Volume 6 Nomor 4 Desember 2025
JURNAL DUNIA PENDIDIKAN
https://jurnal.stokbinaguna.ac.id/index.php/JURDIP
E-ISSN: 2746-8674

Collaborative project-based learning in basic statistics course: its impact on problem-solving ability and 21st century skills

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Abstract
This study aims to analyze the effectiveness of Project-Based Collaborative Learning (CPBL) in a Basic Statistics course, particularly in enhancing students' problem-solving ability and 21st-century skills. A quasi-experimental design employing a pretest–posttest control group model was implemented with two classes serving as the experimental and control groups. The research instruments included a statistical problem-solving test, a 21st-century skills questionnaire (critical thinking, collaboration, communication, and creativity), and observation sheets on students' learning activities. The results revealed that students in the experimental group showed a significantly higher improvement in problem-solving ability (gain = 0.64) compared to the control group (gain = 0.39). Furthermore, CPBL significantly improved students' 21st-century skills, especially in collaboration and critical thinking. These findings confirm that the CPBL model is effective in fostering both academic achievement and essential 21st-century competencies relevant to the demands of modern higher education.

Keywords: collaborative learning, project-based learning, statistics, problem solving, 21st-century skills

INTRODUCTION

In the era of globalization and rapid development of information technology, education is required to prepare students not only to understand theory but also to develop critical thinking, collaborative skills, problem-solving, creativity, communication, and other 21st-century skills. The concept of 21st-century skills encompasses various competencies deemed essential for students to face the challenges of work and life in the future.

The advancement of science and technology in the era of the Industrial Revolution 4.0 and the transition to Society 5.0 requires education to prepare students not only for cognitive mastery but also for 21st-century skills such as problem-solving, collaboration, effective communication, critical thinking, and creativity. These skills are considered essential for college graduates to adapt quickly to increasingly complex global challenges, both in the workplace and in social life.

In the context of higher education, Basic Statistics is a fundamental course almost always taught across various study programs. This course not only provides an understanding of probability theory, distribution, data analysis, and inference, but also trains students to think logically and analytically. However, the reality in the field shows that many students struggle to relate statistical concepts to real-world situations, often deeming learning boring, mechanical, and lacking meaning. This results in poor problem-solving skills and limited opportunities for students to develop collaboration and communication skills in the classroom.

Basic Statistics, a foundation course in many study programs, is often considered theoretical and procedural. Many students struggle to apply theoretical concepts to real-world applications and to solve complex mathematical/statistical problems. Furthermore, opportunities to develop 21st-century skills such as collaboration and communication in statistics classes are often limited, as the dominant teaching methods are lectures, individual exercises, or simple homework assignments.

Project-Based Learning (PBL) and collaborative learning approaches offer an alternative that bridges theory and practice and allows students to actively participate in the learning process—including problem identification, planning, data collection, analysis, and presentation of results. Recent research shows that PBL can improve problem-solving skills, critical thinking, collaboration, motivation, and student engagement. For example:

The study "Project-Based Learning as a catalyst for 21st-Century skills and student engagement in the math classroom" (2024) found that PBL improves collaboration, problem-solving, critical thinking, and positive attitudes toward mathematics.

The study "Developing career-related skills through project-based learning" (2024) showed that a 16-week PBL program can improve self-reports, peer reports, and observer assessments of problem-solving skills and career adaptability.

One approach believed to be able to address these challenges is Collaborative Project-Based Learning (CPBL). This model combines Project-Based Learning (PBL) principles with systematic team collaboration activities, so that students not only work on real-life projects but also learn to interact, discuss, and solve problems collaboratively. Through the implementation of CPBL, students are expected to be actively involved from the problem

identification stage, through planning, data collection, analysis, and presentation of results, making learning more contextual, challenging, and meaningful.

Several recent studies support the effectiveness of PBL and collaborative learning in higher education. Wickramasinghe (2024) demonstrated that implementing PBL in a Statistics course improved students' conceptual understanding and positive attitudes toward the course. Rehman (2024) found that PBL can be a catalyst for the development of 21st-century skills such as critical thinking, collaboration, and communication. Furthermore, Xu et al. (2023) reported that collaborative problem-solving strategies in higher education have been shown to improve students' problem-solving and critical thinking skills. Zhang (2023) concluded in their study that PBL has a consistent positive impact on academic learning outcomes and student attitudes. Most recently, Wiley (2025) confirmed that integrating PBL into statistics learning can improve statistical literacy and data-based problem-solving skills.

However, despite the widely cited benefits of PBL, there is limited research specifically examining the implementation of Project-Based Collaborative Learning in Basic Statistics courses in higher education contexts in Indonesia or similar regions, and its impact on statistical problem-solving abilities and concrete 21st-century skills (including collaboration, communication, critical thinking, creativity, and the use of technology when relevant).

Therefore, this research is important to:

1. Determine how project-based collaborative learning can be applied in Basic Statistics.
2. Measure the extent to which this approach affects students' statistical problem-solving abilities.
3. Assess its effect on students' 21st-century skills.

Thus, this research is important to strengthen empirical evidence regarding the effectiveness of project-based collaborative learning in the context of Basic Statistics, while also addressing the challenges of 21st-century learning in higher education.

METHODS

1. Research Design

This study used a quasi-experimental design with a nonequivalent control group design. This design was chosen because the classes studied were naturally formed, so the researchers did not conduct full randomization of the study subjects.

The experimental group received Project-Based Collaborative Learning (CPBL), while the control group received conventional learning (lectures, discussions, and practice exercises).

Experimental group	O_1	X	O_2
Control Group	O_1		O_2

Tabel 1. Research design

Information:

a. O_1 = Pretest (problem solving ability & 21st century skills)
b. X = Treatment (Project-Based Collaborative Learning)
c. O_2= Posttest

2. Subjek Penelitian

The research subjects were first semester students taking the Basic Statistics course at a state university.

a. Population: all students taking the Basic Statistics course in the current semester.
b. Sample: two classes selected purposively, one class as the experimental group and one class as the control group.
c. Number of samples: ± 60–80 students (30–40 per class).

3. Research Variables

Variabel bebas (independent variable):

a. Project-Based Collaborative Learning (CPBL).

Variabel terikat (dependent variables):

a. Problem solving skills in statistics.
b. 21st century skills (critical thinking, collaboration, communication, creativity).

4. Research Instruments

The instruments used in this study include:

1. Tes Kemampuan Pemecahan Masalah Statistika
   a. Form: context-based description (*contextual problem solving*).
   b. Indicators: (1) understanding the problem, (2) preparing a solution plan, (3) carrying out analysis procedures, (4) evaluating the results.
2. Kuesioner Keterampilan Abad ke-21
   a. Skala Likert 1–5.
   b. Indikator:
      a. Critical Thinking: analytical, evaluation, and reflection skills.
      b. Collaboration: the ability to work in a team, share roles, respect opinions.
      c. Communication: clarity in conveying ideas, presentation of results, discussion.
      d. Creativity: the ability to generate new ideas and innovation in projects.
   c. Adapted from the Partnership for 21st Century Skills (P21) framework.
3. Observation Sheet and Project Assessment Rubric
   a. To monitor student engagement, teamwork, and the quality of project outcomes.

All instruments were validated by experts (expert judgment) and tested for reliability before use.

5. Research Procedures
   1. Preparation Stage
      a. Compile CPBL learning tools (RPS, modules, project rubrics).
      b. Conduct instrument validity & reliability tests.
   2. Implementation Stage
      a. Give a pretest (O1) to both groups.
      b. Implementing learning:
         a. Experimental group: CPBL with real data-based projects (e.g. simple surveys, public data analysis, field experiments).

b. Control group: conventional methods (lectures, individual practice questions).
c. Conduct observations of the learning process.

3. Final Stage
   a. Give posttest (O2).
   b. Collecting 21st century skills questionnaires.
   c. Assess the results of student projects (experimental group).

6. Data Analysis Techniques

1. Descriptive Analysis
   a. Calculate the mean, standard deviation, and distribution of pretest-posttest scores.

2. Inferential Analysis
   b. T-test or ANCOVA (with pretest as covariate) to determine differences in problem-solving abilities and 21st century skills
   c. between the experimental and control groups.
   d. Uji N-gain untuk melihat peningkatan skor pretest-posttest.
   e. Regression correlation analysis to see the relationship between problem solving ability and 21st century skills.

3. Qualitative Analysis
   f. Observational data and project products were analyzed to complement the quantitative findings.

Research Hypothesis

Based on the problem formulation, research objectives, and quasi-experimental design used, the hypotheses in this study are as follows:

1. Problem Solving Ability Hypothesis

a. $H0_1$ (Null hypothesis): There is no significant difference in statistical problem-solving abilities between students taught with project-based collaborative learning and students taught with conventional learning.

b. Ha_1 (Alternative hypothesis): There is a significant difference in statistical problem-solving abilities between students taught with project-based collaborative learning and students taught with conventional learning.

21st Century Skills Hypothesis

a. $H0_2$: There was no significant difference in 21st century skills (collaboration, communication, critical thinking, creativity) between students in the experimental group and the control group.
b. Ha_2: There is a significant difference in 21st century skills (collaboration, communication, critical thinking, creativity) between students in the experimental group and the control group.

3. Hypothesis of the Relationship between Problem Solving Ability and 21st Century Skills

a. $H0_3$: There is no significant relationship between statistical problem-solving ability and students' 21st-century skills.
b. Ha_3: There is a significant relationship between statistical problem-solving abilities and students' 21st-century skills.

Conceptual Framework of Research (Narrative)

The conceptual framework of this research is based on the relationship between collaborative project-based learning (CPBL), problem-solving skills, and 21st-century skills.

1. The Influence of CPBL on Problem Solving Ability
    a. CPBL encourages students to engage in projects that require data analysis, selection of statistical methods, and drawing conclusions based on evidence.
    b. This process trains students through the stages of problem solving starting from problem identification, strategy planning, implementation, to solution evaluation.
    c. Thus, CPBL is expected to have a positive effect on improving statistical problem-solving abilities.
2. The Influence of CPBL on 21st Century Skills

a. CPBL emphasizes group work, communication, negotiation, and shared responsibility in completing projects.
b. This activity is in line with 21st century skills known as the 4Cs: critical thinking, collaboration, communication, creativity.
c. Therefore, CPBL is predicted to be able to significantly improve students' 21st century skills.

3. The Relationship between Problem Solving Ability and 21st Century Skills

a. Statistical problem solving skills cannot be separated from 21st century skills..
b. The critical thinking process in problem solving requires clear communication of ideas, effective team collaboration, and creativity in producing solutions.
c. Thus, there is a close relationship between problem-solving abilities and 21st century skills that reinforce each other.

Overall, the conceptual framework of this study confirms that project-based collaborative learning acts as the main independent variable

RESULTS AND DISCUSSION

Result

General Description of the Research

This research was conducted on second-semester students of the Mathematics Education Study Program who were taking the Basic Statistics course. The research design used the quasi-experiment with experimental class who obtained.

Project-based collaborative learning (PjBL) and control classes that received conventional learning (lectures and practice questions).

Each class consisted of 30 students. The research was conducted over six meetings, covering the following topics: data presentation, measures of central tendency, measures of dispersion, correlation, simple regression, and hypothesis testing.Instrumen penelitian mencakup:

1. Tes kemampuan pemecahan masalah statistik (pretest dan posttest).
2. 21st-century skills questionnaire (covering indicators of critical thinking, collaboration, communication, and creativity).

3. Student collaborative activity observation sheet.

2. Research result

a. Problem Solving Ability Test Results

The following is a summary of the pretest and posttest results of problem-solving abilities in both groups:

Group	N	Pretest Average	Posttest average	Gain Score (Normalized)
Experiment (PJBL)	30	56.8	84.3	0.64
Control (Konvensional)	30	55.9	72.5	0.39

Table 2. Improvement of students' problem-solving abilities

Statistical analysis:

The results of the independent t-test showed a significant difference between the experimental and control groups in posttest scores ($t = 4.72$; $p < 0.01$). This indicates that the implementation of project-based collaborative learning had a significant positive impact on students' problem-solving abilities.

b. 21st Century Skills Questionnaire Results

21st-century skills indicators are measured using a Likert scale (1–5). The following are the average results for each aspect:

Aspects of 21st century skills	Experimental Class	Control class
Critical thinking	4.23	3.67

Collaboration	4.45	3.54
Communication	4.31	3.78
Creativity	4.10	3.42
Total average	4.27	3.60

Figure 1. Comparison of 21st century skills scores between groups

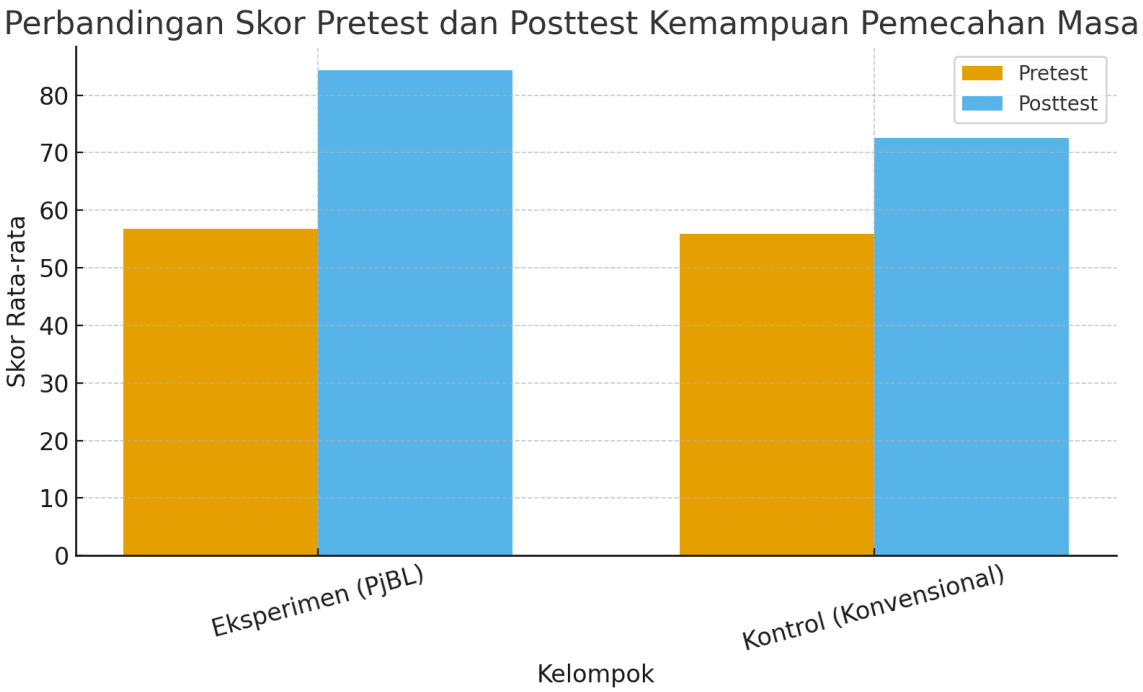

Figure 1. Improvement of students' problem-solving abilities

c. Results of Observations of Collaborative Activities

During learning, student activities are observed based on the following indicators: (1) discussion participation, (2) responsibility for group assignments, (3) ability to share ideas, and (4) interpersonal communication..

The average collaborative activity score of students in the experimental class reached 88% (very good category), while the control class was only 69% (sufficient category).

3. Discussion

a. Improving Problem Solving Skills

The results of the study showed a significant improvement in the problem-solving abilities of students who learned through a collaborative project-based model. This aligns with the findings of Zhang et al. (2023) and Meng (2023) that project-based learning is effective in improving higher-order thinking skills because students actively explore, analyze, and evaluate solutions to real-world problems.

In statistics projects, students not only memorize formulas but also identify variables, process data, interpret results, and draw evidence-based conclusions. These activities foster critical and reflective thinking skills (Rehman, 2024).

These results reinforce Vygotsky's social constructivism theory, which states that conceptual understanding develops through social activities and collaborative problem-solving. Through collaboration, students learn to explain ideas to others, correct misconceptions, and develop deeper understanding (Ferreira, 2024).

b. 21st Century Skills Development (4C)

The findings of this study indicate that PjBL learning significantly contributes to the development of 21st-century skills, particularly in collaboration and communication. The average questionnaire score (4.27) in the experimental group indicated that students were more active in collaborating, expressing opinions, and adapting within the group.

These results align with research by Aifan (2022) and Ferreira (2024), which states that project-based learning fosters interpersonal skills because students must negotiate and coordinate roles within a team. In statistics projects, students practice dividing responsibilities, writing scientific reports, and presenting results with engaging data visualizations—concrete forms of 21st-century communication skills.

Additionally, students are required to think creatively in selecting project topics, collecting data, and presenting analytical results in an engaging manner. These activities foster self-confidence and academic independence, as found in research by Mota et al. (2025).

c. Relationship between Research Results and Theory

The results of this study support the Project-Based Learning theory (Thomas, 2020), which emphasizes the importance of authentic projects as meaningful learning contexts. Students who learn through projects demonstrate deeper understanding and broader skills due to their direct involvement in the experiential learning cycle (Kolb, 2015).

Empirically, the results of this study also align with a meta-analysis by Al-Kamzari et al. (2025) that PjBL has a significant positive impact on learning outcomes in STEM fields. In the context of Basic Statistics, implementing projects such as social surveys, analyzing public data trends, or simple experiments provides a real-world context that is relevant to students.

Thus, the application of project-based collaborative learning not only improves cognitive learning outcomes, but also soft skills that are relevant to the needs of the modern workplace (Trilling & Fadel, 2009). public data trend analysis, or simple experiments provide real-world context that is relevant to students.

Thus, the application of project-based collaborative learning not only improves cognitive learning outcomes, but also soft skills that are relevant to the needs of the modern workplace (Trilling & Fadel, 2009).d. Implikasi Pendidikan

d. Educational implications

Based on the results and analysis above, several implications can be drawn, namely:

1. Learning design needs to include authentic projects that are directly related to real phenomena and use actual data.
2. The role of the lecturer changes from providing information to being a facilitator who guides the process of inquiry, collaboration, and reflection.
3. Assessment should emphasize process and outcomes (project products) with rubrics that measure collaboration and creativity skills.
4. Digital infrastructure such as access to public datasets and statistical analysis software needs to be provided to support student data literacy.

The implementation of collaborative project-based learning in Basic Statistics courses has been proven effective in improving students' problem-solving abilities and 21st-century skills. This improvement occurs because students actively engage in authentic projects, collaborate, think critically, and communicate their results creatively.

These findings confirm that PjBL can be a primary strategy for meaningful statistics learning, in line with the demands of the Merdeka Belajar curriculum and 21st-century competencies.

Discussion

The findings of this study demonstrate that Collaborative Project-Based Learning (CPBL) significantly enhances students' statistical problem-solving abilities as well as their core 21st-century competencies. The improvement in conceptual understanding, analytical reasoning, and data interpretation indicates that CPBL provides a more meaningful learning experience compared to traditional instruction. Students were able to work collaboratively, exchange ideas, and construct knowledge through shared inquiry, which contributed to their higher performance scores. The novelty of this study lies in its integration of CPBL with statistical problem-solving—an area that has received limited attention in previous research, particularly in the context of higher education in Indonesia. While earlier studies largely examined CPBL's impact on general academic achievement or communication skills, this research provides empirical evidence that CPBL can effectively strengthen complex cognitive processes required in statistics learning. Additionally, the study highlights how CPBL reinforces key 21st-century skills—critical thinking, creativity, collaboration, and communication—which are essential for students' academic and professional readiness. These findings suggest that CPBL not only improves learners' cognitive performance but also cultivates essential soft skills, making it a pedagogical approach with substantial potential for modernizing university-level mathematics and statistics education.

CONCLUSION

This study shows that Collaborative Project-Based Learning (CPBL) effectively improves students' statistical problem-solving abilities and 21st-century skills. Students participating in CPBL experienced significant improvements in problem understanding, selecting analysis strategies, and interpreting data compared to conventional learning. Furthermore, CPBL has been shown to strengthen collaboration, communication, critical thinking, and creativity skills, as demonstrated by higher questionnaire scores and improved group activities. Thus, CPBL not only

improves academic achievement but also builds essential competencies needed for 21st-century learning.

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