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Enhancing Students' Conceptual Understanding of Buffer Solutions Through Peer-Led Problem-Based Learning

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Abstract

This research seeks to assess the impact of peer-led problem-based learning on students' comprehension of buffer solutions. Employing a quasi-experimental design, seventy-two 11th-grade students from a state high school in Bekasi, Indonesia participated, with 36 students in the experimental group receiving peer-led problem-based learning and the control group undergoing traditional instruction. The study was conducted between May and June 2023, utilizing pretest and posttest data collection, analyzed using t-tests. Findings indicated significantly higher conceptual understanding among students in the experimental group, with a mean post-conceptual test score of 87.93 (SD=6.27) compared to the pretest score of 69.52 (SD 6.83). The treatment effect in the experimental group, indicated by Cohen's d value of 1.82, surpassed that of the control group, which had a Cohen's d value of 1.46. Thus, peer-led problem-based learning emerged as a significant factor in enhancing students' comprehension of buffer solutions.

Keywords: *Conceptual Understanding, Chemistry, Buffer Solutions, Peer-Led Problem-Based Learning*

INTRODUCTION

Chemistry holds significant importance in the realm of science, interconnected with various branches, and exerting a wide-ranging influence on everyday life (Olaleye, 2012). As a scientific discipline, chemistry delves into the structure, composition, properties, and transformations of matter and energy that accompany these changes. A distinctive feature of chemistry education lies in its emphasis on connecting different concepts. It is recognized that the comprehension of chemistry hinges on acquiring conceptual understanding. Conceptual understanding transcends mere memorization of definitions; it involves discerning the interconnections between concepts and how these concepts are mentally constructed by students. Moreover, conceptual understanding materializes when newly acquired knowledge is integrated with previously held knowledge through alternative logical pathways (Driver & Easley, 1978). The ability of students to grasp chemistry concepts and their proficiency in relating interconnected knowledge is pivotal for their academic achievement. However, even students who successfully complete chemistry courses may struggle to spontaneously link chemical concepts and may harbor gaps in their conceptual understanding of specific topics (Cracolice et al., 2008).

Students encounter notable challenges when learning about buffer solutions (Salame, 2022). They view this topic as intricate and daunting due to its involvement with complex calculations. Buffer solutions constitute a significant component of chemistry lessons for 11th-grade students in the science program during the second semester. Understanding buffer solutions necessitates prior comprehension of fundamental chemical concepts from macroscopic, microscopic, and symbolic perspectives (Johnstone, 1991). The abstract nature of buffer solutions often poses difficulties for students, particularly because mastering the concept requires a solid understanding of chemical equilibrium and acid/base chemistry (Orgill & Sutherland, 2008).

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LITERATURE REVIEW

Peer-Led Problem-Based Learning

In this research, a hybrid approach combining problem-based learning (PBL) and peer-led team learning (PLTL) was implemented to enhance the learning outcomes. PLTL was incorporated to augment cognitive development within the PBL framework, thereby positively impacting students' conceptual understanding. Peer-led problem-based learning (PLPBL) emerged as a highly efficacious educational strategy (Lehrer, 2015). During PLPBL sessions, students collaborated to solve problems under the guidance of peer leaders. PBL, rooted in individual inquiry, effectively fostered problem-solving skills, independent learning, and teamwork. This approach offered a distinctive method for teaching buffer solutions. PLPBL proved to be a valuable tool for studying buffer solutions and elevating students' conceptual grasp of the topic. It was anticipated that PLPBL would significantly enhance students' conceptual understanding compared to conventional teaching methods (Bramaje & Espinosa, 2013).

Research Purposes and Research Question

Eren et al. (2018) have identified learning models as influential factors in shaping students' conceptual understanding. Moreover, De Grave et al. (1990) demonstrated through literature that problem-solving instruction within peer groups of similar cognitive levels positively impacts students' conceptual understanding. Thus, the primary aim of this research was to investigate the impact of PLPBL on enhancing the conceptual understanding of senior high school students. In line with this objective, the research posed the following question: "Does the implementation of the PLPBL model influence students' conceptual understanding of buffer solutions?".

RESEARCH METHODOLOGY

Research Design

In this study, a quasi-experimental non-equivalent pretest-posttest control group design was employed. Subjects were not randomly assigned to groups; instead, randomly-formed groups were designated as either experimental or control groups. The experimental group received instruction through Peer-Led Problem-Based Learning (PLPBL), whereas the control group received instruction via a scientific approach from the same lecturer. In this research, PLPBL serves as the independent variable, while students' conceptual understanding constitutes the dependent variable.

Participants

The study involved 72 students who were randomly selected from two intact classes during the second semester of the 2022/2023 academic year. They were 16-17 years old. Two classes were randomly selected, namely XI MIPA-1 and XI MIPA-6 at a state high school in Bekasi, Indonesia. Determination of groups through flipping coins. In the experimental group, there were 36 students (7 males and 29 females), while the control group comprised 31 students (6 males and 30 females). Both groups attended chemistry classes, which consisted of 90-minute sessions held five times over two weeks, focusing on the topic of buffer solutions. All students participated voluntarily and had the option to withdraw at any time. Additionally, the researchers assured the students that their attitude scores would not impact their performance.

Participants

The participants were 72 eleventh-grade students with an age range of 16-17 years old. Samples were taken using random sampling. Two classes were randomly selected, namely XI MIPA-1 and XI MIPA-6 at a state high school in Bekasi, Indonesia. Determination of groups through flipping coins. The experimental group (EG) was XI MIPA 1 with 36 students (7 boys and 29 girls) and the control group (CG) was XI MIPA 6 with 36 students (9 boys and 27 girls) with an age range of 16-17 years old.

Data Collection Tool

The researchers developed a two-tier multiple-choice diagnostic test to assess participants' conceptual understanding before and after the instruction process. This test comprised two levels: the first level contained questions, while the second level presented a choice of reasons corresponding to the answers in the first level (Tuysuz, 2009). This instrument was favored over multiple-choice tests with a scientific approach and problem descriptions because it could evaluate understanding at a higher cognitive level (Tuysuz, 2009). The test consisted of six sub-scales covering various aspects of buffer solutions, including their definition, components, acid and basic concepts, calculations, and functions. Questions for the test were adapted from relevant literature (e.g., Mutlu & Şeşen, 2010). Each item was evaluated using a five-category scale: sound understanding, partial understanding, partial understanding with specific alternative conception, specific alternative conception, and no understanding, scored from 5 to 1, respectively (Çalik & Ayas, 2005). Students were allotted 90 minutes to complete the test. Prior to its use in the pre- and posttests, the instrument underwent validation by five experts, yielding a coefficient of Kuder-Richardson (KR-20) of 0.88, indicating high reliability.

Procedures

Before implementing the various treatments, a pretest was administered to gauge the baseline level of conceptual understanding. Following the intervention, a posttest was conducted to assess any changes in understanding. Additionally, interviews were conducted to gather qualitative insights. The conceptual understanding test was utilized as both the pre- and posttests in both experimental and control groups.

The Treatment for the Experimental Group

The PLPBL model facilitated a structured series of learning activities, including (1) Problem Orientation, (2) Organizing Students, (3) Guiding Experiments, (4) Developing and Presenting, and (5) Analyzing and Evaluating. During the Problem Orientation stage, students were introduced to the problems outlined in the student worksheet, marking the initial phase of problem analysis. In the Organizing Students stage, peer leaders encouraged team members to exchange ideas and provided guiding questions to foster critical thinking strategies. The Guiding Research stage involved collaborative investigative activities among students and peer leaders. Subsequently, in the Developing and Presenting stage, students synthesized their findings and formulated responses to the problem, followed by processing discussion outcomes for presentation. Finally, during the Analyzing and Evaluating stage, the teacher delivered a brief presentation, offering potential responses to the problem, and students shared their progress and comprehension of the problem.

The Treatment for the Control Group

Learning with the scientific approach involved a structured sequence of learning activities, including (1) Observing, (2) Asking, (3) Trying, (4) Reasoning, and (5) Communicating. During the Observing stage, students utilized their senses to observe phenomena, employing various tools when necessary. In the Asking stage, students generated questions to seek clarification on observed information or to gather additional data, ranging from factual to hypothetical inquiries. The Trying stage entailed engaging in activities such as exploration, experimentation, discussion, and consulting additional sources. In the Reasoning stage, students synthesized collected information, drawing upon both experimental results and observations. Lastly, in the Communicating stage, students conveyed their observations and conclusions orally, in writing, or through other media formats.

Data Analysis

The assumption of normality and homogeneity was examined using the Kolmogorov-Smirnov test and Levene's test, respectively. Results indicated a normal and homogeneous distribution of pre- and posttest scores on conceptual understanding ($p > .05$) (see Table 1). Thus, the pretest and posttest data were directly analyzed using the t-test. An independent samples t-test was conducted to determine whether statistically significant gaps existed in the mean scores between the two sample groups. Additionally, a paired samples t-test was employed to investigate the effect of learning models on student conceptual understanding within a single class.

Furthermore, the increase in students' scores before and after treatment was calculated using the effect size formula (*d*) (Cohen, 2007). Cohen's *d* values categorized the strength of the difference between pre- and posttest scores into three categories: weak (0.00 to 0.20), moderate (0.21 to 0.50), strong (0.51 to 1.00), and very strong (>1.00) effects (Cohen, 2007). Statistical analysis was performed using SPSS 24.0.

Table 1. The normality and homogeneity test for the pre- and posttests scores

Groups	Pretest		Posttest	
	Normality	Homogeneity	Normality	Homogeneity
EG	0.16	0.40	0.20	0.06
CG	0.20		0.05	

Note: $p > 0.05$ = Data were normally/homogeneously distributed

RESEARCH RESULTS

The results of the independent samples *t*-test comparing pretest scores between the EG and CG are summarized in Table 2. Initially, students in the CG achieved higher mean scores than those in the EG in four conceptual understanding indicators: buffer solution definition, acid buffer solution concept, base buffer solution concept, and function and role of buffer solution. Conversely, in the other two indicators, buffer solution calculations, and buffer solution components, the EG demonstrated comparable or slightly superior results. Overall, there was no statistically significant gap in the pretest scores between the EG and CG ($t(70) = –0.08$; $p = 0.94$). Additionally, the gaps in scores across conceptual understanding indicators were not statistically significant ($p > 0.05$). This suggests that all participants had similar levels of understanding at the beginning of the intervention.

Table 2. The gaps in pretest conceptual understanding scores between the two groups

Indicators	Groups	M	SD	*t*	*p*
Buffer solution definition	CG	3.61	1.03	-0.16	0.87
	EG	3.56	1.13		
Buffer solution components	CG	3.67	0.95	0.00	0.10
	EG	3.67	1.18		
Acid buffer solution concept	CG	3.52	0.91	-0.09	0.93
	EG	3.51	0.79		
Base buffer solution concept	CG	3.41	1.25	-0.09	0.93
	EG	3.39	1.27		
Buffer solution calculations	CG	3.15	0.89	1.20	0.84
	EG	3.20	0.91		
Function and role of buffer solution	CG	3.71	0.81	-0.33	0.74
	EG	3.65	0.87		
All indicators	CG	69.78	13.13	-0.08	0.94
	EG	69.52	14.07		

At the end of the treatment, significant gaps were observed in all indicators (refer to Table 3). Notably, the posttest scores between the CG and EG were significantly different overall ($t = 2.53$; $p = 0.01$). These findings indicate that the PLPBL model has proven effective in enhancing the conceptual learning of senior high school students.

Table 3. The gaps in pretest conceptual understanding scores between the two groups

Indicators	Groups	M	SD	*t*	*p*
Buffer solution definition	CG	4.55	0.88	1.00	0.32
	EG	4.75	0.76		
Buffer solution components	CG	4.21	0.87	1.75	0.09
	EG	4.54	0.74		
Acid buffer solution concept	CG	3.71	0.64	1.08	0.28
	EG	3.87	0.58		
Base buffer solution concept	CG	3.67	1.33	2.37	0.02
	EG	4.36	1.15		
Buffer solution calculations	CG	3.92	0.90	1.39	0.17
	EG	4.19	0.69		
Function and role of buffer solution	CG	4.76	0.44	1.37	0.18
	EG	4.88	0.29		
All indicators	CG	83.07	9.64	2.53	0.01

	EG	87.93	6.27		

The paired-sample *t*-test revealed significant gaps in both the CG and EG, with p-values of 0.00, indicating significance below 0.05. This suggests that the alternative hypothesis (Ha) is accepted, indicating an increase in the average conceptual understanding of students regarding buffer solutions before and after treatment in both the CG and EG. Furthermore, Cohen's *d* values were calculated to describe the effects of peer-led problem-based learning and the scientific approach. In the EG, the Cohen's *d* value was 1.82, indicating a very large effect size. This suggests that PLPBL had a substantial impact on increasing students' conceptual understanding of buffer solutions. Similarly, in the CG, the Cohen's *d* value was 1.46, indicating a large effect size. This implies that learning with the scientific approach also had a significant influence on enhancing students' conceptual understanding of buffer solutions.

Table 4. Changes in CG and EG students' conceptual understanding

Groups	Indicators	Test	Paired Differences		*t*	*p*	*d*
			M	SD			
CG	Buffer solution definition	Pretest	3.61	1.03	-5.85	0.00	0.97
		Posttest	4.55	0.88			
	Buffer solution components	Pretest	3.67	0.95	-3.91	0.00	0.65
		Posttest	4.21	0.87			
	Acid buffer solution concept	Pretest	3.53	0.91	-1.73	0.09	0.29
		Posttest	3.71	0.64			
	Base buffer solution concept	Pretest	3.42	1.25	-1.16	0.26	0.19
		Posttest	3.67	1.33			
	Buffer solution calculations	Pretest	3.16	0.90	-5.28	0.00	0.88
		Posttest	3.92	0.90			
	Function and role of buffer solution	Pretest	3.71	0.81	-8.85	0.00	1.47
		Posttest	4.76	0.45			
	All indicators	Pretest	69.8	13.1	-8.77	0.00	1.46
		Posttest	83.1	9.64			
EG	Buffer solution definition	Pretest	3.56	1.13	-6.08	0.00	1.01
		Posttest	4.75	0.76			
	Buffer solution components	Pretest	3.67	1.18	-5.09	0.00	0.85
		Posttest	4.54	0.74			
	Acid buffer solution concept	Pretest	3.51	0.79	-2.58	0.01	0.43
		Posttest	3.87	0.58			
	Base buffer solution concept	Pretest	3.39	1.27	-4.49	0.00	0.75
		Posttest	4.36	1.15			
	Buffer solution calculations	Pretest	3.20	0.91	-8.49	0.00	1.42
		Posttest	4.19	0.69			
	Function and role of buffer solution	Pretest	3.65	0.87	-8.37	0.00	1.39
		Posttest	4.88	0.28			
	All indicators	Pretest	69.5	14.1	-10.97	0.00	1.82
		Posttest	87.9	6.26			

DISCUSSION

This research investigated the impact of Peer-Led Problem-Based Learning (PLPBL) on the conceptual understanding of buffer solutions among 11th-grade students. The findings of the study suggest that PLPBL effectively enhances students' conceptual grasp of buffer solutions, aligning with previous research. For instance, Eren et al. (2018) demonstrated that Peer-Led Team Learning (PLTL) positively impacts conceptual understanding, while Clinton et al. (2017) found that combining Problem-Based Learning (PBL) with PLTL yields positive effects on learning outcomes.

The EG exhibited a greater improvement in conceptual understanding compared to the CG. In the PLPBL approach, students collaboratively tackle problems presented in the student worksheet, guided by peer leaders within each group. The problems within the SW are structured to occupy an entire session, during which students work individually or in teams to propose solutions. This iterative process enables continual review and refinement of their skills, supplemented by daily feedback from both peer leaders and teachers, thereby enhancing their learning strategies.

In solving conceptual problems in chemistry, a direct correlation exists between reasoning ability and problem-solving proficiency (Deming et al., 2003). The PLTL method challenges students to utilize problem-solving, critical thinking, and reasoning skills, thereby enhancing their reasoning abilities and fostering a robust conceptual understanding (Cracolice & Deming, 2004). Similarly, the implementation of PLPBL encourages active participation from all group members, fostering collaboration and mutual support to achieve optimal results. This collaborative environment helps diminish the disparity between students who grasp information quickly and those who require more time, promoting social cohesion and ultimately enhancing student motivation (Cracolice & Deming, 2004).

In PLPBL, the involvement of peer leaders plays a pivotal role in enhancing students' cognitive abilities. These peer leaders, acting as tutors, demonstrate determination that extends beyond academic grades, influencing students' attitudes and sense of responsibility. It's important to note that students' academic aptitudes in chemistry vary widely. Grounded in constructivism and social learning theory, PLPBL strategically positions students within their zone of proximal development (ZPD). By presenting challenging problems that students cannot easily tackle independently, but can engage with their peers to solve, PLPBL fosters collaborative learning experiences (Eberlein et al., 2008). This approach capitalizes on the social aspects of learning, leveraging peer interaction to promote cognitive growth and deeper conceptual understanding.

In PLTL, students collaborate with peer leaders who are better aligned with their ZPD compared to a typical classroom setting. This allows for opportunities to tackle challenging problems collaboratively, which may be difficult to solve individually. Peer leaders offer additional structure and content knowledge to students, facilitating peer interaction within the group. Moreover, peer leaders are actively engaged not only in facilitating classes but also in direct participation alongside fellow peer leaders and chemistry teachers in weekly meetings. During these meetings, they engage in problem-solving activities, which they later assign to their respective student groups. Additionally, peer leaders enhance their critical thinking skills through a weekly journal writing process. This multifaceted approach not only benefits students by providing additional support and guidance but also contributes to the professional development and critical thinking skills of peer leaders.

In this research, enhanced conceptual understanding was facilitated through direct student involvement in the PLPBL process, comprising various stages such as problem orientation, organizing students, guiding investigations, developing and presenting, as well as analyzing and evaluating the problem-solving process. During the problem orientation stage, students were introduced to problems presented in student worksheets, marking the initial phase of problem analysis. These problems were crafted to resonate with students' everyday experiences, particularly regarding familiar concepts like buffer solutions. Complex technical language was intentionally avoided in the student worksheets to mitigate students' comprehension difficulties. In the initial session, students were given time to read a narrative in the student worksheets, which addressed issues such as dental plaque accumulation and teeth discoloration resulting from prolonged chewing habits. Subsequently, students engaged in group discussions guided by peer leaders to explore their initial responses to the problems presented in the worksheets. Through this collaborative process, students identified gaps in their understanding and formulated strategies to address the issues at hand. This collaborative setting provided students with the opportunity to activate their prior knowledge, relate new information to existing concepts, and share ideas with peers. This exchange of ideas not only activated students' prior knowledge but also facilitated the formation of new conceptual understandings, highlighting the importance of peer interaction in the learning process (De Grave, Boshuizen & Schmidt, 1996).

In this stage of the PLPBL method, students are challenged to utilize problem-solving, critical thinking, and reasoning skills to enhance their reasoning abilities and foster a robust conceptual understanding (Cracolice & Deming, 2004). During the student organizing stage, peer leaders encourage the entire team to share their ideas, providing them with a conducive environment for collaboration (Barrows & Hmelo-Silver, 1989). Peer leaders also guide students by suggesting questions to stimulate their thinking, thereby facilitating the development of effective thinking strategies (Collins et al., 1989). In the initial meeting, students are given time to gather information regarding questions about the relationship between the narratives provided and the concept of buffer solutions. Through group discussions, students become aware of gaps in their current knowledge and identify the information they need to acquire to address these gaps. This process enables students to pinpoint areas for further study. By engaging in teamwork and individual study prompted by the presented problem, students gradually develop a comprehensive understanding of the concept of buffer solutions (Daniel, 2007).

In the stage of guiding the investigation, students are provided with time to work individually and collaboratively on the student worksheets. During this stage, students engage in investigative activities with their peers and peer leaders after gathering relevant information. Drawing from the problem narrative provided, students investigate the components of the buffer solution outlined in the narrative, as well as explore the concept of buffer solutions by examining their applications in everyday scenarios. Students are encouraged to utilize available resources, including textbooks, to aid their investigations. Following individual and group investigations, each group reaches a consensus solution, which is then shared with other groups. This collaborative exchange allows groups to compare their findings and insights, facilitating a deeper conceptual understanding of the topics under discussion (Quitadamo et al., 2009). Through this iterative process of investigation and collaboration, students are able to synthesize information, clarify misconceptions, and reinforce their understanding of buffer solutions.

At this stage, students engage in independent study and team discussions to solidify their findings and formulate responses to the problem at hand. Subsequently, they process the results of their discussions to prepare a presentation outlining their response to the problem. Students dedicate time to preparing their presentations and rehearsing their content. Each team then presents their findings, consolidated responses, and defenses to the problems, responding to questions raised by classmates and peer leaders. The process of asking critical questions and explaining one's ideas plays a crucial role in student learning, fostering a deeper conceptual understanding of the topic under discussion (Vygotsky, 1978). Peer leaders may intervene at this stage to clarify key concepts as needed, ensuring that students have a clear understanding of the material being presented. Through this interactive presentation phase, students not only demonstrate their understanding but also refine their communication and critical thinking skills.

In the stage of analyzing and evaluating the problem, the teacher delivers a brief presentation outlining possible responses to the problem following the presentations by the six teams. Students then share their progress and understanding of the problem, fostering a collaborative learning environment. The teacher offers suggestions for addressing learning difficulties and enhancing conceptual understanding, leveraging insights gained from students' approaches to problem-solving. By actively engaging with students and identifying their individual learning barriers, the facilitator can provide targeted support to help them overcome challenges. Additionally, students are prompted to reflect on their learning process using the student worksheet. This reflective practice enables students to gain awareness of their learning journey, pinpoint areas of difficulty, and contemplate strategies for improving their conceptual understanding (Yew & Kweek, 2010). Through this reflective process, students develop metacognitive skills and become more self-directed learners, ultimately enhancing their overall learning experience.

Absolutely, providing students with opportunities for deep thinking and reflection is crucial for their conceptual development. When students engage in reflection, they evaluate their experiences, identify inconsistencies between their existing knowledge and new information (known as cognitive dissonance), and endeavor to revise their conceptual frameworks to integrate the new learning. Without these opportunities for critical thinking and reflection, new knowledge may remain superficial and fail to lead to deeper conceptual understanding. Effective instructional activities allocate sufficient time for students to engage in thought and reflection. This reflective process imbues learning with meaning and facilitates an increase in students' conceptual understanding (Daniel, 2007). By encouraging students to think deeply about their learning experiences, educators promote meaningful learning that extends beyond memorization, fostering genuine comprehension and retention of knowledge.

CONCLUSION AND SUGGESTION

Based on the results of data analysis and discussion, it can be concluded that peer-led problem-based learning has a more significant impact than the scientific approach in enhancing students' conceptual understanding of buffer solutions. This conclusion is supported by descriptive data, which indicates that the average conceptual understanding scores for the pretest in the EG were 69.52, compared to 69.78 in the CG. However, for the posttest, the average conceptual understanding score increased to 87.93 in the EG and 83.07 in the CG. Additionally, the statistical significance of the paired sample *t*-test for both the EG and CG was found to be <0.05, indicating a significant increase in conceptual understanding for both groups. However, the effect of treatment on the EG has a greater effect than the effect of treatment on the CG. This is also shown by Cohen's *d* value of the EG of 1.82 while Cohen's *d* value of the CG was 1.46. Cohen's results in both classes were in the range of > 1.00. This indicates that even though the results of Cohen's *d* in the EG were greater, the fact was that the PLPBL model and learning with a scientific approach have a very strong effect on students' conceptual understanding.

This research has several limitations that should be considered. Firstly, the sample size was relatively small, which may limit the generalizability of the findings. Future research should aim to involve a larger and more diverse sample to ensure broader applicability of the results. Secondly, time constraints restricted the duration of the study to only five relatively short meetings. Extending the duration of the intervention could provide a more comprehensive evaluation of the effectiveness of the PLPBL model. Additionally, this study focused solely on the effect of PLPBL on students' conceptual understanding of buffer solutions. Future research could explore the applicability of PLPBL to other topics within chemistry or across different subjects, enhancing the breadth and depth of the findings. Addressing these limitations will contribute to a more robust understanding of the potential benefits and applications of PLPBL in educational settings.

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