International Journal of Evaluation and Research in Education (IJERE)
Vol. 14, No. 3, June 2025, pp. 2278~2289
ISSN: 2252-8822, DOI: 10.11591/ijere.v14i3.27725

Enhancing preservice teachers' collaborative problem solving through STEM project-based learning

Rita Fitriani[1,2], Hadi Suwono[1], Ibrohim[1], Betty Lukiati[1]
[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, Indonesia
[2]Department of Biology Education, Faculty of Teacher Training and Science Education, Universitas Siliwangi, Tasikmalaya, Indonesia

Article Info

Article history:

Received Jun 9, 2023
Revised Oct 6, 2024
Accepted Nov 31, 2024

Keywords:

Collaborative problem solving
Preservice teachers
Project-based learning
STEM education
Teaching collaboration

ABSTRACT

This study aimed to determine the effect of science, technology, engineering, and mathematics project-based learning (STEM-PjBL) on the collaborative problem solving (CPS) of preservice teachers (PSTs). The pretest-posttest non-equivalent control group design was employed. A total of 72 PSTs enrolled in plant physiology course participated in this study. Self-assessment and project were used to evaluate PSTs' CPS skills. Self-assessment scores were analyzed by analysis of covariance (ANCOVA), while project scores were analyzed by the Mann-Whitney U test. The results of self-assessment indicated that STEM-PjBL enhances CPS skills, particularly in social regulation, task regulation, and knowledge building. The results of the team's problem-solving skills in completing the project did not differ between the two groups. But the result of integrated STEM skills showed that the STEM-PjBL group was better at integrating STEM disciplines into their project. This study highlights the importance of interdisciplinary projects in a PjBL environment that can be adopted by teacher preparation programs for enhancing PSTs' CPS skills as well as gaining knowledge of STEM integration.

Corresponding Author:

Hadi Suwono
Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang
Semarang 5 Street, Malang 65145, Indonesia
Email: hadi.suwono.fmipa@um.ac.id

1. INTRODUCTION

The digital revolution has caused complex social, economic, and environmental problems [1]. The rapid and unpredictable change in this digital age has had an impact on changing the way of life and opening new dimensions in education [2]. Educational transformation is required to ensure that teachers provide their students with the knowledge and skills they need to be successful in the future [3]. Academic researchers recommend a modern approach that is no longer monodisciplinary but interdisciplinary in educational practice [4]. This highlights the importance of science, technology, engineering, and mathematics (STEM), which is a form of education that focuses on the integration of various disciplines for solving real-world problems [5], [6].

STEM education is used to combine STEM disciplines into one class, unit, or learning experience that is based on the relationship between learning and real-world problems for long-term academic success [7], [8]. Teachers play a crucial role in ensuring the success of integrated STEM in the classroom, including biology teachers. Biology teachers need interdisciplinary knowledge across STEM disciplines that supported the implementation of effective STEM integration [9]. For instance, the environment has a significant physiological effect on the growth of plants, which is an essential topic in biology because it can affect food production. To address these problems, an interdisciplinary approach is needed to find an effective way.

The development of biology teachers who can incorporate STEM can start with the development of preservice teachers (PSTs) during their studies in teacher education program [10]. It will be challenging for PSTs who have never been exposed to STEM activities to implement STEM in their classrooms [11]. Therefore, PSTs must engage in STEM-integrated learning to gain a better understanding of STEM [12]. However, STEM-integrated learning is a complex process that emphasizes certain skills for success. The complexity of STEM-integrated learning requires PSTs to comprehend the process of knowledge acquisition by exchanging ideas, perspectives, knowledge, and experiences to solve problems involving social and cognitive aspects [13]. Considering the integrated nature of STEM, problem solving needs to be done collaboratively because trying to solve it alone may be less effective than doing it as a team. In this case, collaborative problem solving (CPS) is considered an effective skill for success in STEM-integrated learning. CPS skills can facilitate the acquisition of knowledge due to their benefits in fostering the understanding of knowledge through scientific investigation for solving practical problems [14].

The CPS refers to the skills of PSTs to collaborate with others to solve problems in a variety of situations [15]. Each PSTs contributes to the execution of a complex task as a team by dividing responsibilities and labor, taking action to achieve the team goal, and navigating task requirements [16]. CPS involves two aspects: social aspects associated with the collaboration process, and cognitive aspects associated with the problem-solving process [17]. The social aspect of CPS emphasizes managing the interaction and contributions of each PSTs, while the cognitive aspect emphasizes effort in task regulation and problem-solving skill application [18]. Furthermore, PSTs who are skilled in CPS will be more capable of solving problems in this digital age, which are very diverse and give rise to new challenges.

There are a variety of methods for evaluating CPS skills. Previous studies showed that CPS can be assessed through self-assessment that reflected PSTs' perceived knowledge of CPS skills [13]. Since the self-assessment is typically prone to memory distortions, another important aspect of CPS assessment is the creation of situations in which collaboration is essential for task completion, such as situations that require interdependence between PSTs in support of both exchanging information and team organization [16]. One of the most effective ways to assess CPS is through projects, because projects provide a realistic and practical context for teams to work together, apply their problem-solving skills, and achieve a specific goal [19]. Thus, to assess PSTs' CPS skills, learning to integrate projects is required. Furthermore, the previous study showed that interdisciplinary STEM projects increase collaboration and problem-solving skills [20].

However, learning experiences with integrated STEM that enhance PSTs' CPS skills remain lacking. Review of the previous studies revealed that most studies only focused separately on using various approaches that promoted problem solving and teamwork skills, while still lacking enhancement of the combination of both skills [21]. The task still focuses on subject-specifics, while authentic tasks with an interdisciplinary approach can better recognize connections between STEM disciplines to solve real-world problems and encourage collaboration with others to establish links between STEM disciplines [22], [23]. The other studies also revealed that PSTs who still receive conventional instruction without technological support do not significantly improve their CPS skills [24].

PSTs have to engage directly in STEM-integrated learning that enables them to solve problems collaboratively by applying knowledge of science and mathematics supported by technology and engineering design [25]. This can be accomplished by actively involving PSTs in problem-solving and collaboration through projects that integrate STEM [26]. One of the learning models that uses projects to organize learning around complex tasks to answer inquiry questions, generate peer collaboration, and develop solutions to a problem is project-based learning (PjBL) [27]. Through PjBL, STEM concepts can be incorporated into the development of long-term learning. Thus, this study provides instruction through PjBL with STEM projects, which researchers call STEM PjBL. Since the project was created STEM PjBL is defined as student-centered instruction with a well-defined outcome but an ill-defined task. This learning requires PSTs to identify and define a problem as they investigate the project topic as part of an interdisciplinary activity [28]. This innovative instructional practice can construct PSTs' understanding based on challenging interdisciplinary tasks and requires them to develop a plan to investigate, design, and create a product [29]. This learning encourages PSTs to identify problems and determine solutions in collaboration with their peers [30]. The implementation of this learning can assist PSTs in solving complex problems and constructing their own knowledge through a deep comprehension of STEM disciplines [31]. Previous studies also suggest that STEM PjBl has been proposed as an effective learning model for integrating STEM [32].

The STEM project is usually complex and difficult, so teaching collaboration with teachers from STEM disciplines is required [33]. Collaborative teaching has been recognized as an educational reform approach to solving complex problems in an interdisciplinary way. This collaboration consists of the interaction of teachers from various disciplines to achieve learning goals more effectively than when a teacher acts alone [34]. PSTs are actively involved in observing, practicing, and developing knowledge and cognition through social interaction, which can facilitate knowledge construction [35]. Thus, collaborative teaching can foster robust support systems across STEM disciplines and promote conceptual depth.

In this study, the STEM project related to plant growth in the plant physiology course is projected. PSTs were exposed to plant growth problems that were influenced by growing media, nutrition, pH, and environmental factors. This concept has been widely recommended for STEM integrated learning in higher education due to the potential for long-term engagement with practical scientific tasks with mathematical processing, technology, and engineering demands [36]. PSTs were asked to solve plant growth problems by developing hydroponic systems supported by mist cooling systems to maintain stable temperatures in the greenhouse setting. In this regard, a hydroponic practitioner and an engineering lecturer were involved to facilitate PSTs in completing the project in STEM PjBL.

This study bridges the gap between a limited number of STEM practices and the demands of developing PSTs who can integrate STEM in the 21st century through the lens of CPS. It is crucial to engage PSTs in integrated STEM learning to promote their CPS skills for better knowledge acquisition. In this study, the hydroponics and mist cooling systems are used as a complex designed project in STEM PjBL. We evaluated their perceived knowledge of CPS skills before and after the STEM PjBL intervention. In addition, since the projects were created based on the results of PSTs' collaborative problem-solving in each group, an evaluation of the projects was required to determine how well they utilized their CPS skills when creating real-world artifacts. Furthermore, this study contributes to the body of knowledge on STEM integration in teacher education programs by providing PSTs with the skills to work with STEM integration and enhancing their STEM knowledge. Thus, based on the explanations, the purpose of this study was to enhance PSTs' CPS skills through STEM PjBL.

2. RESEACRH METHOD

2.1. Research design

This study used a quasi-experimental method to investigate the effect of STEM PjBL on PSTs' CPS skills. The pretest-posttest non-equivalent control group design was employed in this study. The independent variable of this study was the learning model, which involved two groups: STEM PjBL as a treatment group and PjBL as a control group. The dependent variable was collaborative problem-solving. In addition, there are confounding variables that have the potential to influence the dependent variable. Confounding variables in this study are prior problem-solving skills and group dynamics. To minimize these confounding variables, participants were randomly assigned to different groups (treatment and control groups). This will help to ensure that any differences in problem-solving skills are distributed evenly across the group and reduce the impact of this confounding variable. This will also help to distribute potential group dynamic effects evenly across the group, making it less likely that one group is significantly advantaged or disadvantaged in terms of collaboration.

2.2. Participants

The population consisted of 105 PSTs who attended a plant physiology course during the 2021-2022 academic year in the teacher education programmed at Biology Education, Faculty of Teaching and Education, Siliwangi University, Tasikmalaya, West Java, Indonesia. Prior to participant selection, an analysis of variance (ANOVA) test was performed to compare the academic level of the PST based on the grade point average (GPA). The results indicated no difference in the participants' GPA, with significant values of 0.282 (>0.05). To determine the number of participants, the Slovin formula with a 10% tolerable error was used. Slovin's formula is a mathematical system used to calculate the number of specific objects with undetermined characteristics. Slovin's calculations indicated that the minimum number of participants should be 52, but we randomly selected up to 72 participants, which were divided into two groups: 36 PSTs in the STEM PjBL group and 36 PSTs in the PjBL group. A total of 66 females and 6 males with ages between 20 and 22 participated in this study. For reliable statistical inference, a sample size of at least 30 per group is often recommended [37]. Therefore, the sample size requirements for this study were already met.

2.3. Research procedure

This study was carried out for eight weeks in a plant physiology course for both STEM PjBL and PjBL groups. Before the study, informed consent was given to all participants. We described the learning process that will be implemented. We also conducted a pretest to obtain prior data on the CPS abilities of both groups, while a posttest was conducted to obtain data on CPS abilities after intervention. During the implementation process, the stage of PjBL was adopted in both groups but with different projects. In the STEM PjBL group, the project was explicitly related to STEM project, while in the PjBL group, it was not.

In the STEM PjBL group, PSTs were divided into six teams consisting of six members. Three teams working on the hydroponic design project were assisted by a horticulture practitioner, and three other teams working on the mist cooling systems project were assisted by an engineering lecturer. These projects were conducted in a greenhouse environment located near Siliwangi University. PSTs were given worksheets as instructions for completing project tasks. For details, the teaching stages for the implementation of STEM PjBL can be seen in Table 1. Even though the PSTs project started out differently, they were all able to see how well the hydroponic system supported by a mist cooling system worked during the test and evaluation stages. Thus, in the communicating and refining stages, each team explained the results and how those projects affected the plant's growth.

In the PjBL group, PSTs were also divided into six teams consisting of six members. The teaching stages of implementation, PSTs' activities, and learning settings are detailed in Table 1. In the PjBL group, PSTs were not engaged in STEM projects or any teaching collaboration. Only a plant physiology lecturer assisted the learning process. Each team was given a project related to plant growth. They investigated the factors that influence plant growth and designed a project to observe these factors. They collaborated with other team members to complete the project assignment, using the worksheet as guidance. These projects were carried out outside the greenhouse setting.

Table 1. The teaching stage of STEM PjBL and PjBL implementation

Week	Stage	PSTs' activity		Teaching collaboration		Learning setting
		STEM PjBL	PjBL	STEM PjBL	PjBL	
1	Identifying the problem	– Collaborate with peers. – Identify the problem. – Identify the requirements and constraints. – Exploring and gathering information. – Generate ideas. – Discuss strategies and develop plan projects.	– Collaborate with peers. – Identify the problem. – Identify the requirements and constraints. – Exploring and gathering information. – Generate ideas. – Discuss strategies and develop a plan project.	– Plant physiology lecturer – Engineering lecturer – Horticulture practitioner	Plant physiology lecturer	– Synchronous: virtual meeting to explain and discuss the learning project. – Asynchronous: team discussion to identify problems, requirements, and constraints, gather information, generate ideas, and develop plans for projects.
2-3	Designing and constructing project	– Create the design project of a hydroponic and mist cooling system to effectively support plant growth. – Interpret the design. – Build the design.	– Create design project related to plant growth. (e.g., effect of essential nutrients on plant growth). – Interpret the design. – Build the design.	– Plant physiology lecturer – Engineering lecturer – Horticulture practitioner	Plant physiology lecturer	– Synchronous: virtual meeting to communicate and discuss the planned project. – Asynchronous: team conducted the design and construction of the project.
4–7	Testing and evaluating project.	– Experiment of plant growth using hydroponics supported by a mist cooling system to keep the temperature stable in the greenhouse for four weeks. – Check the constraints. – Evaluate the design	– Conducting experiments related to plant growth for 4 weeks. – Check the constraints. – Evaluate the project	– Plant physiology lecturer – Engineering lecturer – Horticulture practitioner	Plant physiology lecturer	– Synchronous: virtual meeting for progress reports. – Asynchronous: research project, team discussion for testing and evaluating the project.
8	Communicating and refining project	– Communicate the results. – Review the first project. – Refine the project. – Make suggestion for future project.	– Communicate the results. – Review the first project. – Refine the project. – Make suggestion for future project.	– Plant physiology lecturer – Engineering lecturer – Horticulture practitioner	Plant physiology lecturer	– Synchronous: virtual meeting to communicate and discuss the results. – Asynchronous: team discussion for refining project and make suggestion for future project.

2.4. Research instrument

2.4.1. Self-assessment

Self-assessment of CPS was collected using a questionnaire to assess the PSTs perceived knowledge of CPS skills before and after intervention. The questionnaire was developed according to CPS components by Chen *et al.* [13]. A four-point Likert scale ranging from "strongly disagree" to "strongly agree" was used.

The CPS questionnaire contains 22 items divided into two aspects: social and cognitive skills. Social skills consist of four items of participation, five items of perspective taking, and four items of social regulation. Cognitive skills consist of five items of task regulation and four items of knowledge building. These components could represent how the PSTs perceived the collaborative activities and their cognitive processes when completing STEM project tasks. Two experts were involved to evaluate the construct and content validity. The expert in assessment evaluated the construct validity, while the expert in biology evaluated the content validity. The field test for empirical validity and reliability of the instrument was also conducted with different participants who had taken a plant physiology course. By calculating the Pearson's correlation coefficient, all items are strongly valid, with validity values ranging from 0.372 to 0.654. The reliability test using Cronbach's α value of the CPS questionnaire was 0.886, which indicated that the instrument was reliable.

2.4.2. Project

The projects that were created by PSTs while they participated in learning reflected their CPS skills. The scores of the projects were calculated based on the rubric's indicators, and each group member received the same scores. The rubric was developed using the following steps. First, we consulted and discussed with assessment and biology experts to determine CPS indicators that could be evaluated through the project. Second, we developed a rubric based on predetermined indicators. Third, experts in assessment and biology evaluated the rubric for construct and content validity. Fourth, the reliability of the rubric was tested using inter-rater reliability. Two raters evaluate projects carried out in one sample classroom by PSTs who have taken a plant physiology course. It was found that there was a significant correlation between the scores of the two raters ($r=0.897$, $p<0.05$). It was concluded that the form was acceptable.

The final form of the rubric consisted of 15 items, divided into two aspects: the team's problem-solving skills and integrated STEM skills. The team's problem-solving skills were examined to evaluate PSTs' teamwork in solving problems to attain project goals, while integrated STEM project skills were examined to evaluate PSTs' teamwork in solving problems that integrate the interdisciplinary perspective in the project. The team's problem-solving skills consist of ten items, including identification of the problem, objective of the project, design methodology, planning of the project, team structure, incorporation of suggestions, project presentation, description of key concepts, conclusion and future project suggestions, and technology for collaboration. The integrated STEM project consists of five items, including interdisciplinary thinking, scientific knowledge, technological application, engineering design, and mathematical processing.

2.5. Data analysis

Quantitative analysis was conducted for the data analysis. To calculate means and standard deviations, descriptive statistics were conducted first. The scores of the self-assessment CPS were analyzed for normality and homogeneity. The Shapiro-Wilk test was used to determine the normality scores of the pretest and posttest. The results of pretest scores showed that the STEM PjBL group had a p value of 0.20 (>0.05) and the PjBL group had a p value of 0.56 (>0.05), indicating that pretest from both groups were normally distributed. The results of posttest scores showed that the STEM PjBL group had a p value of 0.60 (>0.05) and the PjBL group had a p value of 0.27 (>0.05), indicating that posttest from both groups were normally distributed. Levene's test was used to determine homogeneity, and the result showed a p value of 0.63 (>0.05), indicating both groups' homogeneity. Then, to determine significant differences between STEM PjBL and PjBL groups, analysis of covariance (ANCOVA) was used.

The scores of the projects were also analyzed for normality. First, we conducted a Shapiro-Wilk test for the normality of the team's problem-solving skills, and the result showed that the STEM PjBL group had a p value of 0.03 (<0.05) and the PjBL group had a p value of 0.03 (<0.05), indicating that both groups were not normally distributed. Since we had non-normal distributions of data, we adopted the nonparametric Mann-Whitney U test to determine significant differences in the team's problem-solving skills between STEM PjBL and PjBL groups. Second, we conducted the Shapiro-Wilk test for normality of integrated STEM skills, and the result showed that the STEM PjBL group had a p value of 0.01 (<0.05) and the PjBL group had a p value of 0.04 (<0.05), indicating that both groups were not normally distributed. Then, to determine significant differences in integrated STEM skills between STEM PjBL and PjBL groups, we also used the Mann-Whitney U test.

3. RESULTS

3.1. Finding of PSTs self-assessment of CPS

Table 2 shows the results of the descriptive analysis and the ANCOVA test of the PSTs' self-assessment of CPS. The ANCOVA test for all components showed significant differences between STEM PjBL and PjBL groups, with F (1, 69)=9.96, p<0.05. For more details, the ANCOVA test for each component of the CPS showed that there was no significant difference only in two components: participation, with p=0.52 (>0.05), and perspective taking, with p=0.62 (>0.05), while other components were significantly different with p<0.05. From Table 2, it can also be seen that PSTs's posttest scores for those who participated in STEM PjBL were generally higher than PjBL, which indicated that STEM PjBL better enhanced PSTs' CPS than PjBL.

Table 2. The descriptive and ANCOVA test of PSTs's self-assessment of CPS

Component	STEM PjBL				PjBL				ANCOVA test
	Pretest		Posttest		Pretest		Posttest		
	M	SD	M	SD	M	SD	M	SD	
Social skills									
Participation	2.76	0.45	3.30	0.40	2.73	0.66	3.23	0.49	0.52
Perspective taking	2.61	0.49	3.24	0.39	2.61	0.51	3.19	0.54	0.62
Social regulation	2.77	0.48	3.30	0.55	2.53	0.51	2.92	0.60	0.03*
Cognitive skills									
Task regulation	2.56	0.51	3.20	0.44	2.80	0.53	2.97	0.55	0.00*
Knowledge building	2.22	0.44	3.23	0.54	2.72	0.61	2.99	0.57	0.00*
All components	2.59	0.33	3.27	0.25	2.62	0.37	3.08	0.36	0.00*

M=means, SD=standard deviation, *p<0.05

These results showed that the PSTs who participated in the STEM PjBL had significant self-assessments of perceived CPS skills, particularly in social regulation, task regulation, and knowledge building. They had a better understanding of social regulation, which required team members to bring diverse knowledge, resources, and problem-solving experience for solving problems. This ability is useful for interacting with differing perspectives and opinions. They understood how to regulate their own learning for task completion, such as problem analysis, determining the goals, use resource management, use appropriate ways to collect data, and use an efficient approach to problem-solving. They know how to expand their own knowledge through the acquisition of new content, strategies, and skills, as well as how to deal with setbacks and coordinate, collaborate, and negotiate with others. There was no significant difference in terms of participation and perspective taking, indicating that both STEM PjBL and PjBL emphasize PSTs' active participation in the learning process and responsiveness to situations from another person's perspective.

3.2. Finding of PSTs project

First, the results of the Mann-Whitney U test for team's problem-solving skills reveal there was no significant difference between STEM PBL and PjBL groups, with p=0.22 (>0.05). The scores for each component of the team's problem-solving skills from both groups can be seen in Figure 1. Second, the result of the Mann-Whitney U test for STEM project evaluation for all components showed that there was a significant difference between the STEM PjBL and PjBL groups, with p=0.01 (<0.05). For details, a Mann-Whitney U test was also conducted for each component, and the results showed that there was no significant difference only in mathematical processing, with p=0.52 (>0.05), while the other components were significantly different, with p<0.05. Table 3 also shows that the mean scores of STEM project evaluation from the STEM PjBL group were higher than the PjBL group, which indicated that PSTs who participated in STEM PjBL were better at making connections with other disciplines for solving problems, particularly in integrating STEM disciplines.

The results in Figure 1 showed that both STEM PjBL and PjBL groups emphasize collaboration in solving problems to attain project goals. During the process of preparation, PSTs can collaboratively identify the problem, determine the objective of the project, select the appropriate method, create a plan, develop team structure, and incorporate suggestions from others. They can present the results of the project, describe the key concepts, draw a conclusion, and make suggestions for a better result. Both groups can utilize technology for effective collaboration.

The results in Table 3 showed that PSTs who participated in STEM PjBL had a better understanding of how to integrate STEM into projects. They can integrate other disciplines into the completion of the project by investigating the science aspect of the project, using technology to support the effective completion of projects, and designing a project using the engineering design concept. But, in terms of mathematical processing, both STEM PjBL and PjBL groups showed understanding of the problem's mathematical concepts and principles.

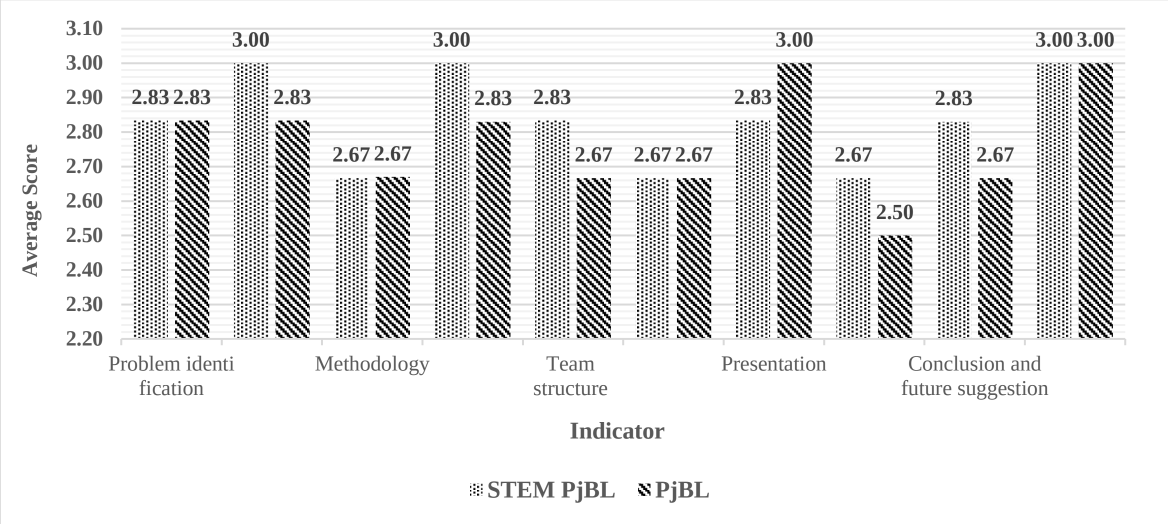

Figure 1. The mean scores of teams problem-solving skills STEM PjBL and PjBL groups

Table 3. The descriptive and Mann-Whitney U test of integrated STEM skills

Component	STEM PjBL		PjBL		Mann-Whitney U test
	M	SD	M	SD	*p*
Interdisciplinary thinking	2.83	0.41	1.00	0.00	0.00*
Scientific knowledge	2.83	0.41	1.83	0.41	0.01*
Technological application	2.83	0.41	2.00	0.00	0.00*
Engineering design	2.67	0.52	2.00	0.00	0.02*
Mathematical processing	2.83	0.41	2.67	0.52	0.52
All components	2.80	0.40	1.90	0.15	0.00*

M=means, SD=standard deviation, *p<0.05

4. DISCUSSION

According to the findings, STEM PjBL has a greater effect on enhancing PSTs' CPS than PjBL. The learning process in STEM PjBL provided opportunities for PSTs to engage in an ill-structured problem-solving process collaboratively with interdisciplinary approaches. PSTs were focused on resolving complex, real-world problems that required solutions from diverse disciplines. PSTs collaborated in small groups to investigate, search for solutions, discuss the solutions, find the best solutions, develop a plan, design, observe, collect data, discuss the results, communicate, and make suggestions for better solutions. Even though both groups have the same learning stages, the interdisciplinary approach facilitated by experts in STEM PjBL eliminates STEM content fragmentation and encourages the development of original problem-solvers who can apply knowledge from multiple disciplines. During this CPS process, PSTs actively engaged in meaningful learning as well as gained knowledge of CPS skills better than the PjBL group.

These findings are in line with previous research that indicated completing an interdisciplinary project with team members in STEM PjBL increases opportunities for collaboration and enhances problem-solving engagement [38], [39]. Previous research also concluded that interdisciplinary STEM facilitates the development of learners' problem-solving [40] and collaboration skills [41], [42]. The challenging task of solving problems through STEM projects encourages PSTs to communicate, discuss, share responsibility, and attempt to solve them collaboratively rather than individually [21]. Each collaborative team works towards the same goal, so each member should not attempt to tackle the problem on their own [43]. During the process of discussing the interdisciplinary project, there may be conflicting information between members, which requires the sharing and resolution of information to determine which information best addresses the problem. This dynamic situation can facilitate the development of collaboration skills because they can only solve the problem by working together [44].

In terms of specific findings in comparing each component of CPS, we did not detect any differences in the components of participation and perspective-taking. Both STEM PjBL and PjBL groups used the PjBL stages, which has been defined by numerous studies as learning that actively involves learners in the creation and completion of projects [45]. This PSTs' active engagement through hands-on experiences led to their active participation during the learning process [46]. Working in a collaborative environment also encourages the development of perspective-taking in order to comprehend and value the perspectives and contributions of others, since each member must integrate their contributions to solve problems [47].

On the contrary, in terms of social regulation, task regulation, and knowledge building, STEM PjBL was better than the PjBL group. In STEM PjBL, PSTs were required to not only collaborate with teachers from the science discipline but also collaborate and communicate with teachers or experts from other disciplines to discuss the requirements and constraints related to the projects. This is why the STEM PjBL group with more diversity has better social regulation [16]. This finding also correlates with the findings of Vogler *et al.* [30], which cast light on the significance of interdisciplinary collaboration among teachers in PjBL to encourage PSTs to collaborate across disciplines. The complexity of STEM-integrated projects required PSTs to overcome numerous obstacles, as the optimal solution step is not always easily recognized. Consequently, they must analyses the best task regulation for problem solution, manage, obtain, and utilize resources, establish clear goals, identify, and collect information to solve a problem, and pursue a variety of problem solutions [48]. These processes, supported by the exchange of ideas with members and teachers, contributed to PSTs' knowledge construction. PSTs constructed their own knowledge with a deep understanding of the disciplines in STEM PjBL [49]. The interdisciplinary approach in STEM PjBL also provides opportunities to resolve and clarify misconceptions about the role of science in STEM education for better knowledge acquisition [50].

Interestingly, differences in PSTs' perceived CPS skills are not always reflected in different project results. The findings of this study showed that there was no significant difference in the team's problem-solving skills during project completion. Since the projects were a representation of the PSTs collaboration in solving problems using real artifacts, both STEM PjBL and PjBL groups produced projects that meet the general criteria for a successful project evaluation. The stages of PjBL used by the two groups encourage PSTs to conduct scientific inquiry throughout the project's completion [51]. Participation in the in-depth problem-solving process stimulates progressive inquiry thinking via problem-solving experience. This process involved planning, searching, coordinating, selecting, and designing a viable solution to the problem, which led to the successful projects [52]. Engaging PSTs with hands-on activities that involve the inquiry process is one of the key successes of project teams, including successful utilization of digital tools, such as Google Docs, Google Drive, video conferencing, and digital discussion forums to facilitate problem-solving collaboration [53].

However, when it comes to evaluating integrated STEM skills, the results showed a statistically significant difference between STEM PjBL and PjBL groups. PSTs who participated in STEM PjBL in completing STEM-focused projects are better able to integrate multiple STEM disciplines into their project completion than those who are still primarily using a science-focused approach to completing projects. This finding is consistent with the previous study, which found that a real-world problem-solving process that emphasizes the link between the four STEM disciplines is one of the successful factors in STEM integration [13], [54]. Integrated STEM projects supported PSTs' engagement in STEM by planning projects incorporating STEM disciplines [55]. STEM projects involving cognitive processes facilitate the acquisition of interdisciplinary solutions and interdisciplinary modeling for the development of STEM concepts [56]. However, in our specific analysis, we did not detect any differences in the mathematical processing component. Both groups showed complete understanding of the problem's mathematical concepts in collecting, analyzing, and presenting their data due to their experiences using mathematical concepts in conducting experiments.

Although PjBL has been identified as an effective pedagogy for teachers to facilitate PSTs' acquisition of interdisciplinary knowledge through projects [27], the important finding in this study suggested that if the teachers did not properly direct PSTs to solve problems using an interdisciplinary approach, PSTs would still be lacking in making connections with other disciplines. This finding highlights the importance of the project that led to STEM integration. The process of creating STEM projects requires PSTs to work together to find solutions to authentic problems and acquire knowledge of integration during the process [57]. Despite the fact that PjBL provides PSTs opportunities for real-world challenges and concerns with connections to interdisciplinary integration, offering STEM projects is the most effective way to implement these interdisciplinary integrations [27], [58].

Findings of this study further explain how the differences in CPS self-assessment scores are reflected in the different results of integrated STEM skills. This also further shows that enhancing CPS through STEM PjBL is better than PjBL. This study highlights the importance of STEM projects as interdisciplinary activities that should be solved collaboratively in a PjBL environment not only for better CPS skills but also for deeper comprehension of STEM integration. The inability to integrate STEM disciplines into PSTs' projects, as shown by the PjBL group, will affect their understanding of how to integrate STEM when solving problems. STEM PjBL enables PSTs to investigate and apply theories and knowledge to enhance their CPS skills, as well as integrate the comprehension and implementation of complex STEM disciplines for project completion [13], [21]. This study implied that teacher education programs should incorporate learning models that provide PSTs with interdisciplinary project experience for CPS development, such as STEM PjBL.

5. CONCLUSION

This study showed that STEM PjBL can enhance PSTs' CPS skills better than PjBL. According to the results, there were three important findings from this study. First, based on the results of self-assessment, PSTs who were taught using STEM PjBL have better CPS skills than the PjBL group, particularly in social regulation, task regulation, and knowledge building. Second, based on the results of the team's problem-solving skills, which reflect the CPS from each group, both STEM PjBL and PjBL groups meet the requirements for a successful project evaluation. However, in terms of integrated STEM skills, both groups show significant differences, particularly in interdisciplinary thinking, scientific knowledge, technological application, and engineering design. Third, this study emphasizes the use of STEM-integrated projects in PjBL settings as the key to engaging learners to collaborate in solving interdisciplinary problems as well as providing knowledge of STEM integration in learning.

Despite the significance of the results, this study also has some limitations related to a small sample size. In order to more generalize the results, similar studies in different contexts should be conducted with larger sample sizes. Future research should combine the self-assessment of CPS behavior observation sheet to evaluate CPS skills during the project completion process.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of an engineering lecturer for providing technical insights, a horticulture practitioner for sharing practical knowledge on plant cultivation, and all pre-service teachers who willingly participated in this study. Their contributions were valuable in enriching the research process. The authors have obtained consent from all individuals mentioned in this acknowledgment.

FUNDING INFORMATION

This work was supported by the Ministry of Education, Culture, Research, and Technology Republic of Indonesia which provided funding for the present work under Grant No. 2.6.48/UN32.20.1/LT/2022.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Rita Fitriani	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			
Hadi Suwono	✓		✓	✓	✓		✓			✓		✓	✓	
Ibrohim	✓	✓		✓	✓		✓			✓		✓		
Betty Lukiaty	✓	✓		✓	✓			✓		✓				

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

Not applicable in this study

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [HS], upon reasonable request.

REFERENCES

[1] M. Knell, "The digital revolution and digitalized network society," *Review of Evolutionary Political Economy*, vol. 2, no. 1, pp. 9–25, 2021, doi: 10.1007/s43253-021-00037-4.

[2] T. Schröder, "A regional approach for the development of TVET systems in the light of the 4th industrial revolution: the regional association of vocational and technical education in Asia," *International Journal of Training Research*, vol. 17, no. sup1, pp. 83–95, 2019, doi: 10.1080/14480220.2019.1629728.

[3] X. Huang, S. Erduran, P. Zhang, K. Luo, and C. Li, "Enhancing teachers' STEM understanding through observation, discussion and reflection," *Journal of Education for Teaching*, vol. 48, no. 5, pp. 576–591, 2022, doi: 10.1080/02607476.2021.2006571.

[4] K. Parti and A. Szigeti, "The future of interdisciplinary research in the digital era: obstacles and perspectives of collaboration in social and data sciences - an empirical study," *Cogent Social Sciences*, vol. 7, no. 1, p. 1970880, 2021, doi: 10.1080/23311886.2021.1970880.

[5] A. L. Tan, Y. S. Ong, Y. S. Ng, and J. H. J. Tan, "STEM problem solving: inquiry, concepts, and reasoning," *Science and Education*, vol. 32, no. 2, pp. 381–397, 2023, doi: 10.1007/s11191-021-00310-2.

[6] M. Marsono, F. Khasanah, and Y. Yoto, "Integrating STEM (science technology engineering and mathematics) education on advancing vocational student's creative thinking skills," in *Proceedings of the 2nd International Conference on Vocational Education and Training (ICOVET 2018)*, 2019, pp. 170–173, doi: 10.2991/icovet-18.2019.43.

[7] F. I. McLure, K.-S. Tang, and P. J. Williams, "What do integrated STEM projects look like in middle school and high school classrooms? A systematic literature review of empirical studies of iSTEM projects," *International Journal of STEM Education*, vol. 9, no. 1, p. 73, Dec. 2022, doi: 10.1186/s40594-022-00390-8.

[8] M. Reyza, A. Taqwa, A. A. Ardiansyah, and M. A. Nurhidayat, "STEM on science learning in Indonesia: an opportunity and a challenge," *Indonesian Journal of Educational Research and Review*, vol. 3, no. 3, pp. 160–170, 2020, doi: 10.23887/ijerr.v3i3.27660.

[9] E. M. Amiri, R. Zerhane, A. Aidoun, R. J. Idrissi, and M. Madrane, "The adoption of the interdisciplinary approach in the teaching of life and earth sciences at university: a reality or a wish? Case of the faculty of sciences of Tetouan, Morocco," *Journal for Educators, Teachers and Trainers*, vol. 13, no. 3, pp. 23–32, 2022, doi: 10.47750/jett.2022.13.03.003.

[10] N. R. Ergül, "Investigation of STEM competencies of teacher candidates," *European Journal of Physics Education*, vol. 12, no. 1, pp. 38–55, 2021.

[11] F. Berisha and E. Vula, "Developing pre-service teachers conceptualization of STEM and STEM pedagogical practices," *Frontiers in Education*, vol. 6, p. 585075, May 2021, doi: 10.3389/feduc.2021.585075.

[12] Purnomo, Yoto, and S. Hadi, "Optimization of essential skills in 21st in students through STEM integrated research based learning," *International Journal of Current Science Research and Review*, vol. 7, no. 7, pp. 4759–4767, 2024, doi: 10.47191/ijcsrr/v7-i7-18.

[13] L. Chen *et al.*, "Direction of collaborative problem solving-based STEM learning by learning analytics approach," *Research and Practice in Technology Enhanced Learning*, vol. 14, no. 1, p. 24, Dec. 2019, doi: 10.1186/s41039-019-0119-y.

[14] F. Ouyang, Z. Chen, M. Cheng, Z. Tang, and C.-Y. Su, "Exploring the effect of three scaffoldings on the collaborative problem-solving processes in China's higher education," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, p. 35, Jul. 2021, doi: 10.1186/s41239-021-00273-y.

[15] P. Jiang, X. Ruan, Z. Feng, Y. Jiang, and B. Xiong, "Research on online collaborative problem-solving in the last 10 years: current status, hotspots, and outlook—a knowledge graph analysis based on citespace," *Mathematics*, vol. 11, no. 10, p. 2353, May 2023, doi: 10.3390/math11102353.

[16] Y. Rosen, I. Wolf, and K. Stoeffler, "Fostering collaborative problem solving skills in science: the animalia project," *Computers in Human Behavior*, vol. 104, p. 105922, Mar. 2020, doi: 10.1016/j.chb.2019.02.018.

[17] J. Pöysä-Tarhonen, P. Häkkinen, P. Tarhonen, P. Näykki, and S. Järvelä, "'Anything taking shape?' Capturing various layers of small group collaborative problem solving in an experiential geometry course in initial teacher education," *Instructional Science*, vol. 50, no. 1, pp. 1–34, Feb. 2022, doi: 10.1007/s11251-021-09562-5.

[18] Z. Swiecki, A. R. Ruis, C. Farrell, and D. W. Shaffer, "Assessing individual contributions to collaborative problem solving: a network analysis approach," *Computers in Human Behavior*, vol. 104, p. 105876, Mar. 2020, doi: 10.1016/j.chb.2019.01.009.

[19] E. Unal and H. Cakir, "The effect of technology-supported collaborative problem solving method on students' achievement and engagement," *Education and Information Technologies*, vol. 26, no. 4, pp. 4127–4150, 2021, doi: 10.1007/s10639-021-10463-w.

[20] Y. Li *et al.*, "On thinking and STEM education," *Journal for STEM Education Research*, vol. 2, no. 1. pp. 1–13, 2019, doi: 10.1007/s41979-019-00014-x.

[21] T. Lertcharoenrit, "Enhancing collaborative problem-solving competencies by using STEM-based learning through the dietary plan lessons," *Journal of Education and Learning*, vol. 9, no. 4, pp. 102–117, 2020, doi: 10.5539/jel.v9n4p102.

[22] S. Uddin, T. Imam, and M. Mozumdar, "Research interdisciplinarity: STEM versus non-STEM," *Scientometrics*, vol. 126, no. 1, pp. 603–618, Jan. 2021, doi: 10.1007/s11192-020-03750-9.

[23] W. Park, J. Y. Wu, and S. Erduran, "The nature of STEM disciplines in the science education standards documents from the USA, Korea and Taiwan: focusing on disciplinary aims, values and practices," *Science and Education*, vol. 29, no. 4, pp. 899–927, 2020, doi: 10.1007/s11191-020-00139-1.

[24] Y.-H. Chien, "Technology-enhanced learning: an optimal CPS learning application," *Sustainability*, vol. 11, no. 16, p. 4415, Aug. 2019, doi: 10.3390/su11164415.

[25] K. C. Margot and T. Kettler, "Teachers' perception of STEM integration and education: a systematic literature review," *International Journal of STEM Education*, vol. 6, no. 1, p. 2, Dec. 2019, doi: 10.1186/s40594-018-0151-2.

[26] J. Han, T. Kelley, and J. G. Knowles, "Building a sustainable model of integrated STEM education: investigating secondary school STEM classes after an integrated STEM project," *International Journal of Technology and Design Education*, vol. 33, no. 4, pp. 1499–1523, 2023, doi: 10.1007/s10798-022-09777-8.

[27] N. Meng, Y. Dong, D. Roehrs, and L. Luan, "Tackle implementation challenges in project-based learning: a survey study of PBL e-learning platforms," *Educational Technology Research and Development*, vol. 71, no. 3, pp. 1179–1207, 2023, doi: 10.1007/s11423-023-10202-7.

[28] M. Baran, M. Baran, F. Karakoyun, and A. Maskan, "The influence of project-based STEM (PjBL-STEM) applications on the development of 21st-century skills," *Journal of Turkish Science Education*, vol. 18, no. 4, pp. 798–815, 2021, doi: 10.36681/tused.2021.104.

[29] K. Y. Lin, Y. T. Wu, Y. T. Hsu, and P. J. Williams, "Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking," *International Journal of STEM Education*, vol. 8, no. 1, pp. 1–15, 2021, doi: 10.1186/s40594-020-00258-9.

[30] J. S. Vogler, P. Thompson, D. W. Davis, B. E. Mayfield, P. M. Finley, and D. Yasseri, "The hard work of soft skills: augmenting the project-based learning experience with interdisciplinary teamwork," *Instructional Science*, vol. 46, no. 3, pp. 457–488, 2018, doi: 10.1007/s11251-017-9438-9.

[31] B. Wahono, P.-L. Lin, and C.-Y. Chang, "Evidence of STEM enactment effectiveness in Asian student learning outcomes," *International Journal of STEM Education*, vol. 7, no. 1, p. 36, Dec. 2020, doi: 10.1186/s40594-020-00236-1.

[32] Z. H. Wan, W. M. W. So, and Y. Zhan, "Developing and validating a scale of STEM project-based learning experience," *Research in Science Education*, vol. 52, no. 2, pp. 599–615, 2022, doi: 10.1007/s11165-020-09965-3.

[33] T. L. Tinnell, T. R. Tretter, W. Thornburg, and P. S. Ralston, "Successful interdisciplinary collaboration: supporting science teachers with a systematic, ongoing, intentional collaboration between university engineering and science teacher education faculty," *Journal of Science Teacher Education*, vol. 30, no. 6, pp. 621–638, 2019, doi: 10.1080/1046560X.2019.1593086.

[34] M. Salmela, M. MacLeod, and J. M. af Rosenschöld, "Internally incentivized interdisciplinarity: organizational restructuring of research and emerging tensions," *Minerva*, vol. 59, no. 3, pp. 355–377, 2021, doi: 10.1007/s11024-020-09431-4.

[35] T. R. Kelley, E. Sung, J. Han, and J. G. Knowles, "Impacting secondary students' STEM knowledge through collaborative STEM teacher partnerships," *International Journal of Technology and Design Education*, vol. 33, no. 4, pp. 1563–1584, Sep. 2023, doi: 10.1007/s10798-022-09783-w.

[36] H.-H. Wang, M. Charoenmuang, N. A. Knobloch, and R. L. Tormoehlen, "Defining interdisciplinary collaboration based on high school teachers' beliefs and practices of STEM integration using a complex designed system," *International Journal of STEM Education*, vol. 7, no. 1, p. 3, Dec. 2020, doi: 10.1186/s40594-019-0201-4.

[37] L. Cohen, L. Manion, and K. Morrison, *Research methods in education*, 8th ed. London: Routledge, 2017, doi: 10.4324/9781315456539.

[38] T. Michalsky and A. Cohen, "Prompting socially shared regulation of learning and creativity in solving STEM problems," *Frontiers in Psychology*, vol. 12, p. 72253, 2021, doi: 10.3389/fpsyg.2021.722535.

[39] S. K. Chen, Y. T. C. Yang, C. P. Lin, and S. S. J. Lin, "Dispositions of 21st-century skills in STEM programs and their changes over time," *International Journal of Science and Mathematics Education*, vol. 21, no. 4, pp. 1363–1380, 2023, doi: 10.1007/s10763-022-10288-0.

[40] J. Melton, J. A. Saiful, and P. P. Shein, "Interdisciplinary STEM program on authentic aerosol science research and students' systems thinking approach in problem-solving," *International Journal of Science Education*, vol. 44, no. 9, pp. 1419–1439, 2022, doi: 10.1080/09500693.2022.2080886.

[41] S. M. Stehle and E. E. Peters-Burton, "Developing student 21st century skills in selected exemplary inclusive STEM high schools," *International Journal of STEM Education*, vol. 6, no. 1, p. 39, Dec. 2019, doi: 10.1186/s40594-019-0192-1.

[42] A. Wibowo, S. Utaya, W. Wahjoedi, S. Zubaidah, S. Amin, and R. Prasad, "Critical thinking and collaboration skills on environmental awareness in project-based science learning," *Jurnal Pendidikan IPA Indonesia*, vol. 13, no. 1, pp. 103–115, 2024, doi: 10.15294/jpii.v13i1.48561.

[43] A. C. Graesser, S. M. Fiore, S. Greiff, J. Andrews-Todd, P. W. Foltz, and F. W. Hesse, "Advancing the science of collaborative problem solving," *Psychological Science in the Public Interest*, vol. 19, no. 2, pp. 59–92, 2018, doi: 10.1177/1529100618808244.

[44] A. J. Griffiths, J. Alsip, S. R. Hart, R. L. Round, and J. Brady, "Together we can do so much: a systematic review and conceptual framework of collaboration in schools," *Canadian Journal of School Psychology*, vol. 36, no. 1. pp. 59–85, 2021, doi: 10.1177/0829573520915368.

[45] K. M. Malik and M. Zhu, "Do project-based learning, hands-on activities, and flipped teaching enhance student's learning of introductory theoretical computing classes?" *Education and Information Technologies*, vol. 28, no. 3, pp. 3581–3604, 2023, doi: 10.1007/s10639-022-11350-8.

[46] E. S. Kibga, J. Sentongo, and E. Gakuba, "Effectiveness of hands-on activities to develop chemistry learners' curiosity in community secondary schools in Tanzania," *Journal of Turkish Science Education*, vol. 18, no. 4, pp. 605–621, 2021, doi: 10.36681/tused.2021.93.

[47] Y. Hayashi, "The power of a 'maverick' in collaborative problem solving: an experimental investigation of individual perspective-taking within a group," *Cognitive Science*, vol. 42, pp. 69–104, 2018, doi: 10.1111/cogs.12587.

[48] C. Sun, V. J. Shute, A. Stewart, J. Yonehiro, N. Duran, and S. D'Mello, "Towards a generalized competency model of collaborative problem solving," *Computers & Education*, vol. 143, p. 103672, Jan. 2020, doi: 10.1016/j.compedu.2019.103672.

[49] K. Kim and A. A. Tawfik, "Different approaches to collaborative problem solving between successful versus less successful problem solvers: tracking changes of knowledge structure," *Journal of Research on Technology in Education*, vol. 55, no. 4, pp. 628–645, 2023, doi: 10.1080/15391523.2021.2014374.

[50] V. Županec, T. Lazarević, V. Sekulić, and T. Pribićević, "The effectiveness of an interdisciplinary approach in biology teaching in primary school: a comparison with monodisciplinary approach," *International Journal of Educational Methodology*, vol. 9, no. 1, pp. 169–182, 2023, doi: 10.12973/ijem.9.1.169.

[51] N. D. Napitupulu, J. Hutahaean, and A. N. L. Fauziyyah, "Trends research project based learning (PjBL) model to improve science process skills in students' science learning (2015-2024): a systematic review," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 7, pp. 488–497, 2024, doi: 10.29303/jppipa.v10i7.8577.

[52] J.-Y. Fan and J.-H. Ye, "The effectiveness of inquiry and practice during project design courses at a technology university," *Frontiers in Psychology*, vol. 13, p. 859164, May 2022, doi: 10.3389/fpsyg.2022.859164.

[53] M. Zhu and K. Zhang, "Promote collaborations in online problem-based learning in a user experience design course: educational design research," *Education and Information Technologies*, vol. 28, no. 6, pp. 7631–7649, 2023, doi: 10.1007/s10639-022-11495-6.

[54] E. A. Dare, K. Keratithamkul, B. M. Hiwatig, and F. Li, "Beyond content: the role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education," *Education Sciences*, vol. 11, no. 11, p. 737, Nov. 2021, doi: 10.3390/educsci11110737.
[55] Y.-L. Chen and C. D. Tippett, "Project-based inquiry in STEM teaching for preschool children," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 18, no. 4, p. em2093, Mar. 2022, doi: 10.29333/ejmste/11899.
[56] L. D. English, "Ways of thinking in STEM-based problem solving," *ZDM - Mathematics Education*, vol. 55, no. 7, pp. 1219–1230, 2023, doi: 10.1007/s11858-023-01474-7.
[57] P. Guo, N. Saab, L. S. Post, and W. Admiraal, "A review of project-based learning in higher education: student outcomes and measures," *International Journal of Educational Research*, vol. 102, p. 101586, 2020, doi: 10.1016/j.ijer.2020.101586.
[58] P. M. Kurup, Y. Yang, X. Li, and Y. Dong, "Interdisciplinary and integrated STEM," *Encyclopedia*, vol. 1, no. 4, pp. 1192–1199, 2021, doi: 10.3390/encyclopedia1040090.

BIOGRAPHIES OF AUTHORS

Rita Fitriani is a Ph.D. Candidate, Department of Biology, Faculty of Mathematics and Natural Sciences, State University of Malang, Indonesia. She is a lecturer at Siliwangi University, Indonesia. Her research interests are in integrated STEM in Biology education, interdisciplinary collaborative teaching, technological pedagogical content knowledge, collaborative problem solving, and self-regulated learning. She can be contacted at email: ritafitriani@unsil.ac.id.

Hadi Suwono is a professor at the Department of Biology, Faculty of Mathematics and Natural Sciences, State University of Malang, Indonesia. His research areas are biology education, integrated STEM education, scientific literacy, information literacy, and critical thinking. He can be contacted at email: hadi.suwono.fmipa@um.ac.id.

Ibrohim is a lecturer at the Department of Biology, Faculty of Mathematics and Natural Sciences, State University of Malang, Indonesia. His research areas are biology education, technological pedagogical content knowledge, preservice teacher professional development, and inquiry learning. He can be contacted at email: ibrohim.fmipa@um.ac.id.

Betty Lukiati is a lecturer at the Department of Biology, Faculty of Mathematics and Natural Sciences, State University of Malang, Malang, Indonesia. Her research areas are plant structure, development and physiology, bioinformatics, herbal medicine and biology education. She can be contacted at email: betty.lukiati.fmipa@um.ac.id.