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Enhancing Third Graders' Understanding of the Water Cycle through Problem-Based Learning and Wordwall Integration

Hafizhah Rahmiati Auliya*, Banu Setyo Adi, Sari Rakhmawati, Lilis Suryani, Theresa Dwita Halim, Dindha Pangastuti
Department of Primary Education, Universitas Negeri Yogyakarta
Colombo Street No. 1, Karangmalang, Yogyakarta 55281, Indonesia
*Corresponding Author. E-mail: hafizhahrahmiati.2023@student.uny.ac.id

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Abstract: Third-grade students often face difficulties in understanding the abstract and cyclical nature of the water cycle, leading to misconceptions and fragmented knowledge. This study aims to investigate the effectiveness of integrating Problem-Based Learning (PBL) and Wordwall (WW) in improving students' conceptual understanding of the water cycle. A quasi-experiment employed in this study. The participants involved 105 third-grade students from one elementary school, divided into three groups: PBL+Wordwall, PBL-only, and a conventional instruction group. Over six sessions, students received instruction aligned with their group's assigned strategy. The results, based on pretest and posttest comparisons analysed through t-tests and MANCOVA, show that both PBL and PBL+Wordwall outperform conventional teaching; however, PBL+Wordwall did not significantly surpass PBL alone. These findings suggest that PBL is a powerful strategy for teaching scientific concepts and that visual tools like Wordwall may offer added benefits in vocabulary reinforcement and engagement. This research supports the adoption of active learning and digital aids to enhance science instruction in elementary education.
Keywords: Problem-Based Learning, Wordwall, water cycle, conceptual understanding, elementary education

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Introduction

An essential concept in elementary school science classes, the water cycle provides children with a foundation for understanding the Earth's natural processes and the interconnectedness of its ecosystems. Despite its significance, studies reveal that a large number of third graders find it difficult to comprehend the abstract and cyclical character of this idea, which frequently results in misunderstandings regarding evaporation, condensation, and precipitation (Aragües, 2023; Lee et al., 2019; Realdon et al., 2019; Sujana et al., 2019). For instance, students often confuse evaporation with transpiration, thinking that water only evaporates directly from lakes or oceans and are unaware of the role plants play in the water cycle (Romine et al., 2015; Schmid & Bogner, 2018). A thorough grasp of the water cycle cannot be fostered by traditional education approaches, which mostly rely on textbook explanations and memorization (Lee et al., 2019). To solve this issue and ensure correct comprehension of this scientific phenomenon, active learning techniques must be incorporated by providing students with relevant learning experiences (Freeman et al., 2014; Lekshmi & Teena, 2024; Ordoñez et al., 2024; Vats & Joshi, 2024). Problem-Based Learning (PBL) is particularly effective in this regard because it immerses students in complex scenarios that require active problem-solving and collaboration, reducing dependency on rote memorization and fostering conceptual understanding.

Problem-Based Learning (PBL) has emerged as an effective educational approach that emphasizes active student engagement (Bhuttah et al., 2024; Pangestu et al., 2024; Wu et al., 2025) and

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real-world problem-solving (Arici & Yilmaz, 2023; Wibawa et al., 2024). By allowing students to explore authentic challenges, PBL enhances critical thinking, collaboration, and conceptual understanding (Hmelo-Silver, 2012; Pangestu et al., 2024). Concurrently, instructional tools such as Wordwall, a visual representation of key vocabulary, can significantly aid in reinforcing science literacy by promoting word recognition and contextual understanding (Albright & Ariail, 2005; Windiyani et al., 2024). However, few studies have explored the combined potential of PBL and Wordwall integration to improve elementary students' grasp of complex scientific concepts like the water cycle. This study addresses that gap by systematically investigating the synergistic effect of these strategies, particularly in a third-grade context where abstract concepts require both scaffolding and reinforcement.

Despite the critical importance of understanding the water cycle in elementary education, current teaching practices often fall short of effectively conveying its complexities to third graders (Darling-Hammond et al., 2020). Many educators rely on traditional didactic methods, such as lectures and textbook-based instruction, which fail to engage students actively or address their diverse learning needs (Lee et al., 2019). Consequently, students frequently develop misconceptions, such as oversimplified views of evaporation or misunderstanding the interconnection between various stages of the water cycle (Barrutia et al., 2021; Fandel et al., 2018; Romine et al., 2015; Schmid & Bogner, 2018). Previous studies have highlighted that without interactive and contextual learning, these misconceptions persist, hindering students' ability to apply their knowledge to real-world contexts (Cai, 2021; Lee et al., 2011). The urgency of addressing these gaps is underlined by research advocating for the integration of active methodologies and multimodal media in early science education to cultivate inquiry and reduce misconceptions (Oliveira et al., 2023; Winarni & Purwandari, 2020). The lack of integration between innovative instructional approaches and tools, such as PBL and Wordwall, further exacerbates these issues, leaving a significant gap in effective pedagogical practices for teaching at the elementary level (Kusuma et al., 2024). Addressing this problem requires a reevaluation of teaching strategies to foster both conceptual clarity and sustained engagement among young learners.

In an ideal educational setting, third graders would develop a comprehensive and accurate understanding of the water cycle through immersive and interactive learning experiences (Cai, 2021; Dewi et al., 2024; Lee et al., 2011). Guided by constructivist principles, students should actively engage in exploring real-world problems that illustrate the interconnected processes of evaporation, condensation, precipitation, and collection. PBL provides an ideal framework for this approach, enabling students to collaboratively investigate and solve meaningful challenges related to the water cycle. Additionally, integrating Wordwall (WW) as a supportive instructional tool would enhance students' science literacy, helping them internalize and apply key terminology within their problem-solving activities (Mukhamadiarova & Nizamutdinova, 2023; Pimpuang & Yuttapongtada, 2023; Tomczyk et al., 2024). Together, these strategies would ensure that learning is not only engaging but also rooted in deep comprehension, empowering students to connect abstract scientific concepts to their everyday lives. This scenario envisions a transformative educational environment where innovative teaching practices equip young learners with both critical thinking skills and a solid foundation in scientific literacy (Stehle & Peters-Burton, 2019).

Existing literature highlights the effectiveness of both PBL and visual aids, such as WW, in enhancing student engagement and conceptual understanding (Altiok & Yükseltürk, 2022). Studies on PBL have demonstrated its potential to foster critical thinking, collaboration, and deeper comprehension of complex scientific concepts by allowing students to actively explore and solve real-world problems (Pitaloka et al., 2021; Puspita et al., 2023; Sarnoko et al., 2024; Utaminingsih et al., 2024). Similarly, research on WW has demonstrated its ability to enhance vocabulary retention and promote a contextual understanding of subject-specific terminology (Arsyad, 2024; Hasram et al., 2021). However, most studies have focused on these strategies in isolation, with limited exploration of their combined application in elementary science education. Furthermore, while PBL has been widely studied in secondary and higher education, its use in teaching abstract topics like the water cycle to younger learners remains underexplored. This gap presents an opportunity to investigate how integrating PBL with Wordwall can create a synergistic effect, improving both conceptual understanding and literacy skills in third-grade students learning about the water cycle.

The objective of this study is to examine the effectiveness of PBL and Wordwall, either as standalone methods or in combination, in enhancing third grade students' conceptual understanding of the water cycle. The objective of this study is twofold: first, to compare these strategies with conventional learning, and second, to determine which approach produces the most meaningful learning outcomes. Based on these objectives, this study answers the following research questions: (1) Is there a difference in the conceptual understanding of the water cycle between students taught using PBL+WW and those taught using PBL only? (2) Is there a difference in the conceptual understanding of the water cycle between students taught using PBL+WW and those taught using conventional strategy? (3) Is there a difference in the conceptual understanding of the water cycle between students taught using PBL and those taught using conventional strategy? (4) Which teaching strategy is the most effective in improving the conceptual understanding of the water cycle among third-grade students: PBL+WW, PBL only, or conventional strategy? The novelty of this research lies in its focus on the synergistic impact of these strategies, which have rarely been studied together in elementary education. The scope of the study encompasses third-grade students, with an emphasis on the developmental appropriateness and classroom feasibility of these approaches to inform broader educational practices in early science education.

Methods

This study employed a quasi-experimental design utilizing a nonequivalent control group design with three groups to assess the effectiveness of integrating Problem-Based Learning (PBL) and Wordwall (WW) in teaching the water cycle to third-grade students. The first group received a combination of PBL and Wordwall integration (PBL+WW), the second group was taught using only PBL, and the third served as the control group, following conventional instructional methods. Each experimental group underwent six instructional sessions designed to align with the curriculum and progressively deepen students' understanding of the water cycle. Pretests and posttests were administered to evaluate students' conceptual understanding, with a 45-day interval between these assessments to account for the retention and consolidation of knowledge. This rigorous design ensured a structured comparison of learning outcomes across the groups, enabling a robust analysis of the impact of the combined pedagogical strategies on students' academic performance.

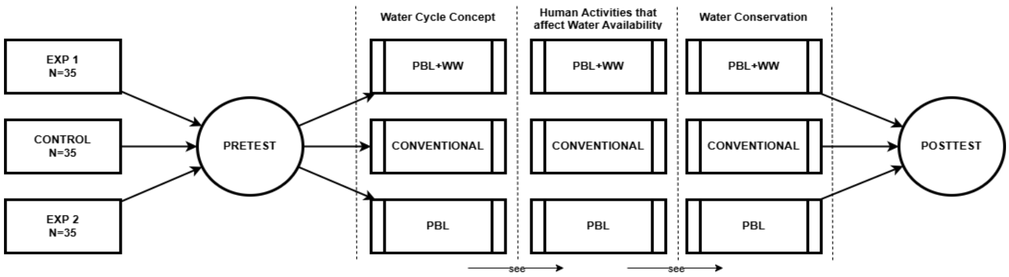

Figure 1. Research Procedure

The population for this study consisted of third-grade students from a single elementary school with four intact classrooms, each comprising 35 students. From this population, three classrooms were purposively selected for inclusion in the study, with each assigned to one of the experimental conditions: PBL+WW, PBL-only, and the control group. This resulted in a total sample size of 105 students, with 35 students in each of the three groups. Analysis of pretest scores revealed significant differences among the groups, indicating variations in students' initial conceptual understanding of the water cycle. Given these baseline differences, pretest scores were used as a covariate in the subsequent MANCOVA to statistically control for initial ability. Moreover, students were classified into three levels of initial ability (low, medium, and high) based on their pretest performance, allowing for a more nuanced investigation of how instructional strategies interacted with prior knowledge. Utilising intact classrooms enabled the practical implementation of the interventions in a real-world educational setting, thereby enhancing the ecological validity of the study.

The instruments used in this study included a conceptual understanding test on the water cycle, consisting of multiple-choice and short-answer questions designed to assess students' comprehension of key processes such as evaporation, condensation, precipitation, and collection. The test was developed based on the curriculum standards for third-grade science and reviewed by subject matter experts to ensure content validity. A pilot test was conducted with a similar cohort of students to evaluate the reliability and clarity of the instrument, resulting in minor revisions to improve item wording and alignment with learning objectives. Sample items included questions such as “Which of the following shows the correct sequence of the water cycle?” and “Create a short sentence to describe what happens after condensation in the water cycle”. These examples reflect the range of cognitive skills assessed, from recall to conceptual application. The final test demonstrated strong internal consistency, as indicated by Cronbach's alpha value of 0.87.

Additionally, a teacher observation checklist was employed to monitor fidelity of intervention implementation, ensuring that PBL and Wordwall strategies were delivered consistently across sessions and groups. The checklist included indicators such as “students are engaged in problem-solving activities,” “key vocabulary from the Wordwall is referenced during discussions,” and “teachers follow the planned lesson sequence.” Observers recorded the presence or absence of each indicator during every session to ensure consistent delivery across all groups. The intervention process was found to have proceeded according to plan, as no significant obstacles were indicated in the observer's notes.

Data collection for this study was conducted in three phases: the pretest, the intervention, and the posttest. Initially, all participating students completed a pretest to assess their baseline understanding of the water cycle. Following the pretest, the intervention phase consisted of six instructional sessions, structured over a specific timeline. During this period, the PBL+WW and PBL-only groups received their respective treatments, while the control group followed standard teaching methods. Teachers in the experimental groups used detailed lesson plans to ensure consistency in the delivery of Problem-Based Learning and Wordwall activities. Classroom observations were conducted during the intervention to verify adherence to the study protocols. After a 45-day interval to assess retention and consolidation of learning, students completed a posttest identical in format to the pretest. All test scores and observation data were collected systematically and securely to ensure the reliability and validity of the data for subsequent analysis.

The data collected in this study were analyzed using both descriptive and inferential statistical methods. Descriptive statistics, including mean and standard deviation, were used to summarize students’ scores. Due to significant differences in pretest scores among the groups, a Multivariate Analysis of Covariance (MANCOVA) was performed with pretest scores as covariates to control for initial disparities. Students were also classified into low, medium, and high ability levels based on their pretest results, allowing the analysis to examine the effects of instructional group, initial ability level, and their interaction on posttest and gain scores. Post hoc pairwise comparisons with Bonferroni adjustments were conducted to identify specific group differences. Additionally, effect sizes (Cohen’s d) were calculated to determine the magnitude of the intervention’s impact. All statistical tests were performed at a 0.05 significance level.

Results and Discussion

Results

This section presents the findings regarding students’ conceptual understanding of the water cycle after receiving instruction through three different strategies: Problem-Based Learning with Wordwall (PBL+WW), Problem-Based Learning (PBL) only, and conventional teaching. The analysis aims to examine both the score improvements from pretest to posttest and the relative effectiveness of each instructional strategy.

Table 1. Descriptive Statistics and Normality Test

	Group	N	Mean	SE	Median	SD	Range	Min	Max	25th	50th	75th	W (p)
Pretest	PBL+WW	35	54.1	1.64	55	9.68	40	35	75	47.50	55.0	61.0	0.826
	PBL	35	47.7	2.01	48	11.87	57	23	80	41.00	48.0	56.0	0.783
	Conventional	35	44.6	1.99	47	11.75	57	14	71	35.50	47.0	51.5	0.598
Posttest	PBL+WW	35	72.2	1.90	73	11.25	48	44	92	65.50	73.0	79.0	0.355
	PBL	35	71.6	2.81	71	16.64	73	44	117	62.00	71.0	81.5	0.550
	Conventional	35	61.6	1.95	64	11.56	46	38	84	55.50	64.0	69.0	0.317
Gain Score	PBL+WW	35	18.1	2.79	23.0	16.48	68.0	-17.0	51.0	7.00	23.0	29.5	0.742
	PBL	35	23.9	3.45	23.0	20.43	93.0	-18.0	75.0	12.50	23.0	38.5	0.678
	Conventional	35	17.0	2.77	15.0	16.39	71.0	-12.0	59.0	7.50	15.0	27.5	0.560

Table 1 presents the descriptive statistics and normality test results for each group. The Shapiro-Wilk test values indicate that all distributions (pretest, posttest, and gain scores) do not significantly deviate from normality ($p > 0.05$). However, a violation of the homogeneity of variances is observed for the posttest scores (Levene's $p = 0.040$), which necessitates the use of adjusted statistical methods such as Welch's t-test. Figure 1 visually compares the distribution of scores across the three instructional groups. The PBL+WW group consistently demonstrates higher medians and more concentrated interquartile ranges in all three measures, suggesting more consistent performance, despite the presence of outliers.

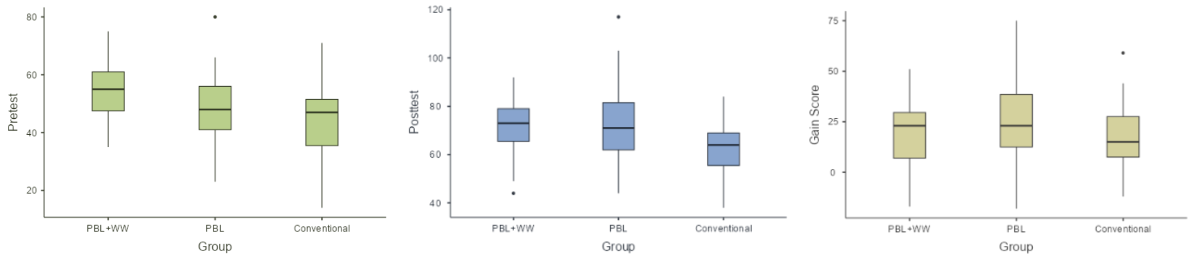

Figure 2. Boxplots of Pretest, Posttest, and Gain Scores Across Teaching Strategies

Inferential statistical analyses were conducted to examine differences in students' conceptual understanding of the water cycle following instruction with PBL+WW, PBL-only, and conventional methods. A Multivariate Analysis of Covariance (MANCOVA) was employed to simultaneously evaluate posttest and gain scores as dependent variables, while controlling for students' initial conceptual understanding (pretest scores) as covariates. This approach enhances the precision of the comparisons by adjusting for baseline differences and assessing interaction effects between instructional strategies and students' initial ability levels. Assumptions of MANCOVA – normality (Shapiro-Wilk), homogeneity of variances (Levene's test), and homogeneity of covariances (Box's M test) – were tested and met or statistically adjusted, supporting the validity of the analysis. These analyses were intended to identify which instructional method most effectively enhanced students' conceptual understanding of the water cycle.

Table 2. Normality and Homogeneity Test Results (PBL+WW and PBL)

(Shapiro-Wilk)						(Levene's)
	W	**p**	**F**	**df**	**df2**	**p**
Pretest	0.989	0.807	0.849	1	68	0.360
Posttest	0.979	0.274	4.407	1	68	0.040
Gain	0.984	0.538	0.993	1	68	0.322

Note. A low p-value suggests a violation of the assumption of normality and equal variances

The Shapiro-Wilk test results indicate that none of the distributions significantly deviate from normality ($p > 0.05$), suggesting that the assumption of normality is met for the pretest, posttest, and gain scores. However, Levene's test indicates a significant result for posttest scores ($p = 0.040$), which violates the assumption of homogeneity of variances between the PBL+WW and PBL groups. To address this violation, Welch's t-test – robust to unequal variances – was used for posttest comparisons, while standard independent samples t-tests were applied for pretest and gain scores where the assumption of homogeneity was not violated.

Table 3. T-Test Results for Pretest, Posttest, and Gain Scores (PBL+WW and PBL)

		Statistic	**df**	**p**	**Mean difference**	**SE difference**
Pretest	Student's t	2.449	68.0	0.008	6.343	2.59
Posttest	Welch's t	0.168	59.7	0.433	0.571	3.39
Gain	Student's t	-1.301	68.0	0.901	-5.771	4.44

Note. H_a $\mu_{PBL+WW} > \mu_{PBL}$ | [a] *Levene's test is significant* ($p < .05$)*, suggesting a violation of the assumption of equal variances*

Table 3 reveals a statistically significant difference in pretest scores between the PBL+WW and PBL groups ($t(68) = 2.449$, $p = 0.008$), with the PBL+WW group scoring an average of 6.34 points higher. Due to unequal variances indicated by Levene's test, Welch's t-test was applied to the posttest scores. The result showed no statistically significant difference between groups (t(59.7) = 0.168, p = 0.433). Similarly, the gain score comparison yielded a non-significant result (t(68) = -1.301, p = 0.901), indicating comparable improvements in both groups. These findings suggest that despite initial differences in prior knowledge, the learning outcomes in terms of posttest performance and score improvements were statistically similar between the PBL+WW and PBL groups. The next section compares the PBL+WW group with the Conventional group to further explore differences in students' conceptual understanding.

Table 4. Normality and Homogeneity Test Results (PBL+WW and Conventional)

(Shapiro-Wilk)						(Levene's)
	W	p	F	df	df2	p
Pretest	0.989	0.790	1.212	1	68	0.275
Posttest	0.973	0.128	0.208	1	68	0.650
Gain	0.994	0.988	0.121	1	68	0.729

Note. A low p-value suggests a violation of the assumption of normality and equal variances

Table 4 shows that both the Shapiro-Wilk and Levene's tests yield p-values greater than 0.05 across all variables, confirming that the assumptions of normality and equal variances are satisfied for comparing the PBL+WW and Conventional groups. As shown in Table 5, independent samples t-tests reveal statistically significant differences in both pretest (t(68) = 3.664, p < .001) and posttest (t(68) = 3.867, p < .001) scores, with the PBL+WW group outperforming the Conventional group by mean margins of 9.43 and 10.54 points respectively. In contrast, the comparison of gain scores reveals no significant difference (t(68) = 0.284, p = 0.389), indicating that although the PBL+WW group achieved higher overall scores, the extent of improvement from pretest to posttest was statistically similar between the two groups.

Table 5. T-Test Results for Pretest, Posttest, and Gain Scores (PBL+WW and Conventional)

		Statistic	df	p	Mean difference	SE difference
Pretest	Student's t	3.664	68.0	<.001	9.43	2.57
Posttest	Student's t	3.867	68.0	<.001	10.54	2.73
Gain	Student's t	0.284	68.0	0.389	1.11	3.93

Note. H_a $\mu_{PBL+WW} > \mu_{PBL}$ | [a] Levene's test is significant (p < .05), suggesting a violation of the assumption of equal variances

The subsequent analysis compares the PBL group to the conventional group in terms of conceptual understanding, focusing on differences in pretest, posttest, and gain scores.

Table 6. Normality and Homogeneity Test Results (PBL and Conventional)

(Shapiro-Wilk)						(Levene's)
	W	p	F	df	df2	p
Pretest	0.989	0.786	0.0152	1	68	0.902
Posttest	0.981	0.351	3.1534	1	68	0.080
Gain	0.990	0.863	1.5794	1	68	0.213

Note. A low p-value suggests a violation of the assumption of normality and equal variances

As shown in Table 6, the Shapiro-Wilk and Levene's tests yield p-values above 0.05 across all variables, indicating that the assumptions of normality and equal variances are met for comparing the PBL and conventional groups. The independent samples t-test shows no significant difference in pretest scores (t(68) = 1.09, p = 0.139), suggesting that the PBL and conventional groups had comparable initial understanding. A significant difference in posttest scores is observed (t(68) = 2.91, p = 0.002), with the PBL group outperforming the conventional group by 9.97 points on average, indicating a more effective conceptual acquisition. The gain score difference was marginally non-significant (t(68) = 1.56, p = 0.062), implying that although the PBL group achieved higher posttest results, the magnitude of improvement from pretest was not significantly different between the groups.

Table 7. T-Test Results for Pretest, Posttest, and Gain Scores (PBL and Conventional)

		Statistic	df	p	Mean difference	SE difference
Pretest	Student's t	1.09	68.0	0.139	3.09	2.82
Posttest	Student's t	2.91	68.0	0.002	9.97	3.42
Gain	Student's t	1.56	68.0	0.062	6.89	4.43

Note. H_a $\mu_{PBL+WW} > \mu_{PBL}$ | [a] Levene's test is significant (p < .05), suggesting a violation of the assumption of equal variances

The error bar plots in Figure 3 illustrate comparisons of group means and confidence intervals for pretest and posttest scores, allowing visual inspection of significant differences. In the comparison between the PBL+WW and PBL groups, the PBL+WW group shows higher pretest scores, with non-overlapping 95% confidence intervals, suggesting a statistically significant difference in initial knowledge levels. In the posttest comparisons, both PBL+WW and PBL groups outperform the Conventional group. This is supported by the visibly higher means and the lack of overlap in confidence intervals, indicating statistically significant differences in final conceptual understanding. These visual and statistical patterns provide further evidence of the effectiveness of PBL-based strategies (with or without Wordwall) in fostering students' conceptual understanding of the water cycle compared to conventional instruction.

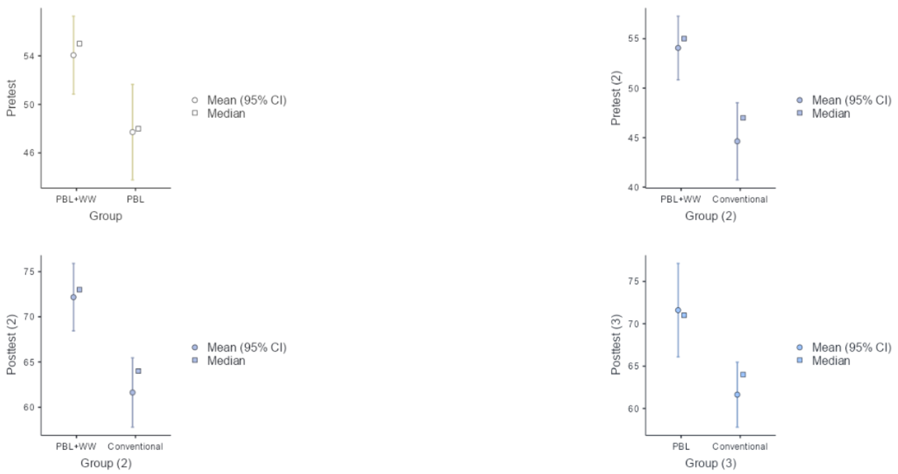

Figure 3. *Pretest and Posttest Score Comparisons Across Groups*

Finally, the analysis addresses the final research question, focusing on identifying the most effective teaching strategy (PBL+WW, PBL, or Conventional) in enhancing students' conceptual understanding of the water cycle. This evaluation involves comparing both posttest and gain scores across the instructional groups.

Table 8. Multivariate Test Results for Group, Initial Ability Levels, and Their Interaction

Multivariate Tests		value	F	df1	df2	p
Group	Pillai's Trace	0.3832	11.376	4	192	<.001
Initial Ability Levels	Pillai's Trace	0.6760	24.508	4	192	<.001
Group ∗ Initial Ability Levels	Pillai's Trace	0.0664	0.825	8	192	0.582

To answer this question, a Multivariate Analysis of Covariance (MANCOVA) was conducted to compare posttest and gain scores across the three groups, with students' initial ability levels (based on pretest performance) used as a covariate. This analysis allows simultaneous evaluation of multiple dependent variables (posttest and gain scores), as well as the main and interaction effects of group membership and initial ability levels. Assumptions of normality (Shapiro-Wilk), homogeneity of variances (Levene's), and homogeneity of covariance matrices (Box's M test) were examined and met, justifying the use of MANCOVA. Post hoc pairwise comparisons were subsequently performed to explore specific group differences and gain a deeper understanding of how each teaching strategy affected students at different initial ability levels.

Table 9. Univariate Test Results for Group, Initial Ability Levels, and Their Interaction

Univariate Tests	Dependent Variable	SS	df	MS	F	p
Group	Posttest	2461	2	1230	6.988	0.001
	Gain Score	956	2	478	1.925	0.152
Initial Ability Levels	Posttest	468	2	234	1.330	0.269
	Gain Score	8152	2	4076	16.407	<.001
Group ∗ Initial Ability Levels	Posttest	887	4	222	1.259	0.292
	Gain Score	549	4	137	0.552	0.698
Residuals	Posttest	16903	96	176		
	Gain Score	23848	96	248		

MANCOVA results (Table 8) indicate a significant multivariate effect of instructional group (Pillai's Trace = 0.3832, F(4, 192) = 11.376, p < .001), suggesting that the teaching strategy used has a substantial impact on students' posttest and gain scores. Initial ability levels also have a significant effect (Pillai's Trace = 0.6760, F(4, 192) = 24.508, p < .001), indicating that students' prior knowledge has a significant influence on their post-intervention outcomes. No significant interaction was found between group and initial ability levels (Pillai's Trace = 0.0664, F(8, 192) = 0.825, p = 0.582), indicating that the effects of the instructional strategies are consistent across students' starting ability levels.

Univariate analysis (Table 9) shows that group membership has a significant effect on posttest scores (F(2, 96) = 6.988, p = 0.001), indicating that certain instructional strategies result in higher conceptual understanding. However, no significant effect of the group was observed on gain scores (F(2, 96) = 1.925, p = 0.152), suggesting comparable levels of improvement across the three groups. Initial ability levels significantly influence gain scores (F(2, 96) = 16.407, p < .001), indicating that students with higher pretest performance show greater learning gains. However, they do not have a statistically significant effect on posttest scores (F(2, 96) = 1.330, p = 0.269), implying similar end-point achievement regardless of initial level. Additionally, there is no significant interaction between group and initial ability level for posttest scores (F(4, 96) = 1.259, p = 0.292) or gain scores (F(4, 96) = 0.552, p = 0.698), suggesting that the effectiveness of each strategy does not depend on students' initial knowledge level. Overall, these findings confirm that teaching strategy has a clear effect on posttest performance, but its influence is consistent across varying levels of prior ability.

Table 10. Post Hoc Comparisons for Posttest Scores Across Groups

Group		Group	Mean Difference	SE	df	t	p_{tukey}	$p_{bonferroni}$	Cohen's d
PBL+WW	-	PBL	-8.27	6.62	95.0	-1.25	0.427	0.643	-0.626
	-	Conventional	12.32	6.69	95.0	1.84	0.161	0.206	0.933
PBL	-	Conventional	20.59	6.71	95.0	3.07	0.008	0.008	1.559

Table 11. Post Hoc Comparisons for Posttest Scores Across Initial Ability Levels (Pretest)

Pretest		Pretest	Mean Difference	SE	df	t	p_{tukey}	$p_{bonferroni}$	Cohen's d
High	-	Middle	16.82	8.64	95.0	1.946	0.132	0.164	1.273
	-	Low	19.52	10.27	95.0	1.900	0.144	0.181	1.478
Middle	-	Low	2.70	4.29	95.0	0.630	0.804	1.000	0.205

Post hoc comparisons (Table 10) indicate that the PBL strategy is significantly more effective than the conventional strategy in enhancing posttest scores (mean difference = 20.59, p = 0.008), with a large effect size (Cohen's d = 1.559), suggesting substantial practical impact. Although the PBL+WW group shows higher average posttest scores than the conventional group, the differences are not statistically significant when compared to either PBL (p = 0.427) or Conventional (p = 0.206). Regarding initial ability levels (Table 11), comparisons show no statistically significant differences between High, Middle, or Low groups (e.g., High vs Middle, p = 0.132; High vs Low, p = 0.144), suggesting uniform effects of instruction across ability tiers. Nonetheless, the presence of large effect sizes (e.g., Cohen's d = 1.273 for High vs Middle, 1.478 for High vs Low) indicates meaningful practical trends favoring students with higher initial knowledge. Overall, these findings affirm the PBL strategy as the most impactful in enhancing conceptual understanding, while initial ability levels – though not statistically significant – present strong practical implications. This may suggest that the potential benefit of Wordwall integration was not captured in the immediate posttest, possibly due to the short intervention duration or the assessment's focus on conceptual rather than affective learning outcomes. It remains plausible that Wordwall impacts motivational, engagement-related, or long-term retention outcomes, which were not directly assessed in this study. Future studies should consider employing delayed posttests or qualitative methods to capture potential long-term or affective benefits of Wordwall-enhanced instruction.

Discussion

In this study, the four research questions were analysed to determine whether they were fully or partially answered and whether the hypotheses were confirmed or rejected. Explanations are provided with reference to the theoretical framework used, the results of previous research, and the conditions under which this study was conducted on third-grade students.

The Difference in Conceptual Understanding of the Water Cycle Between Students Taught with PBL+WW and PBL

The results showed that there was no significant difference in post-test scores between the PBL+WW and PBL-only groups. The hypothesis (H1) arising from this question was also not confirmed. Although the PBL+WW group recorded a slightly higher average score, the increase was not significant enough to indicate a substantial advantage. This outcome suggests that the core instructional benefit may be derived from the PBL approach itself, which provides structured problem-solving opportunities and active engagement, aligning with constructivist learning theories (Westwood, 2011). This finding aligns with previous research, which has shown that PBL can significantly enhance students' conceptual understanding through problem-solving (Hidayati & Wagiran, 2020; Shishigu et al., 2018; Unissa et al., 2018). Research on developing puzzle media using Wordwall has an impact on student activity, motivation, interest, and learning outcomes. Puzzle media using Wordwall also fosters self-confidence, critical thinking, and group collaboration (Dewi & Alivi, 2023; Vallejo, 2023; Windiyani et al., 2024). However, the primary benefit lies in enhancing vocabulary retention and engagement, which may not have been fully captured through a conceptual test.

The Difference in Conceptual Understanding of the Water Cycle Between Students Taught with PBL+WW and Conventional

This question was answered positively. There was a significant difference in post-test scores between the PBL+WW group and the control group using conventional methods, with the PBL+WW group recording significantly higher scores. The hypothesis (H2) of this question was confirmed, indicating that the combination of problem-based learning strategies and visual aids is significantly more effective than traditional teaching methods. This finding is consistent with previous studies, which have shown that active learning and visual aids can significantly improve students' conceptual understanding (Asraf & Ahmad, 2004; Fajari et al., 2020; Marques et al., 2020; Primamukti & Farozin, 2018). The integration of PBL with Wordwall facilitated the contextualization of abstract scientific concepts, making them more accessible to students through multimodal representations, in line with Mayer's cognitive theory of multimedia learning (Mayer, 2009).

The Difference in Conceptual Understanding of the Water Cycle Between Students Taught with PBL and Conventional

The results showed that PBL was significantly more effective than the conventional method, as observed in many previous studies (Jandrić et al., 2011; Nisa. The PBL group recorded higher post-test scores than the control group, although the relative increase (gain score) was not significantly different. The hypothesis (H3) raised by this question was partially confirmed, as the post-test scores showed significant differences; however, the relative gains were not significantly different. These findings suggest that PBL can effectively help students understand complex water cycle concepts through a problem-solving process that involves active interaction. This supports existing theoretical frameworks emphasizing learner-centered pedagogies, particularly those grounded in socio-constructivism (Vygotsky & Cole, 1978). However, the study also noted that the difference in long-term retention between the two groups requires further investigation.

The Difference in Conceptual Understanding of the Water Cycle Between Students Taught with PBL+WW, PBL, and Conventional

The results of the post-hoc analysis indicate that while the PBL+WW group demonstrated the highest mean post-test scores, the difference between the PBL+WW and PBL-only groups was not statistically significant. Instead, the significant difference was observed between the PBL-only group and the conventional method group. Contrast this with the research by Leasa et al. (2023) on subject teachers, which explores the integration of the RQA method or its integration with competency-based situations (Hwang & Chang, 2016), finding that this approach is more significant than implementation without additional media or methods. This suggests that the active engagement and problem-solving elements of PBL were the primary drivers of improved conceptual understanding, with Wordwall providing additional, though not statistically significant, support.

The hypothesis (H4) that PBL+WW would be the most effective strategy is therefore only partially confirmed. While PBL+WW achieved the highest scores, the statistical evidence suggests that the core effectiveness lies in the PBL framework itself. This aligns with prior research emphasizing the impact of problem-based learning on enhancing conceptual understanding (Can & Ekici, 2024; Hallinger, 2021; Merritt et al., 2017; Westwood, 2011). However, the role of Wordwall should not be dismissed entirely. In the context of teaching the water cycle, Wordwall likely aided in reinforcing vocabulary and helping students organize abstract concepts. The added benefit of Wordwall might be more pronounced in long-term retention or for specific subgroups of students, such as those with weaker initial vocabulary skills, which were not directly evaluated in this study.

The findings of this study align with prior research on the effectiveness of PBL and visual aids like Wordwall (Hidayah & Pujiastuti, 2016; Olckers et al., 2007; Oliveira et al., 2023; Utami et al., 2020; Winarni & Purwandari, 2020) highlighted the effectiveness of PBL in improving critical thinking skills and student engagement in learning. Similarly, research by Windiyani et al. (2024) and Bouzaiane & Youzbashi (2024) has demonstrated that visual aids, such as Wordwall, can strengthen students' vocabulary retention, which aligns with the outcomes of this study. However, this research extends the literature by exploring the combined potential of these two strategies in elementary education, a context where such integration has been underexplored. As such, this study contributes novel insights by demonstrating the synergistic potential of PBL and Wordwall in teaching complex scientific concepts.

This study, while insightful, has limitations that affect its generalizability. The sample size of 105 students from one school may not represent broader contexts, as variations in demographics and teacher expertise were not explored. The six-session intervention may also be insufficient to evaluate long-term retention, as no follow-up assessments were conducted. Additionally, focusing solely on the water cycle limits the applicability of the findings to other topics, and the study did not assess other benefits of PBL, such as critical thinking and motivation. Future research should involve larger samples across multiple schools, include delayed posttests to measure retention, and expand focus to other science topics and cognitive domains.

Conclusion

This study demonstrated that Problem-Based Learning (PBL) significantly enhances third graders' conceptual understanding of the water cycle compared to conventional teaching methods. The integration of Wordwall (PBL+WW) yielded the highest posttest scores, though the difference from PBL alone was not statistically significant. These findings suggest that the core effectiveness stems from the PBL framework itself, which emphasizes active engagement, problem-solving, and student-centered learning. Nonetheless, Wordwall may have contributed practical benefits such as reinforcing vocabulary or aiding visualization—effects that could be more pronounced in the long term or in affective domains not assessed in this study. Conventional methods consistently underperformed, reaffirming their limited ability to convey complex scientific processes. These outcomes support the broader application of constructivist and digitally enriched instructional strategies in science education. Future research should investigate delayed posttest effects, apply these strategies to other scientific topics, and explore their impact across different student profiles and classroom settings.

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