given responsibility for this project, I started to be more courageous in expressing my opinions and finding my solutions*." (PST 3, Final Reflection).

This student's writing demonstrates that they have thought critically about their approach to studying thus far. Initially, the student recognized that they were typically passive when studying. They might have obtained information more frequently without actively participating in debates or problem-solving. However, being directly involved in projects that give people responsibility turned out to be the thing that changed their minds. Students were encouraged to take the lead on the project after they were given responsibility for it. He wanted to make a real difference, so he got braver about saying what he thought. Not only that, but kids are also learning how to solve problems on their own, which is a valuable skill in the business world, especially for future teachers who will serve as role models and help pupils learn. This change from passive to active shows that people are developing both interpersonal skills (the ability to talk to others, share ideas, and work together) and intrapersonal skills (being aware of oneself and having the courage to take on roles). These are important skills for education and leadership.

4) Collaboration as a Catalyst for Independence

Although learning is conducted in groups, students feel that collaboration encourages them to be more active and independent, as the interdependence demands a real contribution from each individual. Interestingly, student reflections indicate that group work does not diminish independence but rather acts as a catalyst for its growth. This is because teamwork requires active participation, individual responsibility for tasks, and the ability to coordinate effectively. In this context, collaboration does not mean independence, but rather co-regulation —a mechanism by which learners help each other develop through social interaction. This aligns with the social constructivist view (Vygotsky, 1978), which posits that cognitive and personal development can be facilitated through dialogue and collaborative work. One prospective teacher wrote:

> "*I didn't want to let the team down, so I studied more seriously. From there, I realized that I could learn more on my own than I thought*." (PST 15, Week 5 Reflection).

This phrase indicates that students have a strong external motivation: the desire not to let their team down. When students feel responsible for their group, they take their studies and responsibilities more seriously. In this process, they not only strive to fulfill their duties but also discover their own potential, realizing they can achieve more than they previously thought possible. This growth in self-efficacy—the belief in one's abilities—is a significant aspect of their development. Additionally, this observation highlights a change in students' mindsets. Those who initially doubted their ability to learn tended to grow more when they felt a sense of responsibility and commitment to their team. As a result, students experienced individual growth in motivation, self-esteem, and the ability to learn independently.

This phenomenon often occurs when individuals collaborate on a project or work in a group. When the group's success hinges on the contributions of each member, students are motivated to strive for excellence to avoid holding the team back. This positive social pressure, driven by the expectations and beliefs of their peers, encourages students to work harder. Moreover, when students take their studies more seriously, they tend to gain a deeper understanding of the subject matter and discover effective learning strategies that suit them. This process fosters self-regulated learning, where students take control of their own time, resources, and learning methods. Direct experience in overcoming challenges provides valuable feedback, reinforcing the idea that they can achieve more than they initially believed. Meeting team expectations boosts confidence and motivates continued learning and progress. This

experience not only enhances students' academic performance but also fosters independence and responsibility, two essential traits for future educators and other professions.

The results of the reflective journal indicate that the project-based collaborative learning model not only improves students' knowledge and skills but also significantly encourages the development of independent learning attitudes. Students begin to demonstrate active, reflective, and responsible learning behaviors about their learning process. These findings suggest that implementing the project-based collaborative learning model not only equips students with academic competencies but also fosters the development of affective and metacognitive aspects that are essential for independent learning. By engaging students in meaningful, open, and reflective learning experiences, this model enables the development of learners who are responsible, confident, and capable of managing their learning processes. These characteristics are highly needed in the profile of future teachers.

C. Observation of Model Implementation

Observations were conducted in two classes: an experimental class using the Project-Based Collaborative Learning (PjBCL) model and a control class using the regular approach. The purpose of this observation was to assess the development of students' learning independence during the learning process, focusing on five main indicators: 1) learning initiative, 2) active involvement in learning, 3) time and task management skills, 4) independent decision-making, and 5) reflection on the learning process. The results of the score summary for each experimental and control class for each indicator are as shown in Table 4.

Table 4. Recap of observation scores

Indicators	Average value	
	Experiment Class	Control Class
Learning initiative	3.8	2.5
Active involvement in learning	3.7	2.3
Time and task management skills	3.6	2.6
Independent decision-making	3.5	2.4
Reflection on the learning process	3.9	2.1

Based on observation scores, it appears that students in the experimental class consistently demonstrated higher levels of independent learning behavior compared to those in the control class. They were more active in taking initiative, engaging in group discussions, managing time and assignments independently, and demonstrating strong reflective skills. Meanwhile, students in the control class exhibited a learning tendency that was still dependent on lecturer instructions and had not yet become accustomed to reflection and independent decision-making. This finding reinforces previous quantitative results, which have shown that the project-based collaborative learning model is effective in shaping the independent learning attitudes and behaviors of prospective science teachers.

D. Correlation of Questionnaire Results, Reflection Journals, and Class Observations

This study used a mixed quantitative and qualitative approach to elucidate the impact of the PjBL model on the learning independence of prospective science teachers. Three primary data sources: questionnaires, reflective journals, and classroom observations, showed consistency and mutually reinforcing. The four indicators, measured as forms of learning independence in prospective teachers, showed positive results.

The Learning Independence Questionnaire for the Learning Initiative Indicator showed a significant increase in the average initiative indicator score in the experimental group from the pretest to the posttest. Reflective journals also revealed that students were becoming accustomed to seeking information independently without waiting for the lecturer to guide them. Observations also revealed that students were actively proposing ideas, seeking references, and initiating discussions without prompting. The third data source demonstrated that PjBCL significantly fostered stronger learning habits.

The questionnaire for indicators of active engagement in learning showed an increase in scores for indicators of engagement in discussions, work groups, and student assignment

reporting. Reflective journals also revealed that students felt more engaged because they took responsibility for the final results of group projects. Observations also revealed that students engaged in intense discussions, asked questions, and demonstrated enthusiasm in presenting project results. This indicates a congruence between students' internal perceptions and actual classroom behavior regarding active engagement.

Questionnaires for time and task management indicators showed that students reported improvements in their ability to manage time and complete assignments on time. Reflective journals also revealed that students recognized the importance of scheduling and personal planning to ensure their contributions were not left behind. Observations also indicated that projects were completed on time, tasks were divided, and no single individual dominated the group. This demonstrates that students' self-management skills are both quantitatively reflected and directly observed in group dynamics.

The questionnaire for the independent decision-making indicator showed that scores on this indicator indicated an increase in the courage to make academic decisions. Students' reflective journals noted that they began to be more confident in determining solutions to problems without waiting for lecturer validation. Meanwhile, observations revealed that students made decisions about the project workflow in a democratic and argumentative manner. This triangulation data demonstrates that the PjBCL model fosters autonomous decision-making skills.

The self-reflection questionnaire showed an increase in awareness scores regarding the learning process and self-evaluation. Reflective journals revealed that students openly wrote about their feelings, accomplishments, and shortcomings on a weekly basis. Observations also showed that students verbally reflected on the results of their group work in the closing discussions of each session. The results of these three instruments demonstrate that reflective habits are qualitatively strong in prospective teachers, reflected in their perceptions and actual behavior.

Three data sources provide strong triangulation that the project-based collaborative learning model enhances individual initiative, active participation, and responsibility, fosters self-management and decision-making skills, and fosters the internalization of reflection as part of the learning process. Thus, this approach is not only statistically effective (through questionnaires), but also has a tangible impact on student learning experiences (as documented in journals) and classroom practice (as observed).

DISCUSSION

The study indicated that using the Project-Based Collaborative Learning (PjBCL) model effectively has a significant impact on the learning independence of prospective science teachers. Sun and Ashari (2023) conducted a systematic study and found that Project-Based Learning (PBL) can enhance motivation and learning outcomes in early scientific education. However, they did not specifically discuss how structured collaboration can be utilized in the learning process. This study supports the notion that collaborative integration at every step of PjBCL enhances autonomous learning, an aspect that has not been thoroughly examined in traditional PjBL studies. Sugianto (2022) found that combining PjBL with collaborative learning can help students learn better; however, they have not yet made making learning more independent the primary goal. In this way, PjBCL is quite helpful since it considers learning from the emotional and character aspects of the kids. Rohmaniyah and Chariyathamsuksa (2022) also stated that PjBL can help students work together and be more creative; however, they have not yet examined how collaboration fits into the overall learning design. This study examines how projects and well-planned teamwork can be integrated into a single model. Riyadi et al.'s (2020) study supports the premise that PjBL can help people think critically and work collaboratively, although it only examines its impact on cognitive achievement.

On the other hand, this study expands its scope by explicitly analyzing how prospective teachers' ability to learn independently has grown. Anggriani et al. (2023) reached a similar conclusion when they demonstrated that PjBL facilitates students' collaboration in science class; however, they did not examine the aspect of learning autonomy. Lastly, Khoudri et al. (2023)

demonstrated that PjBL can help language learners become more independent, which supports the idea that well-designed project-based models can facilitate student independence. This study contributes to the body of research by combining project-based and collaborative learning and shifting the primary goal of science teacher development from autonomous learning.

The results of this study show that the Project-Based Collaborative Learning (PjBCL) approach not only motivates students to work together but also significantly changes the way prospective science teachers learn independently. This finding aligns with Rediani's (2023) research, which suggests that PjBL effectively helps children become more independent and improve their science skills. Yuliani and Lengkanawati (2019) have found that PjBL can help students become more independent by utilizing self-direction and self-instruction strategies in the context of language acquisition. Rostom's (2019) research further shows that working on real-world projects boosts intrinsic motivation and commitment to the self-directed learning process. Shin et al. (2021) also demonstrated that a PjBL built by a group can help individuals acquire 21st-century skills such as problem-solving and computational thinking, which share similarities with specific characteristics of intellectual independence. Therefore, incorporating collaborative features into the PjBCL model in a planned manner enhances the cognitive and emotional aspects of learning independence more comprehensively than other methods.

The findings of this study have significant implications for the development of teacher education practices, particularly in creating learning techniques that can enhance the self-directed learning of prospective science teachers. These results demonstrate that the Project-Based Collaborative Learning (PjBCL) model not only enhances students' cognitive learning but also facilitates their development in regulating emotions, taking initiative, and being responsible in the learning process. Therefore, the PjBCL model can be applied more widely in the curriculum for pre-service teachers, particularly in classes that require the simultaneous development of professional character and teaching skills. In addition, the use of PjBCL provides Teacher Education Institutions (LPTK) with a means to promote a more integrated, contextual, and collaborative approach to learning. This method could be a strategic option for preparing future instructors to address the challenges of real-world learning practice. Teachers who are independent learners are generally better at adapting to new situations, devising innovative lesson plans, and critically evaluating their teaching methods.

In theory, this study enables the exploration of creating additional learning models that incorporate project aspects, teamwork, and self-reflection in a planned manner. Further research can be conducted to determine the effectiveness of PjBCL in various educational settings, across different subjects, and at different levels of education. It might also be helpful to measure psychosocial factors, such as self-efficacy, resilience, and leadership learning, to gain a better understanding of how this model will impact individuals in the long term. Finally, this study also helps change the way people learn in college and university, from a teacher-centered approach to a student-centered one. The PjBCL model encourages the development of a more collaborative, interactive, and real-world problem-solving learning environment. This aligns with the needs of 21st-century education and what future professional teachers need to develop their character.

This study makes a significant contribution to the development of the Project-Based Collaborative Learning (PjBCL) model as a method of learning that can enhance the independence of prospective science teachers in their learning. However, like other research, this study has several issues that need to be addressed. First, this study focuses on only one college or university, and the sample size is relatively small. This could make it harder to apply the results to a larger group of people or the population of potential teachers in other areas or schools. Second, although the research design incorporates cognitive and emotional aspects in measuring learning independence, it still relies on quantitative tools, such as questionnaires, which may not effectively capture the changes in participants' behavior and subjective experiences in depth.

Third, this study only uses the PjBCL model for some science education courses. This makes it hard to know how well the concept might work in other courses or fields. Fourth, we cannot yet fully understand the long-term effects of using the PjBCL model on the professional

growth of future teachers, as we have only had a limited amount of time to observe it. Therefore, further research is necessary to determine the impact of the model on teaching preparedness in real-world settings, such as the context of field practice (PPL). Due to these issues, future studies should include a broader range of participants from diverse institutions and geographic areas to enhance the applicability of the results to the real world. It is also suggested that researchers employ a mixed-methods approach to examine the qualitative aspects of students' learning experiences, perceptions, and difficulties in adhering to the PjBCL paradigm more closely. Another primary research goal may be to develop a PjBCL model that can be applied across multiple disciplines of study and at various educational levels. This would evaluate the model's ability to work in varied situations. Additionally, longitudinal research could be conducted to examine the impact of changes in students' learning independence during the learning process on their work as new teachers. In the future, research on PjBCL should not only examine how it might improve learning outcomes, but also investigate how it can help shape teachers' reflective, innovative, and independent character over time. This way, creating learning models like PjBCL can be a key part of a teacher education reform that looks to the future and is more visionary.

CONCLUSION

Based on the data analysis and discussion, it can be concluded that the collaborative project-based learning model has a significant impact on improving the learning independence of prospective science teachers. This is demonstrated by the higher average learning independence scores in the experimental group compared to the control group. Students participating in the collaborative project-based learning model demonstrated a more consistent and even increase in learning independence, as indicated by a lower standard deviation value on the posttest scores compared to the pretest. Statistical test results (paired sample t-test and independent sample t-test) indicate that the differences in learning independence scores both within and between groups are statistically significant ($p < 0.05$), confirming that collaborative project-based learning is more effective than conventional learning in developing independent learning skills. Theoretically, the effectiveness of this model can be explained through the theories of self-regulated learning, self-determination theory, and social constructivism, all of which support the important role of active experience, learning autonomy, and social interaction in developing student learning independence. Therefore, the application of a project-based collaborative learning model is recommended as an alternative strategy in teacher education, especially in preparing prospective science teachers who are independent, reflective, and able to adapt to the challenges of 21st-century education.

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