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Problem-based learning and mathtastic *app* integration to improve reasoning and collaboration in mathematics learning among primary students: an experimental approach

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Abstract

Background: This experimental study explores the integration of Problem-Based Learning (PBL) and the Mathtastic application to enhance mathematical reasoning and collaborative skills among primary school students.
Aims: Grounded in constructivist learning theory, the research aims to determine the effectiveness of a technology-supported PBL approach in fostering students' higher-order thinking and teamwork abilities in the context of mathematics education.
Methods: The study employed a quasi-experimental design with control and experimental groups comprising Grade 5 students from a public elementary school. The experimental group received mathematics instruction through PBL integrated with the Mathtastic app, while the control group was taught using conventional methods. Data were collected using pre- and post-tests on mathematical reasoning, a collaboration rubric, and observation sheets.
Result: The results showed a statistically significant improvement in the reasoning and collaboration performance of students in the experimental group compared to those in the control group. These findings suggest that combining PBL with interactive educational technology like Mathtastic can create a more engaging and effective learning environment for young learners.
Conclusion: The study provides practical implications for teachers seeking to integrate digital tools and inquiry-based approaches to enrich mathematics learning experiences at the primary level.

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INTRODUCTION

In today's rapidly evolving educational landscape, 21st-century skills, such as critical thinking, collaboration, and digital literacy, have become a core priority, particularly in foundational subjects like mathematics (Magdalena, 2022). Traditional teaching methods, which often emphasize rote memorization and individual problem-solving, have shown limitations in cultivating students' higher-order thinking and social interaction. As such, there is a growing demand for innovative instructional strategies that improve conceptual understanding and foster students' reasoning and collaborative abilities (Darwin, 2023).

Problem-Based Learning (PBL) has emerged as an effective pedagogical approach emphasizing student-centered inquiry, real-world problem-solving, and active engagement (Lapek, 2020). By working collaboratively to solve complex, meaningful problems, students are encouraged to reason logically, communicate ideas, and apply mathematical knowledge in authentic contexts. Numerous

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studies have highlighted the positive impact of PBL on students' cognitive and interpersonal development, making it a promising model for mathematics instruction at the primary level (Fita et al., 2021; Nguyen et al., 2024; Waluyo, 2023). In parallel with pedagogical innovations, technological integration has reshaped classroom practices (Wong & Wong, 2021). Educational applications such as the Mathtastic app provide interactive, game-based environments that support visualization, instant feedback, and student motivation. When integrated thoughtfully, such tools can enhance learning outcomes by reinforcing concepts introduced during PBL activities while maintaining student engagement (Hesti & Hardi, 2020).

The PBL is a student-centered instructional approach that places learners in the active role of problem-solvers confronted with real-world, contextualized problems. Rooted in constructivist theory (Dangel, 2017; Hennig, 2010), PBL encourages students to take ownership of their learning by engaging in inquiry, collaboration, and reflection. In mathematics, PBL has been shown to promote deeper conceptual understanding, improve problem-solving strategies, and foster critical reasoning (Ulya et al., 2024). Research indicates that PBL is particularly effective in developing mathematical reasoning, as it demands students to analyze situations, apply logical steps, and justify their conclusions (Voon et al., 2022). Moreover, PBL fosters a collaborative learning environment where students interact, exchange ideas, and build shared understandings, key components for enhancing interpersonal and communication skills.

Meanwhile, mathematical reasoning refers to the ability to make logical connections, justify solutions, and critically evaluate mathematical ideas (Putri & Dwi, 2023). It is an essential component of mathematical proficiency, particularly in primary education, where foundational thinking habits are formed. According to Hughes et al. (2020), reasoning can be fostered through open-ended tasks, discussions, and exploratory learning conditions often present in PBL environments. Several studies (e.g., Kihwele & Mkomwa, 2023; Suwayid & Rezqallah, 2022) argue that when students are encouraged to explain their reasoning processes, they not only retain concepts better but also develop a more flexible understanding of mathematical structures. In mathematics classrooms, collaborative learning enables students to engage in mathematical discourse, co-construct meaning, and gain exposure to diverse problem-solving approaches (Setiyowati & Shodikin, 2022). Studies have found that structured collaborative activities, especially within PBL contexts, enhance students' confidence, communication skills, and cooperative behavior (Nisfah et al., 2022). When collaboration is paired with meaningful tasks, it provides an authentic context for developing reasoning and reflection.

On the other hand, digital tools also support differentiated instruction, allowing students to work at their own pace while engaging with content that challenges their current level of understanding. Integrating apps such as Mathtastic in mathematics instruction has shown promise in improving students' procedural fluency and reasoning ability, especially when combined with student-centered pedagogies (Harris et al., 2020). Despite the individual benefits of PBL and digital tools, limited research has explored the combined impact of both approaches on key student competencies, particularly in the context of primary mathematics education. This study seeks to address that gap by examining the integration of PBL and the Mathtastic app in improving students' mathematical reasoning and collaborative skills. Using an experimental design, this research aims to provide empirical evidence on the effectiveness of this integrated instructional model and offer practical insights for educators seeking to modernize mathematics instruction in the digital age.

The study compared traditional mathematics instruction with lessons incorporating the Mathtastic app learning activities. Therefore, the first question was designed to reflect this comparison. Questions two, three, and four were particularly important as they related directly to student performance, a key measure of the study's effectiveness. Subsequently, the study proposed the following hypotheses:

H1: Students who integrated the Mathtastic App into their PBL achieved better mathematical reasoning than those in the control group.
H2: Students who integrated the Mathtastic App into their PBL achieved better collaboration skills than those in the control group.
H3: The students showed great enthusiasm for incorporating the Mathtastic app into their learning.

METHOD

Research Design

This study employed a quasi-experimental design with a non-equivalent control group pretest-posttest structure (Creswell, 2009). The purpose of this design was to determine the effectiveness of integrating Problem-Based Learning (PBL) and the Mathtastic application in enhancing mathematical reasoning and collaboration among primary school students. The experimental group received instruction using PBL enhanced by the Mathtastic app, while the control group received traditional, teacher-centered instruction without digital tools or PBL elements.

Figure 1 presents the structure of each class session. The first five minutes were devoted to a "Perform the task at hand" activity, a brief exercise for students to complete on the board upon arrival—accompanied by group discussions. The following fifteen minutes involved presenting the day's topic to both groups in a hybrid lecture and group discussion format. For the next fifteen minutes, students used smartphones with AR applications to explore probability concepts.

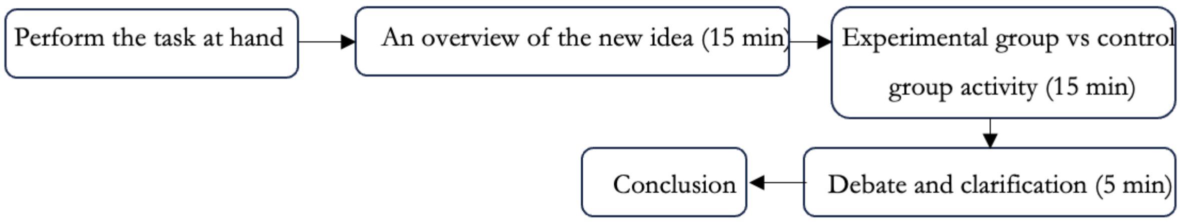

Figure 1. Students Instruction Activites

Participant

The participants were Grade 5 students from two parallel classes at a public elementary school in Central Java, Indonesia. A total of 60 students were involved in the study, with 30 students assigned to the experimental group and 30 to the control group. The groups were selected through purposive sampling based on classroom availability and similarity in academic level, as determined by their previous mathematics scores.

Instrument

Four main instruments were used to measure the effectiveness of the intervention: the Mathematical Reasoning Test (Hughes et al., 2020). A validated test consisting of open-ended and multiple-choice items aimed at assessing logical thinking, justification of solutions, and the ability to draw mathematical conclusions. Collaboration Skills Rubric (Nisfah et al., 2022). A rubric adapted from established collaborative learning frameworks evaluates dimensions such as participation, communication, teamwork, and problem-solving during group activities. Observation Sheet (Townsend, 2018). Used by the teacher and researcher to record classroom interactions, student engagement, and the use of the Mathtastic app during lessons. The findings indicate a high level of reliability, as the questionnaire achieved a Cronbach's Alpha of 0.98, with the three constructs recording values of 0.95, 0.94, and 0.91, respectively. These results confirm the questionnaire's reliability.

Alongside the post-test, some students were asked to respond to several open-ended questions in addition to the quantitative research instruments. After class, the participating students were also interviewed in person by the researchers. For the experimental group, the post-test included five open-ended questions:

1. Which part of the lesson did you enjoy the most?
2. How do you think the Mathtastic app features could improve this unit?
3. What limitations do you see in the Mathtastic app used in this unit?
4. What benefits does using the Mathtastic app offer compared to traditional teaching methods in a mathematics lesson?
5. What benefits do traditional teaching methods (without the Mathtastic app) provide for learning mathematics?

These questions supplemented the questionnaire, aiming to better understand students' perspectives on using the Mathtastic app in the classroom. Following the lessons, four students were randomly chosen for in-depth interviews about their impressions and feelings regarding the Mathtastic app instruction. The interviews covered topics such as:

1. How does using the Mathtastic app in the classroom differ from traditional approaches?
2. What mathematical knowledge did you gain from the Mathtastic app?

Procedures

The intervention was conducted over 4 weeks, with two mathematics sessions per week. The stages of the intervention were as follows: Pretest Phase. Both groups completed the Mathematical Reasoning Test and participated in a collaborative task to establish baseline data. Instructional Phase. The experimental group engaged in Problem-Based Learning cycles supported by the Mathtastic app, where students worked collaboratively to solve contextual problems and reinforce learning through the app's interactive exercises. The control group received conventional mathematics instruction, consisting of lectures, individual worksheets, and textbook-based practice without the use of technology. Posttest Phase. After the intervention, both groups completed the same reasoning test and collaboration activity. Observation data, in-depth interviews, and student feedback were also collected.

Analysis plan

Quantitative data were analyzed using SPSS software. The analysis included: Descriptive statistics (mean, standard deviation) to describe students' reasoning and collaboration scores. Independent sample t-tests to compare the posttest scores between the experimental and control groups. Paired sample t-tests to measure improvements within each group from pretest to posttest. Effect size (Cohen's d) to determine the magnitude of the intervention's impact (Gay & Mills, 2012). Significance was tested at $p<0.05$, and qualitative observations were analyzed thematically to support the quantitative findings.

RESULTS AND DISCUSSION

Results

The Descriptive Statistics

To assess the effectiveness of the integration of PBL and the Mathtastic app descriptive statistics were first calculated for both the mathematical reasoning and collaboration scores in the pretest and posttest for both groups. It is shown in Table 1.

Table 1. Statistical Description of The Study

Group	Test	Mean (M)	Standard Deviation (SD)
Experimental	Pretest	65.47	8.32
Experimental	Posttest	82.90	6.78
Control	Pretest	64.82	7.95
Control	Posttest	71.30	7.44

The results show that both groups improved after the intervention, but the experimental group had a substantially greater increase in both reasoning and collaboration performance.

Analysing Mathematical Reasoning in Experimental and Control Groups – RQ1

Inferential analyses were conducted to determine whether the observed differences were statistically significant. The posttest scores between the experimental and control groups were compared using an independent sample t-test, as shown in Table 2.

Table 2. Statistical t-Test for Mathematical Reasoning

Test	Mathematical reasoning
Mann-Whitney U	121.500
Wilcoxon W	527.500
Z	-4.477
Asymp. Sig. (2-tailed)	.000

To assess the effect of the Mathtastic app, the post-test scores from both groups were analyzed using analysis of covariance (ANCOVA). Student mathematical reasoning was determined by comparing pre-test and post-test results, representing the influence of the independent variables and covariates before and after the Mathtastic app implementation. As shown in Table 3, ANCOVA results ($F = 35.53$, $p < 0.01$, $\eta^2 = 0.36$) reveal that the experimental group scored significantly higher on the post-test than the control group. These findings indicate that using the Mathtastic app-based PBL tools greatly improved students' retention of course material. Moreover, the performance gap between the two groups widened after the lessons, with the experimental group outperforming the control group. Overall, the results validate Hypothesis 1.

Table 3. ANCOVA Results for the Pre-Test and Post-Test in the Experimental Design

		Univariate ANCOVA			
Group	N	Adjusted Mean	Standard Error	F	eta^2
Experimental Group	30	86.63	.78	35.53*	.36
Control Group	30	83.53	.71		

Analysing Collaboration Skills in Experimental and Control Groups – RQ2

This result indicates a statistically significant difference between the groups, with the experimental group outperforming the control group in mathematical reasoning. Similarly, collaboration scores were analyzed in Table 4.

Table 4. Statistical t-Test for Collaboration Skills

Test	Mathematical reasoning
Mann-Whitney U	141.740
Wilcoxon W	52.460
Z	5.527
Asymp. Sig. (2-tailed)	.000

This also indicates a significant improvement in collaboration among students in the experimental group compared to the control group. Table 5 presents the within-group analyses showed the following.

Table 5. Statistical Sample t-Test within Group

Group	Test	t-Value	Sig. Value
Experimental	Mathematical Reasoning	9.21	.000
Experimental	Collaboration Skills	8.65	.000
Control	Mathematical Reasoning	4.17	.000
Control	Collaboration Skills	3.75	.000

Although both groups improved, the experimental group showed greater gains with stronger effect sizes. Table 6 presents the effect size of the sample.

Table 6. Effect Size of Sample

Test	Effect Value (d)
Mathematical Reasoning	1.25
Collaboration Skills	.1.09

Subsequently, these large effect sizes suggest that the integration of PBL and the Mathtastic app had a strong positive impact on both outcomes.

Analysing Statistics of the Mathtastic App-based Questionnaire – RQ3

All 30 students in the experimental group completed the "Collaboration Skills Rubric", with the descriptive statistics presented in Table 7. The highest-rated statement, averaging 4.05, was "Mathematical learning with The Mathtastic app is fun for me," indicating that students see potential for applying The Mathtastic app concepts beyond mathematics. The statement "The content is an intriguing subject, and I find that it is directly related to the content of these applications" also received a high mean score, reinforcing this perspective. In mathematics education, the strong average for the item "These Mathtastic app-based applications can help me discover new problems and questions" suggests that the technology supports students in identifying new areas for exploration. The Mathtastic app was also viewed as a valuable tool for enhancing problem-solving lessons in mathematics classrooms. As all items scored above 3.00, the results suggest that students are generally very satisfied with the Mathtastic app.

Table 7. The Average Scores for the 'Contentment' Construct in the Collaboration Skills Rubric

Aspect	Statement	Mean	S.D.
Contribution	I present ideas clearly by drawing on relevant literature related to the project design.	3.52	.85
	I collaborate with my peers to develop the concept for the illustration or initial design of the product to be created.	3.64	.89
	I seek feedback or opinions about the illustration or initial design of the product to be created.	3.87	.95
Time Management	I understand the group assignments and ensure that collecting literature does not delay the group's work time	3.89	.92
	I attentively listen when my friend shares their opinion about the illustration or initial design of the product to be developed.	3.95	1.01
	I ask for input or suggestions regarding the illustration or early design of the product to be developed.	3.94	1.02
Research Techniques	I thoroughly document information from multiple sources, including books and the internet, related to the project design.	3.57	.95
	I assist in explaining or clarifying my friend's opinion regarding the illustration or initial product design.	3.85	.99
	I feel at ease when collaborating with friends to discuss the initial design of the product to be created.	3.59	.94

The Qualitative Observation Summary

Observational data supported the quantitative findings. Students in the experimental group displayed: Higher engagement and participation in problem-solving discussions. More frequent and meaningful peer collaboration. Increased confidence in explaining mathematical reasoning during group tasks.

The Summary of Semi-Structured Interviews

The experimental group comprised 30 students, all of whom responded openly and honestly to the five open-ended questions. In the first question, students were asked to identify the most enjoyable aspect of the unit. All participants, except one who declined to take part, engaged in the

"Do Now" activities using the Mathtastic app. The majority indicated that the Mathtastic app was the most enjoyable element of the course.

The second and third questions prompted students to evaluate the advantages and disadvantages of integrating the Mathtastic app into lessons. Survey results showed that 84% regarded the Mathtastic app as an engaging and enjoyable learning tool, 68% viewed it as an effective method for PBL, and 52% believed it increased their collaboration skills to study. However, 40% of teachers noted that some students became distracted, daydreaming, or focusing on their phones rather than the lesson.

The fourth and fifth questions encouraged students to reflect on the strengths and weaknesses of traditional mathematics teaching methods. Among the respondents, 38% felt that conventional approaches improved exam performance. This perception may stem from the heavy emphasis on test preparation, leading some students to believe that traditional methods better prepare them for examinations. At the same time, all students agreed that traditional mathematics classes were dull and overly rigid.

Students' Perspectives on the Mathtastic App.

In this study, four students from the experimental group were randomly selected to share their perceptions and feelings about the Mathtastic app-based instruction. When asked, "What is your perception of the difference between traditional mathematics classes and the use of the Mathtastic app technology in modern teaching?", one student responded:

"Using the Mathtastic app in the classroom promotes active participation instead of passively watching the teacher complete tasks. This approach helps students better grasp abstract mathematical concepts, as less time is spent on manual data recording and curve plotting."

Another student remarked:

"The software enhanced the clarity of the study's results by automatically generating an empirical concept. With the Mathtastic app, students could obtain the required knowledge in a fraction of the time compared to traditional methods."

Students also noted that connecting sample spaces to real-world applications deepened their understanding of the underlying theoretical concepts. One interviewee, reflecting on the mathematical insights gained from the Mathtastic app, explained that it was instrumental in helping him comprehend probability in its abstract form. This led him to appreciate the connection between theoretical and practical probability more fully, enabling him to produce fresh and impressive examples using the abstract concept of sample spaces.

When interviewed, the class's original mathematics teacher commented:

"The immediate collection of data from all students and the real-time graphical display of empirical knowledge on the instructional screen enhanced the outcomes, making them more engaging and easier to understand. This fostered greater enthusiasm and curiosity for the Mathtastic app-based PBL lessons compared to traditional mathematics classes."

The Problem-based Learning Processes

The learning activity begins with the teacher presenting a real-world problem that is meaningful and relevant to the students' everyday experiences. For example, students are asked to design a lunch menu for a school canteen, where ingredients must be divided using fractions and measurements, ensuring nutritional balance and fair portions. This initial phase of PBL encourages curiosity and critical thinking as students identify what the problem requires, what they already know, and what mathematical concepts might help them solve it. This setup lays the foundation for developing reasoning and collaborative problem-solving skills.

Students are grouped heterogeneously to encourage peer interaction and diverse perspectives. Each group begins to explore possible solutions by discussing strategies, estimating quantities, and representing fractional values using diagrams or manipulatives. During this process, the Mathtastic App is introduced to support student learning, as shown in Figure 2. This app provides interactive games and tasks specifically designed for primary-level mathematics, including modules on fractions, measurements, and visual problem-solving. Students use the app to test their fractional calculations, check for accuracy, and visualize how portions can be divided or combined, thus reinforcing mathematical reasoning dynamically and engagingly. Figure 3 shows the Mathtastic app's content.

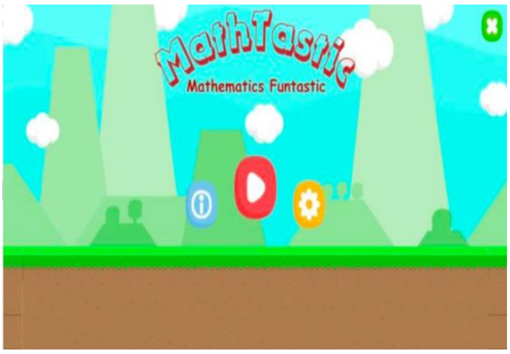

Figure 2. The Mathtastic app's Layout

As the investigation continues, students record their thinking, explain their choices, and adjust their strategies based on app feedback or group discussion. Through these interactions, they develop their ability to construct logical arguments and justify solutions. The collaborative nature of the activity also strengthens communication and teamwork, as students share tasks, challenge each other's ideas, and work together toward a common goal. The teacher acts as a facilitator, guiding inquiry with open-ended questions and encouraging each group to reflect on their thought processes and dynamics. Figure 4 shows students' activity in the Mathtastic app.

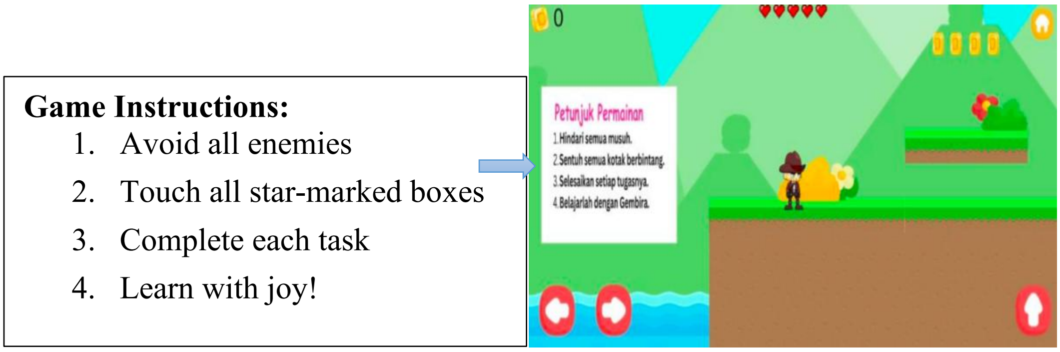

Figure 3. The Mathtastic app's Content

Each group presents their solution to the class, explaining how they used mathematics to make decisions, how they distributed portions, and how the app supported their design. Peers are invited to ask questions or offer feedback, promoting mathematical discourse and critical reflection. This stage of presentation and discussion validates the reasoning behind each solution and enhances students' confidence and collaborative communication skills. The teacher provides feedback on both the mathematical soundness of their work and the effectiveness of their teamwork.

Finally, the activity concludes with a reflection session in which students assess their contributions, how well they worked as a team, and how the Mathtastic App influenced their understanding of the topic. Students also reflect on their reasoning strategies and how they might improve in future problem-solving situations. This comprehensive learning activity illustrates how integrating PBL and the Mathtastic App can significantly enhance students' mathematical reasoning and collaboration, creating a student-centered, interactive, and reflective learning environment in primary mathematics education.

Figure 4. The Mathtastic app Support in Students' Learning

Discussion

The results of this study provide strong evidence that integrating Problem-Based Learning (PBL) with the Mathtastic application significantly enhances both mathematical reasoning and collaboration skills among primary school students. The experimental group, which experienced the PBL Mathtastic approach, demonstrated notably greater gains in posttest scores compared to the control group, which received traditional instruction. These findings align with previous research indicating that student-centered and technology-supported learning environments foster deeper cognitive engagement and interpersonal development (Ulya et al., 2024; Wong & Wong, 2021).

From a cognitive standpoint, the improvement in mathematical reasoning can be attributed to the PBL model's emphasis on inquiry, critical thinking, and contextual problem-solving. By confronting real-world problems, students were encouraged to analyze, synthesize, and justify their mathematical ideas—core elements of higher-order reasoning (Harris et al., 2020; Nisfah et al., 2022). The integration of the Mathtastic app further amplified this process by offering immediate feedback, visual supports, and interactive tasks that reinforced conceptual understanding in a dynamic and engaging format.

In terms of collaboration, the structured PBL framework provided students with continuous opportunities to work in teams, negotiate meaning, and share responsibilities. The Mathtastic app complemented this by facilitating cooperative engagement, where students could explore math challenges together, either in pairs or small groups. This synergy between digital tools and collaborative learning mirrors the findings of Vygotsky's sociocultural theory, which underscores the importance of peer interaction in cognitive development (Vygotsky, 1999).

The statistically significant differences and large effect sizes observed in this study suggest that the combined instructional approach is more than a sum of its parts. While PBL alone is effective in promoting deep learning, the addition of a tailored educational app like Mathtastic provides scaffolding, differentiation, and motivation, three crucial factors for effective primary mathematics instruction. These results also echo studies by Lapek (2020 and Nguyen et al. (2024), which advocate for technology-enhanced, inquiry-driven classrooms in fostering active and meaningful learning. However, Ulya et al. (2024), while the outcomes are promising, implementation challenges must also be acknowledged. Effective integration of PBL and digital tools requires adequate teacher training, sufficient technological infrastructure, and time for collaborative planning. Without these supports, the benefits observed in this controlled study may not be easily replicated in broader classroom contexts (Fita et al., 2021).

A comparison of pre- and post-lesson assessment results between the two groups showed no statistically significant difference in baseline performance. However, ANCOVA analysis indicated that students in the Mathtastic app group, who used the application to learn mathematics, achieved greater learning gains than those in the control group. This finding aligns with previous research

(Devaux et al., 2020; Juuti et al., 2022; Meylani, 2025; Ulya et al., 2024). The quantitative results revealed notable improvements in student learning, while the qualitative findings, derived from open-ended survey responses, highlighted that the Mathtastic app use in the classroom substantially boosted engagement and enthusiasm for mathematics. Most students expressed strong approval of the Mathtastic app, reporting that it enhanced mathematical reasoning, collaborative skills, improved learning efficiency, and made lessons more enjoyable. Feedback from in-person interviews supported these results. One student noted that the Mathtastic app enabled him to actively explore mathematical relationships, illustrating the technology's potential to increase classroom participation. Several interviewees emphasized the importance of thoroughly understanding concepts. From a constructivist perspective, the Mathtastic app provided opportunities for students to build and strengthen their knowledge (Meylani, 2025).

Implications

The results of this study demonstrate that integrating PBL with the Mathtastic App can significantly improve mathematical reasoning and collaboration skills among primary school students. This finding has strong implications for instructional design and pedagogy in mathematics education. The combination of technology and student-centered learning provides an engaging environment that encourages learners to think critically, work together, and solve real-world problems. Educators and curriculum developers can leverage this approach to create more interactive and meaningful learning experiences. Additionally, the study reinforces the importance of equipping teachers with the necessary training and resources to implement digital tools effectively within PBL frameworks.

Limitations

Despite the promising results, several limitations must be considered. The study was conducted within a limited time frame and involved a relatively small sample size, which may affect the generalizability of the findings. Variability in students' access to technology, as well as differences in teacher expertise and comfort with digital tools, may also have influenced the outcomes. Furthermore, the study focused primarily on cognitive and collaborative aspects of learning, without examining other important factors such as student motivation, engagement, or long-term academic achievement. These limitations highlight the need for caution in interpreting the results and suggest areas for further investigation.

Suggestions

Future research should aim to address these limitations by including larger and more diverse samples, extending the duration of the intervention, and exploring additional learning outcomes beyond reasoning and collaboration. Longitudinal studies would help determine the sustained impact of integrating apps like Mathtastic within PBL environments. It would also be beneficial to incorporate mixed-methods approaches, combining quantitative data with qualitative insights from students and teachers, to gain a deeper understanding of how technology-enhanced PBL affects the learning process. Moreover, involving stakeholders in the development and refinement of educational apps can ensure better alignment with learners' needs and curriculum standards.

CONCLUSION

This study concludes that the integration of PBL and the Mathtastic application is an effective instructional strategy for improving mathematical reasoning and collaborative skills among primary school students. The experimental results demonstrated significant differences between students who participated in the PBL–Mathtastic learning environment and those who received traditional instruction. Learners in the experimental group showed higher levels of engagement, deeper understanding of mathematical concepts, and more effective teamwork during problem-solving tasks. These findings support the idea of Meylani (2025) that combining inquiry-based pedagogy with interactive digital tools creates a more dynamic and student-centered learning environment. The synergy between PBL's focus on critical thinking and the Mathtastic app's gamified features helped students actively construct knowledge while working together. The approach not only enhanced academic achievement but also cultivated essential 21st-century skills such as communication, cooperation, and independent thinking (Fadel, 2021).

In light of these outcomes, educators are encouraged to adopt integrated teaching models that promote both cognitive and social development (Özgelen, 2021). This research also opens avenues for further studies exploring the scalability, long-term impact, and adaptation of similar models across different educational levels and learning contexts.

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AUTHOR CONTRIBUTIONS STATEMENT

W.N.Y: Literature review, conceptualization, and writing the manuscript.
S.P.D: methodology, data analysis.
S.A. and A.J.: review-editing and writing, original manuscript preparation.
M.F.: review-editing and writing.

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