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Improving pre-service chemistry teachers' critical thinking and problem-solving skills using project-based learning

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Abstract

Studies confirmed that students' critical thinking skills (CTS) and their problem-solving skills (PSS) tend to be low. Thus, this quantitative study aims to improve students' CTS and PSS using Project-Based Learning (PjBL). In a quasi-experimental design, a total of 50 pre-service chemistry teachers from a public university in Indonesia were recruited as participants. To collect data, the Critical Thinking Skills Test (CTST) and the Problem-Solving Skills Test (PSST) were pre- and post-tested. Paired and independent samples *t*-tests and Cohen's *d* were executed to explain the difference in CTS and PSS scores before and after treatment. The results indicated that there was a significant increase from pre- to post-test in terms of CTS and PSS scores. In addition, there is a significant difference in the CTS and PSS scores between the two groups in favor of the experimental group. It can be concluded that PjBL is an effective method to promote CTS and PSS in the General Chemistry course. As a powerful method, we recommend that lecturers implement PjBL to promote CTS and PSS as an alternative to online learning during the COVID-19 pandemic.

Keywords: Critical thinking, pre-service teachers, problem-solving skills, project-based learning, general chemistry

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Introduction

The demands of learning chemistry currently require learning that involves students to be actively involved during the learning process to create a more conducive classroom climate which is the main goal of higher education. In this context, higher education institutions are expected to produce graduates who are not only focused on achieving cognitive learning outcomes but also on the development of soft skills such as a provision to compete in the globalization era (Simanjuntak et al., 2021; Sumardi et al., 2020; Wahyudiati et al., 2020; Wilcox et al., 2017). Pre-service chemistry teachers need 21st century skills to compete in the era of industrial revolution 4.0, including problem-solving skills, collaboration, communication skills, critical thinking skills, and creative thinking skills (Patonah et al., 2021; Saputro et al., 2019; Syafrial et al., 2022). However, based on the previous studies, chemistry learning was focused more on cognitive learning outcomes compared to the development of soft skills, which has an impact on pre-service chemistry teachers' low critical thinking and problem-solving skills (Fadli & Irwanto, 2020; Valdez & Bungihan, 2019; Wahyudiati, 2022). Thus, to renew the chemistry learning system that refers to improving students' soft skills such as critical thinking and problem-solving skills, it needs the application of project-based innovative and collaborative learning methods.

At present, the COVID-19 pandemic has greatly affected the education sector; thus, it requires students to adapt to the new educational process. During the COVID-19 pandemic, however, higher education institutions need to develop students' critical thinking skills (CTS) as one of the learning objectives. This may be due to the fact that most higher education graduates have relatively unsatisfactory critical thinking skills (Flores et al., 2012; Irwanto et al., 2018; Irwanto et al., 2019a; 2019b; van Peppen et al., 2021). Literature suggested that students should have critical thinking to be the generation for their time and be competitive in the world of work (Patonah et al., 2021; Tiruneh et al., 2018). The competitive trait is essential in adapting to time demands; therefore, it is necessary to develop critical thinking in education (Cintamulya, 2019; Damrongpanit, 2022; Patonah et al., 2021). The development of critical thinking skills through classroom learning activities and experimental activities in the laboratory is believed could increase curiosity, responsibility, self-confidence, and collaboration skills which are the main provisions for each individual to be active and survive in a global society (Bandyopadhyay & Szostek, 2019; Wahyudiati et al., 2019). Moreover, not only using the textbook, real activities relevant to students' daily lives, such as the ability to investigate, express opinions, respond to others' views, and be brave in making a decision, could stimulate CTS (AlJaafil & Sahin, 2019; Ferrell & Barbera, 2015).

Prior research has shown that interactions with the environment, learning resources, and interactions between students and lecturers influence critical thinking skills. This condition is relevant to the research conducted by Wahyudiati (2022), Irwanto et al. (2018), and Patonah et al. (2021), in which they proved that interactions with the environment influence a person's critical thinking skills and the implemented learning method. It can be developed through project-based or experimental learning activities. The development of critical thinking skills is based on the social constructivist learning theory proposed by Vygotsky (Langford, 2005). The construction of knowledge and experience of students will be significant if it is done by integrating culture into the learning curriculum (Sumardi & Wahyudiati, 2021; Sutrisno et al., 2020), as well as social interactions between students and between teachers and students during the learning process (Abramova & Greer, 2013; Frambach et al., 2012). However, various empirical studies have shown that pre-service chemistry teachers' main problems are low critical thinking skills and learning independence due to teacher-centered learning practices (Sutrisno et al., 2020; Villafañe & Lewis, 2016; Wahyudiati, 2021, 2022). Therefore, that impacts the low ability of students' problem-solving skills.

Besides critical thinking, problem-solving skills are the primary skills to be developed in 21st century learning. According to Wanya (2016), problem-solving skills are high-level thinking skills that require creative thinking and critical thinking in decision making. In addition, through problem-solving, each individual could solve a problem faced in everyday life with the right solution (Fadli & Irwanto, 2020; Sumardi & Wahyudiati, 2021; Villafañe & Lewis, 2016; Wahyudiati, 2021). Problem-solving skills are defined as the ability to identify, plan, formulate hypotheses, evaluate, elaborate, and find solutions in formulating the best and appropriate solutions (Günter & Alpat, 2017; Moreno-Peral et al., 2020; Tosun & Taskesenligil, 2013; Wahyudiati, 2021). In practice, the students' problem-solving skills significantly affect their ability to demonstrate knowledge and connect a concept relevant to everyday experience known as a constructivist individual (Singh & Chibuye, 2016; Sutrisno et al., 2020). Constructivist individuals can be facilitated using constructivist learning by providing more meaningful learning. However, previous research findings appear that the current chemistry learning tends to be teacher-centered and emphasizes mastery of concepts by ignoring students' soft skills. As a result, it impacts chemistry students' low critical thinking and problem-solving skills (Zeidan & Jayosi, 2014; Zhou et al., 2019).

As a provision to face job competition in the globalization era, students need problem-solving skills. This is relevant to the research findings by Patonah et al. (2021), Wahyudiati (2021), and Irwanto et al. (2018), which state learning and assessment of problem-solving skills greatly determine student success in academic achievement and in the working world. Moreover, problem solving-skills have a very significant influence on the success of one's life (Zeidan & Jayosi, 2014). Tosun and Taskesenligil (2013) and Simanjuntak et al. (2021) also believe that learning will become less meaningful and less useful for future career development if the lecturer does not develop problem-solving skills. Thus, the transformation of learning practices in higher education should be oriented to developing problem-solving skills using collaborative and innovative learning methods. Existing literature has reported on the effectiveness of PjBL in promoting students' motivation and self-efficacy (Bilgin et al., 2015; Shin, 2018), achievement (Bilgin et al., 2015), and engagement (Almulla, 2020). Thus, a study exploring the impact of PjBL on the critical thinking and problem-solving skills of preservice teachers at the tertiary level is highly required.

The development of students' critical thinking and problem-solving skills can be achieved by applying PjBL. The advantages of the PjBL are the peculiarities of the PjBL syntax, which refers to project-based learning or experimental activities. It trains students' abilities to identify problems, formulate problems, identify research variables, formulate hypotheses and prove hypotheses, and report experimental results to positively impact students' critical thinking and their problem-solving skills (Zhou et al., 2019; Wahyudiati, 2022). Problem-solving activities through experimental activities and presentation of group discussions could develop students' critical thinking and problem-solving skills (Valdez & Bungihan, 2019; Zhao et al., 2022; Zhou et al., 2019). In addition, experimental activities aim to prove the concept of chemistry, make learning more meaningful, and develop critical thinking and problem-solving skills (Irwanto et al., 2018; Singh & Chibuye, 2016; Wahyudiati, 2022). Therefore, through the application of PjBL, it is hoped that it will positively impact the students' critical thinking and problem-solving skills, which so far are done rarely. Furthermore, this research will benefit lecturers and researchers in practicing active and innovative project-based learning methods to improve the 21st century skills of students, both at the primary, secondary, and tertiary levels. To this end, this study came to explore the effectiveness of project-based learning in enhancing the CTS and PSS of first-year pre-service chemistry teachers. The research questions posed in the current study are as follows:

1. Is there a difference in the mean scores of CTS and PSS abilities between the two treatment groups?
2. Is there a significant increase in the ability of CTS and PSS before and after treatment in the experimental group?

Methodology

Research Design

To achieve the objectives of this study, a quantitative research method was adopted. The study employed a quasi-experimental pre- and post-test control group design (see Table 1). The pre-test–post-test design was used to compare the group given treatment (experimental group) with the group that was not given treatment (control group) (Creswell, 2014). This study consisted of one dependent variable (i.e., PjBL and direct instruction method) and two dependent variables (i.e., critical thinking and problem-solving skills). The research was conducted for 3 months (October to December 2021). At the end of the treatment, a post-test was given to the experimental and control groups to find out which method had a significant effect on the two dependent variables being measured.

Table 1. The Nonequivalent Pre-test and Post-test Control Group Design

Group	**Pre-test**	**Treatment**	**Post-test**
Experimental	$CTST_1$, $PSST_1$	Project-based learning	$CTST_2$, $PSST_2$
Control	$CTST_1$, $PSST_1$	Conventional method	$CTST_2$, $PSST_2$

Participants

The participants were 50 first-year pre-service chemistry teachers at a public university in Indonesia in the 2021/2022 academic year. A total of 26 students (8 male, 18 female) were assigned as a control group and 24 students (7 male, 17 female) were assigned as an experimental group using purposeful sampling. The average age of the participants was 19 (between 18 and 21 years). They voluntarily participated in the study and can withdraw at any time. As a note, no incentives were given to them. They were taught by a lecturer with more than 5 years of teaching experience.

Instruments

We used two instruments to collect data; the Critical Thinking Ability Test (CTST) and Problem Solving Ability Test (PSST). It took about 100 minutes to complete each test. The CTST was employed to measure students' critical thinking skills during the treatment which includes six indicators (Facione, 2011): (1) interpretation, (2) inference, (3) analysis, (4) explanation, (5) evaluation, and (6) self-regulation. The CTST consisted of 5 open-ended questions (Figure 1). The minimum and maximum possible scores for students were 0 and 100.

2. A solution when dropped with red metal indicator is orange, if it is dropped with methyl orange it turns yellow. The approximate pH range is obtained as follows:

Indicator	Color Change	pH
Methyl Red	Red -Yellow	4.4 - 6.2
Methyl Orange	Red-Yellow	3.1 - 4.4
Bromthymol Blue	Yellow-Blue	6.0 - 7.6

If the solution is added bromthymol blue indicator, analyze the possible color changes that occur!

Figure 1. A Sample of CTST

The PSST adapted from Polya (1957) was used to assess students' problem-solving skills. It consisted of 4 questions with four indicators: (1) understand the problem, (2) devise a plan, (3) carry out the plan, and (4) look back. The PSST included 5 open-ended questions (Figure 2). The minimum and maximum possible scores for students were 0 and 100.

4. Determine the properties of the following solutions using the litmus paper indicator!
   a) Orange juice
   b) Soft drinks
   c) Vinegar
   d) Sugar
   e) Bleach
   f) Coffee

Then classify the solutions above based on their acidity!

Figure 2. A Sample of PSST

Noted that both instruments were validated by four experts (2 experts held Ph.D. and 2 held MEd.) from the State Islamic University of Mataram and Mataram University, Indonesia. The coefficient of Cronbach alpha for CTS was α = 0.89 and PSST was α = 0.88. The values were above the acceptable limit of 0.70 (Hair et al., 2010); thus, both of the instruments were declared valid.

Procedure

This research complied with the Declaration of Helsinki on research involving humans. Written permission was firstly given by the Dean of the Faculty of Education and Teacher Training (No. 18/UN.12/FTK/T.KIM/1/2021). After the researchers conveyed the research purposes, consent forms were then distributed and signed by all participants prior to the intervention. This research was conducted for three months (October to December 2021) in the General Chemistry course. The topics were Changes in Substance (physical and chemical changes), Elements, Compounds, and Mixtures. The intervention comprised 12 class sessions and each session lasted for 180 minutes. Before treatment, both CTST and PSST were distributed to all students. During the intervention, students in the experimental group were taught using project-based learning, while students in the control group were taught using conventional learning methods. In the experimental group, students were instructed to develop projects in small groups starting by identifying problems, formulating problems and hypotheses, developing project plans to solve problems, discussing and presenting the results, and assessing and evaluating the results. Both groups were taught once a week for 120 minutes for each group. The stages of the PjBL in the experimental group are shown in Table 2.

Table 2. The Relationship Between PjBL Syntax and CTS and PSS

Syntax	CTS Domain	PSS Domain	Student Activities	Lecturer Activities
Driving Question	Interpretation (categorization and classification of problems as project basis)	Understand the problem (identify and formulate problems as the project basis)	Identify physical and chemical changes that occur in everyday life through the observation	Direct students to do observation in the community
Arranging a project plan	Analysis (identify and analyze problem-solving plans)	Devise a Plan (analyze problem-solving plan)	Each group discusses the project plan through observations in the community (analysis of the relevance of physical and chemical changes in everyday life)	Advise students in project plan arrangement
Arranging project activities' schedule	Interpretation (Categorization and staging of project activities)	Devise a plan (Plan each stage of the project carefully and precisely)	Discuss with group members to carefully and precisely schedule each stage	Guide students in planning a schedule for project activities appropriately
Supervising the project process	Inference (compiling temporary conclusions from the process of project activities being implemented)	Carry Out the Plan (implementing project activities in systematic stages)	Implement the stages of project activities appropriately and record the results of observations carefully	Guide students to carry out each stage of the project correctly

Assessing product result	Self-regulation (self-assessment and reflection)	Look Back (doing reflection)	Prepare scientific papers (project activity reports) and present them in front of the class	Guide students to make project reports in the form of scientific papers and provide feedback
Evaluating	Evaluation (assessing the success of the project and evaluating the process and results of activities)	Look Back (Evaluating project planning, implementation, and results)	Each group presents project findings and evaluates the process and results of activities through class discussions	Direct students to present their findings and provide feedback on project activities

Data Analysis

Based on the Shapiro-Wilk test, it was found that the *p*-value for the experimental group was 0.74 > 0.05, while the control group was 0.65 > 0.05. This showed that the data for both groups were normally distributed. After running Levene's test, it showed that the *p*-value was 0.65. This reflected that the data were homogeneous. After fulfilling the assumptions test, inferential statistics were performed. In order to compare the improvement in CTS and PSS scores before and after treatment, a paired-sample *t*-test was run. Then, an independent sample *t*-test was employed to compare the mean scores between the experimental and control groups in terms of CTS and PSS. Cohen's *d* was also performed to explain the magnitude of the effect of PjBL in improving students' critical thinking and problem-solving skills: $0.20 < d < 0.50$, small effect; $0.50 < d < 0.80$, moderate effect, and $d > 0.80$, large effect (Cohen, 1992). The descriptive statistics such as mean and standard deviation were calculated. Quantitative data were analyzed using SPSS 24. The level of significance was set at 0.05.

Findings

Critical Thinking Skills

An independent sample *t*-test was run to check the difference in the mean scores between the experimental and control groups. As observed in Table 3, the pre-test score for the experimental group was ($M = 71.00$, $SD = 6.88$), which was slightly different from the control group ($M = 64.28$, SD 10.24). It can be concluded that there is no significant difference between the two groups ($p = 0.055$; >0.05). This indicates that students' initial critical thinking was similar before treatment.

Table 3. The Difference in Pre-test CTS Scores Between Experimental and Control Groups

Sub-Skills	Group	Mean	SD	*t*	*p*
Interpretation	PjBL	72.48	4.82	5.12	0.000
	Traditional	63.88	6.09		
Inference	PjBL	73.96	6.86	2.10	0.041
	Traditional	64.12	10.18		
Analysis	PjBL	78.48	7.31	4.38	0.000
	Traditional	63.72	7.39		
Explanation	PjBL	71.00	6.86	2.86	0.006
	Traditional	64.20	11.74		
Evaluation	PjBL	70.04	6.89	2.05	0.045
	Traditional	64.20	10.23		

Self-regulation	PjBL	72.04	6.90	2.08	0.045
	Traditional	64.24	10.33		
Overall CTS	PjBL	71.00	6.88	2.09	0.055
	Traditional	64.28	10.24		

Data analysis used an independent sample *t*-test (see Table 4) and the results showed a difference in post-test scores between students in the experimental group (*M* = 81.00, *SD* = 6.91) and the control group (*M* = 73.28, *SD* = 6.34). The results indicate that students taught using PjBL improved in their critical thinking skills compared to those taught using conventional methods (*p* = 0.049; <0.05).

Table 4. The Difference in Post-test CTS Scores Between Experimental and Control Groups

Sub-Skills	Group	Mean	SD	*t*	*p*
Interpretation	PjBL	82.48	4.82	5.77	0.000
	Traditional	74.88	5.67		
Inference	PjBL	83.96	6.97	2.02	0.049
	Traditional	73.12	6.44		
Analysis	PjBL	86.48	5.96	5.88	0.000
	Traditional	73.72	6.12		
Explanation	PjBL	80.00	7.03	7.46	0.006
	Traditional	70.2	6.43		
Evaluation	PjBL	78.03	7.00	1.99	0.048
	Traditional	72.22	6.43		
Self-regulation	PjBL	82.04	6.80	1.96	0.047
	Traditional	72.24	6.35		
Overall CTS	PjBL	81.00	6.91	1.97	0.049
	Traditional	73.28	6.34		

To measure the increase in CTS ability in the experimental group after being given treatment, a paired sample *t*-test was carried out with the results summarized in Table 5.

Table 5. Changes in Experimental Group Students' CTS

Sub-Skills	Paired Differences		*t*	*df*	*p*	Cohen's *d*
	M	*SD*				
Interpretation	10.34	7.99	-9.155	49	0.000	1.29
Inference	10.28	7.88	-9.229	49	0.000	1.30
Analysis	10.56	7.46	-10.011	49	0.000	1.42
Explanation	10.48	7.99	-9.280	49	0.000	1.31
Evaluation	10.18	7.88	-9.140	49	0.000	1.29
Self-regulation	10.46	7.81	-9.474	49	0.000	1.34
Overall CTS	10.60	8.04	-9.319	49	0.000	1.32

The results showed that there was an increase in the post-test score of the experimental group compared to the pre-test score before being given treatment. . This shows that there is a significant difference between the two test scores in the experimental group (*p* = 0.000; <0.05) in favor of the post-test. The highest score increase was found in the sub-skill of "Analysis" (*M* = 10.56, *SD* = 7.46, *d* = 1.42) and the lowest was in "Evaluation" (*M* = 10.18, *SD* = 7.88, *d* = 1.42).

Problem-Solving Skills

An independent sample *t*-test was run to check the difference in the mean scores between the experimental and control groups. The results of the *t*-test showed that the pre-test score of the problem-solving skills of the experimental group students (*M* = 73.40, *SD* = 7.24) was slightly higher than that of the control group students (*M* = 73.72, *SD* = 6.34). However, no statistically significant difference was found (*p* = 0.051; >0.05). It can be concluded that the students' initial problem-solving skills tend to be similar.

Table 6. The Difference in Pre-test PSS Scores Between Experimental and Control Groups

Sub-Skills	Group	Mean	SD	*t*	*p*
Understand the problem	PjBL	74.12	4.82	2.45	0.018
	Traditional	73.64	5.67		
Devise a plan	PjBL	74.48	7.48	7.87	0.000
	Traditional	73.28	6.27		
Carry out the plan	PjBL	72.96	5.96	2.44	0.018
	Traditional	73.72	5.89		
Look back	PjBL	71.52	7.63	2.43	0.019
	Traditional	71.80	6.27		
Overall PSS	PjBL	73.40	7.24	2.57	0.051
	Traditional	73.72	6.34		

After the intervention, both groups were then compared (see Table 7). The results showed that there was an increase in the post-test score of the experimental group from the pre-test score obtained before being given treatment (*M* = 80.68, *SD* = 7.44) and the control group (*M* = 72.12, *SD* = 6.20). The results reflect that students taught using PjBL enhanced their problem-solving skills compared to those taught using traditional teaching methods (*p* = 0.007; <0.05).

Table 7. The Difference in Post-test PSS Scores Between Experimental and Control Groups

Sub-Skills	Group	Mean	SD	*t*	*p*
Understand the problem	PjBL	82.48	7.74	2.74	0.008
	Traditional	75.88	6.28		
Devise a plan	PjBL	80.44	5.96	7.86	0.000
	Traditional	73.64	5.89		
Carry out the plan	PjBL	86.48	8.00	3.06	0.004
	Traditional	70.28	6.27		
Look back	PjBL	85.40	7.62	2.90	0.006
	Traditional	73.80	6.25		
Overall PSS	PjBL	80.68	7.44	2.91	0.007
	Traditional	72.12	6.20		

To measure the increase in CTS ability in the experimental group after being given treatment, a paired sample *t*-test was carried out with the results summarized in Table 8.

Table 8. Changes in Experimental Group Students' PSS

Sub-Skills	Paired Differences		*t*	*df*	*p*	Cohen's *d*
	M	*SD*				
Understand the problem	10.38	7.93	-9.255	49	0.000	1.31
Devise a plan	10.26	7.78	-9.319	49	0.000	1.32
Carry out the plan	11.14	7.27	-10.831	49	0.000	1.53
Look back	10.42	7.93	-9.293	49	0.000	1.31

Overall PSS	10.40	7.76	-9.471	49	0.000	1.34

The results showed that there was a higher score in the treatment group on problem-solving skills than their pre-test score (p = 0.000; <0.05). For the sub-skill of "Carry out the plan", it can be seen that the students in the experimental group had the highest post-test scores (*M* = 11.14, *SD* = 7.27, *d* = 1.53) compared to other subscales, while the lowest was in "Understand the problem" (*M* = 10.38, *SD* = 7.93, *d* = 1.31). Thus, it can be concluded that the post-test scores of the students after the intervention exceeded the pre-test scores.

Discussion

Within this section, the influence of project-based learning on students' CTS dan PSS was explored. The first purpose of this research is to seek the difference between the critical thinking skills (CTS) and problem-solving skills (PSS) of students who are taught using the PjBL and traditional teaching methods. The results showed that there were differences in post-test CTS and PSS scores between students in the experimental and control groups. This indicates that students who were taught using PjBL experienced an increase in their critical thinking and problem-solving skills compared to students who were taught by the lecture method. It means the PjBL significantly affects the students' CTS and PSS. This significant influence is supported by activities in PjBL settings that provide opportunities for students to be actively involved in formulating problems, compiling, designing, and evaluating project activities in order to solve problems; thus, learning becomes more meaningful (Simanjuntak et al., 2021; Turiman et al., 2012; Valdez & Bungihan, 2019). Meaningful learning could be implemented if students are active and independent in constructing knowledge, attitudes, and learning experiences based on experience in solving problems to increase curiosity, responsibility, independent learning, and analytical and synthesis skills. In turn, these situations will impact students' critical thinking and problem-solving skills (Duran & Dökme, 2016; Edelson, 2001; Erozkan, 2013). Another PjBL strength is that it is based on Vygotsky's (1978) social constructivist approach. This theory is in accordance with the syntax of the PjBL, which emphasizes social interaction between students, students-lecturers, or interaction between students and the environment in constructing understanding.

The research findings also prove that the group that was not given treatment (taught by the lecture method) did not experience a significant increase in CTS and PSS abilities. The weakness of the teacher-centered approach influences this condition that makes students not actively involved in constructing knowledge and skills and learning becomes less meaningful (Tiruneh et al., 2018; Wahyudiati et al., 2020; Zeidan & Jayosi, 2014). Furthermore, prior studies (e.g., Simanjuntak et al., 2021; Wahyudiati, 2022; Yusuf & Adeoye, 2012; Zhao et al., 2022) confirmed the traditional teaching method tends to ignore the constructivist learning environment, which makes learning less meaningful and has an impact on students' low CTS and PSS.

According to the results of the paired sample *t*-test, students showed a significant improvement from pre- to post-tests in terms of CTS and PSS. Thus, it can be suggested that applying the PjBL is more effective in developing the CTS and PSS of pre-service chemistry teachers than traditional teaching. This condition is due to the PjBL learning process always prioritizing collaborative problem-solving. It requires effective collaboration and communication between group members and prioritizing aspects of reflection or evaluating the problem-solving process in constructing knowledge, attitudes, and skills. Hence, collaborative project-based learning could improve students' critical thinking, communication, and problem-solving skills (Eskandar et al., 2013; Patonah et al., 2021; Sumardi et al., 2020). For that reason, it is appropriate to apply collaborative and innovative-based learning methods such as the PjBL to develop 21st century skills in order to face the challenges of the globalization era.

The results of the *t*-tests were strengthened by the high Cohen's *d* coefficient. In addition to having a significant effect on the CTS and PSS of pre-service chemistry teachers, the implementation of PjBL also provides a high contribution to the improvement of students' CTS and PSS. This relatively high contribution is due to the collaborative and project-based nature of PjBL. The advantage of PjBL could train students in conducting experimental activities so they learn to formulate problems, identify research variables, formulate and prove hypotheses, and collaborate to report and communicate experimental results. Alternatively, it will positively impact students' CTS and PSS (Su, 2020; Turiman et al., 2012). These findings are relevant to the research findings by Zhao and Wang (2022), Yusuf and Adeoye (2012), and Valdez and Bungihan (2019), which proved that project-based learning is effective in increasing curiosity, confidence, and problem-solving skills needed by individuals to face everyday life problems and be active and survive in a global society. In addition, students with high CTS and PSS are believed to be ready to face global challenges, compete in the era of globalization, and become problem solvers in their lives and society (Patonah et al., 2021; Tiruneh et al., 2018).

The development of 21st century skills through the application of the PjBL is also proven by the improvement of students' CTS sub-skills, namely interpretation, inference, analysis, explanation, evaluation, and self-regulation. According to the results of the *t*-test, it shows that in the experimental group, the highest and lowest aspects of assessment were analysis and evaluation, respectively. The high score of "Analysis" is due to the superiority of the PjBL, which refers to a constructivist approach. Thus, students are actively involved in constructing understanding, attitudes, and learning experiences to make learning more active and meaningful and the existence of social interactions between students and between lecturers and students (Erozkan, 2013; Wahyudiati et al., 2019, 2020; Zhou et al., 2019). On the other hand, the evaluation aspect of students still needs to be improved because, during the learning process, it prioritizes the aspects of solving problems, identifying variables, and proving hypotheses through experimental activities. It takes a long time, which impacts evaluation that can only be done at the end of learning activities. In addition, the research findings in the control group for the highest CTS aspect were the interpretation aspect, while the lowest CTS aspect was the explanation. The low result of the explanation aspect is due to the weakness of traditional teaching methods applied to the control group. Teacher-centered learning activities and students' lack of active involvement in constructing knowledge and learning experiences so that students' CTS abilities are not fully developed (Duran & Dokme, 2016; Su, 2020; Sumardi et al., 2020; Zeidan & Jayosi, 2014; Zhou et al., 2019).

Further results showed that students' problem solving has increased by implementing the PjBL. Likewise, the sub-skills of understanding the problem, devising a plan, carrying out the plan, and looking back also significantly increased. Based on the *t*-test results, it can be suggested that in the experimental group, students scored the highest on the "Carry out the plan" and the lowest on the "Devise a plan". This significant influence refers to the advantages of the inquiry method, which is the main basis for the PjBL in developing critical thinking, training students to understand problems, and planning and implementing problem-solving activities; in turn, it has a positive impact on students' PSS (Simanjuntak et al, 2021; Sumardi et al., 2020; Zeidan & Jayosi, 2014; Zhou et al., 2022). The results of the literature revealed that project-based learning is effective in improving students' critical thinking (Sumardi et al., 2020; Syafrial et al., 2022; Yusuf & Adeoye, 2012; Zhao, Yanan, & Wang, 2022) and problem-solving skills (Duran & Dokme, 2016; Su, 2020; Patonah et al., 2021; Zeidan & Jayosi, 2014; Zhou et al., 2022). Thus, referring to empirical findings and theoretical studies, the application of PjBL in chemistry learning is highly recommended to improve the CTS and PSS of pre-service chemistry teachers.

Conclusion

The current study has successfully investigated the effect of project-based learning on the transferable skills of pre-service chemistry teachers during the COVID-19 pandemic. The findings of this study indicate that project-based learning has a significant effect on students' critical thinking skills and problem-solving skills in the General Chemistry course. The results showed that there were significant differences in CTS and PSS between students who were taught using PjBL and those who were taught using traditional teaching methods. In addition, there was a significant increase in CTS and PSS before and after the implementation of PjBL with a large effect size. The findings can be an alternative solution for lecturers and researchers to apply the PjBL in the learning process. However, in its implementation, it is necessary to consider the characteristics of the topics, students, and environmental conditions that could maximize teamwork to carry out project-based activities in order to develop students' 21st century skills. Therefore, we recommend further studies to investigate the effect of PjBL on attitudes, cognitive achievements, and other 21st century skills.

Limitations

Meanwhile, this study has some limitations that need to be considered. First, we recruited only 50 first-year pre-service teachers at a public university in eastern Indonesia. It is recommended that further studies involve larger samples to obtain more comprehensive and generalizable findings. Second, the interventions were carried out for three months. We recommend future researchers extend the intervention time in order to obtain holistic results.

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