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The Effect of the Problem-Based Learning (PBL) Model with a STEM Approach on Collaboration Skills

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Abstract

This study aims to determine the effect of the STEM-based learning model on collaboration skills and determine the effective contribution of the STEM-based learning model to collaboration skills in the chemistry subject of buffer solution material. This study uses a quantitative quasi-experimental study with a posttest only with control group design. The population used was all students of class XI IPA SMAN 2 Muara Beliti. The sample taken was done by random sampling with a total of 130 students. The study was conducted with 4 classes, namely 2 experimental classes and 2 control classes with different treatments. The treatment of the experimental class was the STEM-based learning model while the control class used the discovery learning model. The results of the study showed that there was a significant influence of the STEM-based learning model on collaboration skills and provided an effective contribution of 9%, including in the small category.

Introduction

Learning and education are inseparable from the various life situations that continuously change. Especially in the 21st century, learning has evolved into more complex problem-solving, requiring specific abilities and skills (Jamaludin & Hung, 2017). The rapid development has made learning a challenge for educators. Education plays a crucial role in helping students face the various problems that arise in the 21st century. Education needs to provide many opportunities for students to adapt to new environments. In other words, student success can be determined, among other things, by their skills and knowledge in adapting to change (Ongardwanich, Kanjanawasee, & Tuipae, 2015; Pheeraphan, 2013). To achieve that goal, students must master 21st-century skills (Kim, Raza, & Seidman, 2019) Such as collaboration skills (Fong, Sidhu, & Fook, 2014).

Learners in the 21st century competition experience the rapid development of science and technology. The skills needed by learners are creative, logical, critical and communication skills (Kuo, Tseng, & Yang, 2019). Learners must have the skills of innovation, learning, technology and information media in the 21st century (Temirton, Kharipova, & Kistaubayeva, 2023). 21st century skills have not been fully achieved including critical thinking problem solving, communication and teamwork (Hanssens, Langle, & Van Soon, 2023). The causes of the low level of 21st century skills in Indonesian students have been suggested by researchers in relation to Indonesia's

PISA results. Among them are a) Selection of textbooks, b) Misconceptions, c) Learning is not contextualised, d) Low reading skills and e) Unconducive learning environment and climate (Altakhyneh & Abumusa, 2020).

One of the 21st century skills is collaboration skills. Learners need to practice collaboration skills to prepare for 21st century learning. Collaboration skills emphasise on the cooperative relationship between learners and their peers (Gonen & Korkmaz, 2022). Learners should improve collaboration skills to help communicate within the group and respect each other when there are differences of opinion (Kongul & Yildirim, 2021). The cause of students' collaboration skills is not optimal because some students tend to be silent during group discussion activities or group work. Research (Landicho, 2020) shows that the collaboration skills and self-confidence of learners are still low. The reason students have poor results in theoretical and practical learning outcomes at school is because collaboration skills and students are afraid to ask questions (Lin H. , 2022). The results of some of these studies show the low collaboration skills of learners. Collaborative learning allows learners to have broad insights, although they tend to spend more time on reflection and discussion activities in problem solving to achieve goals (Luo, Wang, Liu, & Zhou, 2018).

Collaboration skills provide many benefits to learners' development, so collaboration skills should not be eliminated. (Nong, et al., 2022). The learning process can be successful because of the collaboration skills between teachers and learners or between learners during learning (Ozkan, 2022). Collaboration and teamwork skills can be trained through learning experiences in class, in and out of school. Collaboration skills can be developed by using learning models that provide opportunities for direct interaction between learners and teachers and fellow learners so that skills can be developed through tutors in groups (Razi & Zhou, 2022).

Collaboration skills include the ability to demonstrate respect for diverse groups and to practice flexibility and interest in group discussions (D'Agostino, 2013; Balta & Awedh, 2017). Collaboration involves various rules and the participation of team members in their respective roles, while collectively finding mutual benefits (Hidayati, Zubaidah, & Amnah, 2023) By understanding their strengths and weaknesses, collaboration skills serve as a means for joint problem-solving within the group and achieving common goals (Sahin, Ayar, & Adiguzel, 2014; Batlolona, Baskar, Kurnaz, & Leasa, 2018). Through aspects of communication, cooperation, commitment, and skills in completing tasks together during the interactions that occur while collaborating (Chang, et al., 2017; Ivankova, Halakova, & Collakova, 2022).

The important role of collaboration skills in learning positions it as one of the key 21st-century skills (Boholano, 2017; Pellegrino, 2014). Research shows that individuals with strong collaboration skills are able to achieve superior performance (Druskat & Kayes, 2000; Wijaya, Mundilarto, & Wilujeng, 2024), they inspire others to create a shared vision in solving a problem (O'Leary, Choi, & Gerard, 2012; Yanti, Rahmad, & Azhar, 2023) and they provide support for others' work as well as identify and utilize the abilities of other members. Other research shows that training students in collaboration skills can enhance the effectiveness of learning (Prichard, Stratford, & Bizo, 2006; Sumadi, Degeng, Sulthon, & Waras, 2017). Collaboration skills are essential for students to enhance their social competence, including conflict resolution skills and academic self-concept (Ginsburg-Block, Rohrbeck, & Fanruzzo, 2006; Saputra, Joyoatmojo, Wardani, & Sangka, 2019).

Collaboration skills are certainly very important in the learning process. These skills can be integrated into education at various levels (Kim, Raza, & Seidman, 2019). Several research findings indicate that the collaboration skills of students in Indonesia need improvement (Andres-Todd & Kerr, 2019; Lowell & Ashby, 2018). Student collaboration can be fostered and carried out in the context of physical, social, and cultural environments, and more importantly, in an educational environment that provides comfort for students to collaborate and express their ideas. Collaborating requires full student engagement in discussions. Therefore, the role of the teacher or instructor in this context is merely to facilitate the learning process.

The important role of collaboration skills in education positions them as one of the key skills in the 21st century (Chen & Kuo, 2019; England, Nagel, & Salter, 2020). Research results show that individuals with collaboration skills can achieve better performance (Graesser, Kuo, & Liao, 2017), they have the ability to mobilize and energize others to create a shared vision in problem-solving (Haryani, Coben, Pleasants, & Fetters, 2021). Collaboration skills are recognized as crucial and highly important in the learning process. However, empirical evidence indicates that students' collaboration skills are still lacking. For example, research conducted shows (Herrera-Pavo, 2021) that to improve students' collaboration skills, one approach is through team-based game tournaments. Other research also indicates that students' collaboration skills are still low (Sanabria & Aramburo-Lizarraga, 2017; Tsai, 2019). Essentially, collaboration skills can be practiced and developed in the context of physical, social, and cultural environments. More importantly, the educational environment should be sufficiently comfortable for students so they can express their ideas (Splichal, Oshima, & Oshima, 2018). Collaboration skills can be enhanced with the help of the Problem-Based Learning (PBL) model.

Problem-Based Learning (PBL) is an alternative learning model that can be used to address the shortcomings of traditional approaches (Mubuuke, Louw, & Schalkwyk, 2017) And it can enhance students' collaboration skills when integrated through Science, Technology, Engineering, and Mathematics (STEM) (Murphy, Abu-Tineh, Calder, & Mansour, 2018; Said, Science Education Reform in Qatar: Progress and Challenges, 2016) and enhance conceptual understanding (Ediansyah, Kurniawan, Perdana, & Salamah, 2019). The PBL model has been proven effective in building a foundation for students with the aim of enriching knowledge, developing self-directed and collaborative learning skills. Interaction among students during the learning process forms collaborative learning (Hommes, et al., 2014; Fathy & Malkawi, 2023). The PBL model has some weaknesses. PBL requires students to connect their existing knowledge with the information they are going to learn. Some students rarely conduct preliminary research by referring to multiple sources to solve problems. The knowledge that students possess determines the process they must follow to connect old and new information. To address these issues with the PBL model, students can be given mind mapping tasks (Ren & Jiang, 2019). The issues with the PBL model can be addressed by incorporating STEM education.

The PBL learning model is a teaching approach that encourages students to work on real-world problems to build knowledge, enhance critical thinking skills, and achieve independence and collaboration (Devi, Susilawati, & Kosim, 2024). PBL allows students to build their knowledge by basing their learning on real-world challenges. In this process, students are expected to develop critical thinking and fundamental scientific thinking skills (Nurazmi & Bancong, 2021). On the other hand, the STEM approach is one that can engage students in enjoying classroom

discussions and participating in solving meaningful problems (Kayan-Fadlelmula, Sellami, Abdelkader, & Umer, 2022). Meanwhile, science and technology education is closely related to societal life and can be enhanced and supported by technology (Said, Mansour, & Abu-Tineh, 2023). In STEM-oriented learning (science, technology, engineering, and mathematics), these prerequisites actually facilitate integration. The Problem-Based Learning (PBL) paradigm, which includes a set of teaching techniques that allow students to conduct research, integrate theory and practice, and apply knowledge, is another example of a problem-based learning paradigm in institutions focused on STEM (Ardianti, Sulisworo, Pramudya, & Raharjo, 2020). Therefore, the selection of the PBL model integrated with the STEM approach is considered suitable for facilitating students in developing collaboration skills. This study was conducted to examine the impact of the STEM-based PBL model on high school students' collaboration skills

Research Question

In the research, the answers to the research questions are as follows

1. Is there a significant difference in collaboration skills between the experimental class using the PBL learning model with STEM approach and the control class using the Discovery Learning learning model on buffer solution material?
2. What category of effective contribution does the *STEM-integrated problem-based learning* model give to students' collaboration skills on buffer solution?

Method

Research Design

This study was conducted using an experimental design with a posttest-only with groups approach. The research was carried out over 8 sessions on buffer solution material at SMAN 2 Muara Beliti. A random sampling method was used to ensure that the data collected were unbiased. The sample consisted of 130 students. The students were classified into two different classes with different treatments: 1) the experimental class using the STEM-based PBL approach with 65 students, and 2) the control class using Discovery Learning (DL) with 65 students. The research design is shown in Table 1

Table 1. Research design

Group	Treatment	Questionnaire
Experiment	X_1, O1	Q_2
Control	-,O_1	Q_2

O_1 = Observation Sheet of collaboration skills

Q_2 = Collaboration skills questionnaire sheet

X_1 = STEM integrated problem-based learning model

- = discovery learning model

The learning process in the two classes followed different syntaxes. In the experimental class, students engaged in discussions while the teacher explained a small portion of the learning material. The experimental class received the PBL model with a STEM approach, where the teacher's role was primarily as a facilitator, and students were more dominant in the discussion activities. The stages of the STEM-based PBL learning model are shown in Table 2

Table 2. Syntax of the STEM-Based PBL Model

Learning Steps	**Syntax**	**Descriptions**
Introduction		The teacher greets the students, checks their readiness for learning, provides motivation, and explains the learning objectives.
Core Activities	Problem Orientation Phase (Science)	The teacher divides the students into groups of 4-5 members, provides them with Worksheet 1 (LKPD 1), and directs them to examine the problems.
	Organizing Students for Learning Phase (Technology)	The teacher prepares the students to follow the learning process and directs them to access Worksheet 1 (LKPD 1).
	Independent and Group Investigation Phase (Engineering, Mathematics)	The teacher guides the students in conducting group investigations through experiments, and the students record the data obtained about buffer solutions.
	Developing and Presenting Work Phase	The teacher asks the students to answer questions on the worksheet by relating the results of their discussions and experiments.
	Analyzing and Evaluating the Problem-Solving Process Phase (science, Technology)	The teacher asks the students to summarize the results of their investigation; guides them if they have difficulty summarizing; requests each group to present their discussion results in front of the class; directs students to respond to each other's presentations; and assists students in reflecting on or evaluating the investigation.
Conclusion		The teacher asks the students to submit their worksheets.

The control class was treated with the Discovery Learning (DL) model. In the DL model, students are more dominant in discussion activities, with the teacher serving as a facilitator. The stages of the DL model are shown in Table 3.

Table 3. Syntax of the Discovery Learning (DL) Model

Learning Steps	Syntax	Description
Introduction		The teacher greets the students, the teacher checks attendance, the teacher provides an introduction or context, the teacher gives motivation, the teacher presents the learning objectives.
Core Activities	Stimulation	The teacher presents the learning material, divides the students into several groups, and the students engage with and understand the stimulus.
	Problem Statement	Students formulate problems related to the learning material and write down their hypotheses.
	Data Collection	Students discuss the questions in the worksheet, conduct experiments involving the addition of small amounts of acid, base, and dilution of pH.
	Data Proccesing	Students, along with their group members, process and analyze the data.
	Verification	Students present the results of their group discussions and experiments.
	Generalization	Students discuss with their group members and draw conclusions.
Conclusion		Students are guided by the teacher to summarize the material that has been studied.

Research Instruments

The instruments used in the study include student worksheets, lesson plans (Worksheet), and questionnaires as research materials. Collaboration skills are measured by focusing on 4 aspects of collaboration, which are further clarified with 8 indicators. The indicators and aspects of collaboration skills are shown in Table 4.

Table 4. Aspects and Indicators of Collaboration Skills

Aspects	Indicators	Statement	Item	
			Positive	Negative
Communication Skills	Listening	Listening to ideas shared by group members	1	17
		Not interrupting others' opinions while they are sharing their thoughts during task completion	19	2
	Speaking	Sharing ideas for the benefit of the group	3	
		Speaking politely to group	10	18

Aspects	Indicators	Statement	Item	
			Positive	Negative
		members		
		Responding to the opinions/ideas of group members	20	23
Collaboration Skills	Participating	Being present in the group throughout the task completion	21	9
		Working together to overcome difficulties faced by the group	5	22
		Encouraging group members to participate	24	6
	Contributing	Helping a group member who is struggling with completing a task		8,25
		Sharing learning resources with the group	7	26
Commitment Skills	Motivation	Encouraging group members while working on tasks	12	27
	Acceptance	Not dictating how others should complete their tasks	28	30
		Treating all group members equally during group work	11	29
		Accepting feedback fro group members	25,31	
Task Completion Skills	Responsibility	Completing tasks on time	32	34
		Correcting mistakes/shortcomings in completed tasks	15	13
	Hard Work	Staying focused on group work	14	36
		Taking initiative in working on tasks	33	16

Learner worksheets consist of worksheets for experimental and control classes. The worksheets of the experimental class using the problem-based learning model have a learning syntax of orienting students to the problem, organising learning, guiding investigations, developing presentation of results, analysing and evaluating problems. The control class worksheet uses the discovery learning model with stimulation, problem statement, data collecting, data processing, verification, generalisation syntax. To obtain students' ability to answer the experimental class worksheet, there is a section on developing the presentation of results as shown in Figure 1.

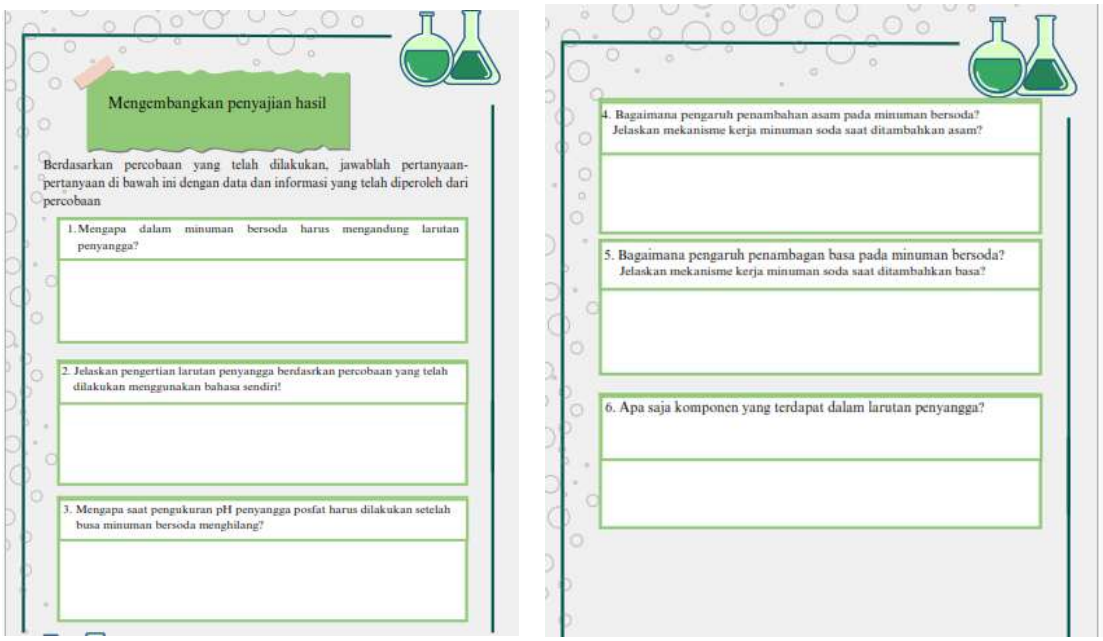

Figure 1. Developed Presentation of Experimental Class Results

To obtain students' ability to answer the control class worksheet is in the section developing the presentation of results as shown in Figure 2.

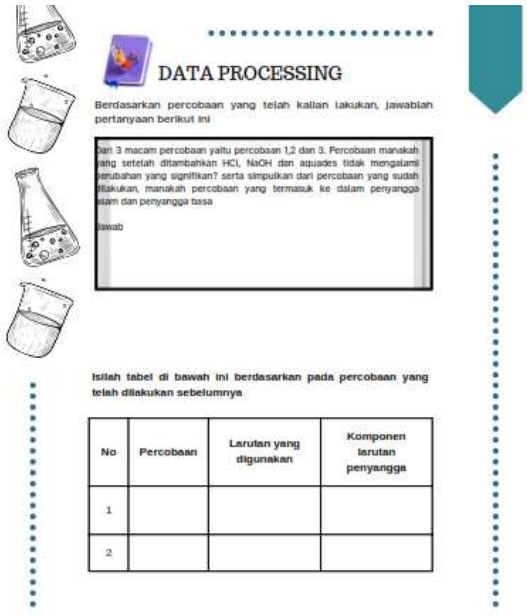

Figure 2. Data Processing in Control Class

Data Analysis

The obtained data were then analyzed using a One-Way ANOVA with a 5% significance level. Before conducting the One-Way ANOVA, normality and homogeneity tests were performed on the data using the Shapiro-Wilk test. The One-Way ANOVA test was then conducted after confirming normality and homogeneity

Results and Discussion

RQ1. Is there a significant difference in collaboration skills between the experimental class using the PBL learning model with STEM approach and the control class using the Discovery Learning learning model on buffer solution material?

Analysis of Collaboration Skills

Collaboration skills of students were measured using a questionnaire. The questionnaire contains 36 statements, focusing on 4 aspects: communication, collaboration, commitment, and task completion. The description of the students' collaboration skills is presented in Table 5

Table 5. Scores of Students' Collaboration Skills

Class	Number of Students	average score	Low Score	High Score
Experiment 1	33	92,64	66	120
Experiment 2	32	92	62	121
Control 1	32	77,97	49	100
Control 2	33	87,15	53	121

Outlier Test

There were no outliers in the dependent variables for each group, assessed univariately. Outliers were examined using univariate Box Plots. The results of the outlier test are shown in Figure 3.

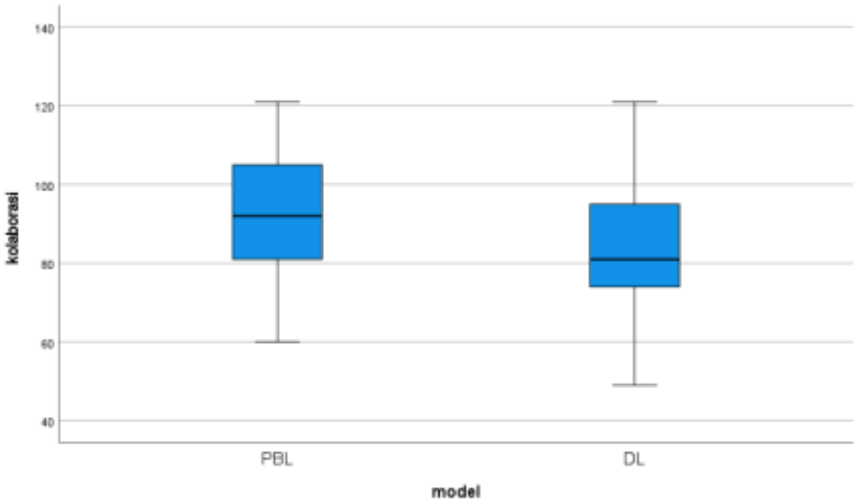

Figure 3. Box Plot of Collaboration Skills in Experimental Class and Control Class

Normality Test

Data that have been confirmed to be free of outliers must then be normally distributed. Univariate normality of the data is tested using the Shapiro-Wilk test. The Shapiro-Wilk test can be performed using SPSS 27, and the

results are presented in Table 6.

Tabel 6. Result Shapiro Wilks

Dependent Variable	Class	*Shapiro Wilks*
Critical Thinking Skills	Experiment	0.188
	Control	0.715

Uji Anova One-Way

To determine the differences between groups with different treatments, a one-way ANOVA test was conducted on collaboration skill. The one-way ANOVA test data for each treatment group is provided in Tables 7 and 8.

Table 7. Homogeneity of Variances Test

Instrument		Levene Statistic	df1	df2	Sig.
Collaboration	Based on Mean	.695	1	128	.406
	Based on Median	.739	1	128	.392
	Based on Median and with adjusted df	.739	1	127.938	.392
	Based on trimmed mean	.695	1	128	.406

Table 8. One-Way Anova Test

Instrument		Sum of Squares	df	Mean Square	F	Sig.
Collaboration	Between Groups	3053.077	1	3053.077	12.543	0.000
	Within Groups	31155.354	128	243.401		
	Total	34208.431	129			

It may consist of several subchapters and use numbering (1,2,3, etc., or a, b, c, etc.). The discussion may contain theoretical discussion as the basis for the research. The research results show that there is an effect of the PBL learning model on students' collaboration skills. This is evidenced by performing a multivariate analysis test using Hotelling's Trace, which has a significance value of 0.000. Thus, it can be concluded that H_0 is rejected and H_a is accepted. These results indicate a significant difference in the collaboration skills of students who participated in PBL learning compared to those who participated in DL learning. The implementation of the PBL model with a STEM approach in the experimental class was more optimal than in the control class.

The learning process using the PBL model involves giving students the freedom to express their own knowledge through contextual problems to understand the subject matter concepts. Students are free to express their thoughts, problem-solving approaches, communication, and learn from their peers' opinions. They take an active role in the discovery and reformulation of the concepts being studied, with the teacher acting as a facilitator (Wang C.-C. , 2021). The PBL learning model presents real-world problems as the starting point of the learning process, making the learning experience more meaningful and beneficial for students (Lin & Wang, 2022)

Collaboration skills are crucial in today's increasingly digitized workforce. The ability to communicate effectively, work in teams, and collaborate with others are essential skills needed in the modern workplace (Ranaut, 2018; Sun, et al., 2022). In addition, collaboration skills contribute to the social and emotional development of students, including enhancing communication skills, teamwork, leadership, and tolerance (Hinyard, Toomey, Eliot, & Breitbach, 2018; Saldo & Walag, 2020). In the context of learning, group activities are not only aimed at developing communication skills that emphasize relationships with others but also at promoting mutual learning, where students can discover and understand perspectives different from their own, as well as explore diverse ideas from group members, leading to a more comprehensive understanding (Le, Janssen, & Wubbels, 2018; Masuda, Marimoto, Matsuodani, & Tsuda, 2016).

The PBL (Problem-Based Learning) model applied in the experimental class allows students to develop collaboration skills. The PBL learning process, which presents problems to students, will enhance their critical thinking skills. By following the PBL syntax, students' collaboration skills are optimized, as the aspects of teamwork, communication, commitment, and task completion can be achieved effectively when real-life problems are given (Redhana, 2019; Zhu & Zhang, 2023).

The control class using the Discovery Learning (DL) model showed lower collaboration skills compared to the experimental class. This occurred because the learning process did not fully utilize the instructional syntax, and classroom learning remained teacher-centered with passive students. Although students collaborated to form concepts from their discoveries, the collaboration was limited in fostering commitment to learning, communication skills, and interaction between students and the teacher (Nainggolan & Purwaningsih, 2024).

The use of the PBL (Problem-Based Learning) model can enhance students' collaboration skills because it enables them to connect theory with practice. This is consistent with research that shows PBL encourages students to think critically, collaborate in groups, and solve real-world problems (Redhana, 2019) that the PBL (Problem-Based Learning) model can enhance collaboration skills in the learning process. The control class used PowerPoint presentations to deliver discussion results, which led to a lack of interest and engagement from students. In contrast, the experimental class employed a learning model that encourages student independence and shifts to a student-centered learning approach, fostering more effective collaboration among students (Peggy, Jason, & Kam, 2022)

RQ2. What category of effective contribution does the STEM-integrated problem-based learning model give to students' collaboration skills on buffer solution?

In line with previous research conducted by (Lestraningsih & Wijayatiningsih, 2017) that the PBL model fosters collaboration between teachers and students. The PBL learning model directs students to collaborate in solving problems. Although face-to-face learning time is limited, the stages of presentation and discussion are maximized. (Yeo, Tan, & Lee, 2012; Wang & Lin, 2021)

Based on the data analysis results, the use of STEM in the learning model is engaging for students, leading to

enthusiastic verbal expression of their opinions. This is in line with research (Rosiningtias, Rosana, Ningseh, Jumadi, & Wilujeng, 2023) The use of STEM-based learning can stimulate students' motivation and interest in learning (Adhelacahya, Sukarmin, & Sarwanto, 2023). STEM-based learning enhances students' collaborative abilities (Hafni, Herman, Nurlaelah, & Mustikasari, 2019). The teacher's provision of stimuli requires students to actively engage in both verbal and written communication, thereby enhancing students' communication skills through the application of the learning process (Zhang, Shi, & Zhang, 2023).

According to the research findings, students who received the STEM treatment obtained a higher effective contribution value than the control class. This finding is similar to the findings of research conducted by (Seltenova, et al., 2023; Wilson, Campbell-Gulley, Anthony, Perez, & Englan, 2022; Yang & Baldwin, 2020). In the research literature on STEM, it is mentioned that the method enhances students' creativity, problem solving, writing, communication, presentation, use of technology, cognitive higher-order thinking capacity, perspective development, critical thinking, collaboration skills and motivation. With the STEM approach, the learning content that students in the experimental group interact with within the scope of the collaboration skills curriculum does not only consist of conventions and facts. Therefore, the strategy of using the STEM approach includes a very rich stimulus, involving language skills and collaboration in everyday life in the realisation of learning in the development of students' collaboration skills.

Learning that involves student participation in small group activities fosters positive interactions (Anggriani, Haryanto, & Atmojo, 2022). In learning activities, students listen to the ideas presented by their group members and respect their peers' opinions. According to research (Lai, 2021) states that to complete the given tasks, students must engage in discussion and work collaboratively within their groups to accomplish the tasks. According to (Wijnia, Noordzij, Arends, Rikers, & Loyens, 2024) factors contributing to the low collaborative skills of students, besides internal factors, include external factors such as culture, gender, and the nature of the tasks faced. These factors are among the reasons for the low effectiveness of collaborative skills. Some students have already engaged in PBL with a STEM approach, and this type of learning has had an impact on improving their collaborative skills.

Based on the results of the research, it can be concluded that the PBL model with a STEM approach has a positive effect on collaborative skills in chemistry learning, specifically on buffer solution material. The implementation of the PBL model with a STEM approach in the classroom makes learning more meaningful, thereby optimizing collaborative skills

Conclusion

Analysis and discussion revealed a significant difference in collaboration skills between students who participated in STEM-integrated PBL and those who participated in Discovery Learning (DL) on the topic of Buffer Solution. The STEM-integrated PBL approach was found to be more effective in improving critical thinking skills compared to the DL model. The contribution of STEM-integrated PBL to collaboration skills was 9%, indicating a moderate level of effectiveness

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