

# Designing Minecraft-Supported Project Learning for Meaningful Elementary Mathematics Experiences

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## Abstract

Despite the increasing integration of digital technologies in elementary education, meaningful models for mathematics learning remain limited. Persistent dependence on procedural, teacher-centered instruction often inhibits students' conceptual understanding and engagement, despite a generation shift toward interactive and technology-enabled learning environments. The purpose of this study was to propose a context-sensitive Minecraft-supported Project-Based Learning (PjBL) framework using the knowledge gained from projects about the learning experiences of mathematics education in elementary schools. Employing an exploratory design study approach, the research synthesizes data from student questionnaires, teacher questionnaires, and classroom observations to identify conceptual difficulties, learning preferences, pedagogical capacities, and contextual constraints. The findings reveal a clear misalignment between students' needs and prevailing instructional practices, as well as limited structured integration of digital media. In response, the study translates empirical classroom evidence into explicit design principles and an instructional storyboard that systematically aligns conceptual goals, collaborative activities, and digital affordances. The study concludes that effective integration of Minecraft-supported PjBL depends not merely on technological adoption but on transparent, contextually grounded instructional design. The implications highlight the importance of evidence-informed design processes to bridge educational technology research and everyday classroom practice in elementary mathematics.

**Keywords:** elementary mathematics, instructional design, Minecraft, project-based learning

## 1. Introduction

As elementary education strives to integrate 21st-century skills, mathematics learning remains dominated by procedural and teacher-focused approaches, which limit student engagement and conceptual understanding and make it difficult to connect concepts to real-world contexts (Putrawangsa & Hasanah, 2020; Bednorz & Bruhn, 2023). Although digital technologies have the potential to enhance engagement, self-directed learning, and contextual understanding, their implementation in mathematics learning has been inconsistent due to limited teacher training, institutional support, and resources, particularly in developing countries (Darmayanti & Sugianto, 2018; Timotheou et al., 2022). At the same time, empirical evidence suggests that pedagogically designed integration of information and communication technologies, including game-based learning and collaborative digital projects that can create more interactive learning environments and support the development of critical thinking and problem-solving skills in mathematics, provides educators with adequate digital literacy and pedagogical competencies (Saal et al., 2019; Khaldi et al., 2023; Harini et al., 2024).

Project-Based Learning (PjBL) represents a highly effective pedagogical strategy for promoting meaningful learning through active problem-solving, collaboration, and exploration. It engages students directly in real-world projects, which helps them better understand their mathematical concepts and also develops critical thinking and problem-solving skills (Huang et al., 2023; Anagnostou et al., 2022). Such an experiential approach develops teamwork spirit and encourages students to be independent when it comes to finding solutions for complex problems, especially if supported with the integration of digital media, which provides a dynamic and interactive learning environment. For example, game-based environments provide opportunities for experiential learning through simulations and role-playing to help students develop a deeper conceptual understanding (Zhyhadlo, 2022; Harikrishnan et al., 2019). Among various digital media, Minecraft is distinguished as an effective platform for visualizing and contextualizing mathematical

concepts through virtual design and collaborative projects, thus bridging the gap between abstract concepts and real-world learning experiences. Through activities such as manipulating shapes, geometric construction, and solving spatial problems in a simulated environment, students acquire a more practical understanding while maintaining motivation and engagement in learning. This makes the integration of PjBL and digital media, particularly Minecraft, a potentially transformative approach in mathematics education and the development of 21st-century competencies (Harikrishnan et al., 2019; Gibson, 2020).

Extensive research on Minecraft and PjBL predominantly emphasizes measurable learning outcomes, such as academic achievement, motivation, and higher-order thinking skills, while the instructional design process is often treated as a "black box" and seldom systematically documented (Ferrero et al., 2021; Loyens et al., 2023; Chistyakov et al., 2023). Systematic reviews and meta-analyses reveal that the evidence of effectiveness reported is frequently inconclusive or highly heterogeneous, affected by methodological weaknesses such as the employment of unvalidated instruments, a high risk of bias, and the absence of adequate comparison conditions (Slattery et al., 2023; Wijnia et al., 2024). Moreover, numerous studies proceed directly to the implementation phase without a theory-based description of how the instructional design was developed, refined, and contextualized within authentic classroom practices, complicating the assessment of alignment with core PjBL principles and opportunities for replication and adaptation (Huang et al., 2023; Yue et al., 2022). However, researchers often describe key design dimensions in general or superficial terms (Slattery et al., 2025; Khaldi et al., 2023). Consequently, despite the plethora of claims regarding the benefits of Minecraft and PjBL, the literature continues to exhibit limited design transparency, particularly in studies that integrate student and teacher perspectives, employ classroom observations, and translate empirical classroom data into explicit instructional design artifacts, such as storyboards, in elementary school mathematics contexts.

In response to the limited design transparency identified in previous research, this study intentionally shifts the focus from effectiveness evaluation to an exploratory design investigation grounded in an authentic classroom context. Rather than treating Minecraft-supported PjBL as a predetermined intervention, this study integrates multiple sources of classroom evidence along with the initial phases of an instructional design model to systematically inform design decisions (Chistyakov et al., 2023; Ferrero et al., 2021). The novelty of this study lies in its emphasis on classroom-informed design, providing a transparent account of how empirical classroom data was translated into instructional storyboards for Minecraft-supported PjBL in elementary mathematics. By producing explicit storyboards and articulating design principles tailored to the realities of elementary mathematics classrooms, this study bridges a critical gap between educational technology research and everyday teaching practice, which is often lacking a connection in outcome-oriented studies (McKay et al., 2022). Therefore, the purpose of this study is to identify students' and teachers' learning needs as a basis for designing Minecraft-supported PjBL storyboards for elementary school mathematics. Specifically, this study aims to (1) examine students' learning needs related to mathematics, digital media use, and project-based activities; (2) explore teachers' pedagogical challenges and expectations related to Minecraft-supported PjBL; (3) document classroom practices to capture contextual features of mathematics instruction, student engagement, and media use; and (4) synthesize questionnaire, interview, and observation data into concrete design specifications and learning storyboards to support meaningful mathematics learning experiences in elementary school.

## 2. Literature Review

### 2.1 *Digital PjBL in Elementary School Mathematics: What Have You Learned?*

"Digital PjBL" is a term widely used in educational technology research, particularly in elementary mathematics, because of its ability to promote mathematical literacy and engagement in collaborative problem-solving. In fact, research consistently shows that PjBL in combination with digital media invites students to engage in authentic, relevant experiences that promote conceptual understanding and the development of 21st-century skills. Engaging students through a wide range of technological tools, such as virtual mathematics kits, is shown to be an effective way of improving classroom-oriented mathematical literacy (Pradana et al., 2020). It can enable them to master the content in new and exciting ways when integrated into a classroom PjBL experience. In the wider context, literature states that digitally supported PjBL fosters exploration, teamwork, and applied use of mathematical concepts in real-world problems, thus making learning more authentic rather than just a procedural fulfillment (Ramadhan et al., 2022; Suwanto et al., 2022). These implications suggest that digital PjBL may serve as a viable pedagogical approach for fostering meaningful, contextualized, and student-centered mathematics learning in elementary education.

Despite these positive results, important aspects of implementation remain under-researched. Most existing research prioritizes student performance and engagement while paying limited attention to how digital project learning is implemented across classroom contexts, particularly regarding instructional strategies, teacher preparedness, and contextual constraints. Studies outside of mathematics education indicate that educators' beliefs about digital media

significantly shape their teaching practices, yet these perspectives are rarely highlighted in research on digital PjBL in mathematics (Strouse et al., 2024). Furthermore, issues of digital equity, access, and continuing professional development are often underrepresented, despite their significant impact on the feasibility and inclusivity of digital project learning, particularly for students from marginalized backgrounds or with varying levels of digital literacy (Böttinger et al., 2023). Consequently, while the effectiveness of digital project learning tools has been well documented, the field lacks systematic and context-sensitive analysis of how instructional designs can be developed to accommodate teacher preparedness, student diversity, and socioeconomic conditions.

### *2.2 Minecraft in Education as a Virtual Learning Media Innovation*

Recent research indicates that Minecraft holds significant promise in elementary education, particularly in the domain of mathematics. Its interactive and open-ended environment enhances student engagement, fosters collaboration, and aids in the visualization of complex mathematical concepts (Alawajee & Delafield-Butt, 2021; Lamont et al., 2021). Minecraft's sandbox nature allows students to learn, create, and solve problems together, making learning experiences more meaningful and context-rich. Furthermore, researchers demonstrated that the empirical findings of design activities conducted virtually, along with collaborative work in Minecraft, helped students understand geometry, algebraic knowledge, and spatial reasoning while improving crucial skills for the 21st century such as communication and collaboration (Panja & Berge, 2021; Shuhaimi et al., 2023). This highlights the importance of Minecraft as a potential tool in shifting abstract mathematical concepts to tangible learning experiences.

However, a closer analysis of the literature uncovers some methodological shortcomings and poor design openness across many studies using Minecraft in educational settings. In many cases, however, Minecraft is simply used as a remedy instead of being integrated into a systematically designed curriculum based on explicit pedagogical foundations (Bösze & Devosa, 2021; Hewett et al., 2020). Several studies mentioned very little about the learning activities' design, mediation of the teacher role, or classroom context influencing implementation, making it difficult to replicate and adapt into practices (Nkadimeng & Ankiewicz, 2022; Guttormsen, 2024; Zuhri et al., 2024). Moreover, teachers and students are often left out as co-designers (whether formally or practically), while student experience is so frequently reduced to numerical proxies like grades or survey-score measures that mask the variety of learning experiences behind these numbers, failing to understand how participation dynamics play out among actors in collaborative projects (Ritella & Marcone, 2024; Slattery et al., 2025). These shortcomings emphasize the necessity of a more participatory and transparent approach to design that invites educators and students to engage in the purpose, goals, methods, and process of the design. An approach like this one would ensure that the integration of Minecraft in mathematics education corresponds to a reality of the classroom and is viable for facilitating inclusive and meaningful learning experiences (Edwards et al., 2021; Sordi & Alia, 2023).

### *2.3 Theoretical Framework: Minecraft Integration into PjBL*

This theoretical perspective establishes the foundation for implementing digital PjBL in elementary school mathematics instruction, as students realize meaningful learning when they engage in contextualized, collaborative, and problem-solving activities. It is known from the references that PjBL, which is integrated with digital media, supports students' conceptual exploration and collaboration, as well as the real work of using mathematics so that students are accustomed to experiencing learning beyond procedural routines (Pradana et al., 2020; Strouse et al., 2024). Here, technology is both a tool and a part of the learning environment that enables interaction with cognitive and social elements. The success of this approach may be associated with the quality and contextualization of learning design as well as a teacher's readiness to use (and students' ability to leverage) digital media through aligned learning objectives and project activities (Böttinger et al., 2023; McKay et al., 2022). As a result, the theoretical digital project learning framework takes classroom context-based instructional design as the chief mediator for how technology use unfolds to produce mathematically courageous learning experiences.

In this context, Minecraft is conceptualized as a virtual learning medium that aligns closely with the principles of digital PjBL. Its open sandbox environment facilitates knowledge construction through exploration, design, and collaboration, while also enabling the visualization of abstract mathematical concepts, such as geometry, algebra, and spatial reasoning (Alawajee & Delafield-Butt, 2021; Guttormsen, 2024). However, the literature indicates that Minecraft's pedagogical potential is not inherently realized, as numerous studies continue to treat the platform as a technological intervention distinct from a systematic and participatory learning design framework (Bösze & Devosa, 2021; Hewett et al., 2020). The insufficient involvement of teachers as co-designers and the limited representation of student experiences highlight a disconnect between technological innovation and actual classroom practice (Ritella & Marcone, 2024; Sauri et al., 2022). Consequently, the theoretical framework of this study underscores the integration of digital PjBL and Minecraft through a transparent and data-driven classroom design approach, wherein the perspectives of teachers, students, and learning contexts serve as the primary foundations for developing storyboards and design

principles for elementary school mathematics education. Figure 1 illustrates the conceptual framework underlying the development of Minecraft-supported PjBL, showing how multiple sources of classroom data inform the derivation of design principles and instructional storyboards.

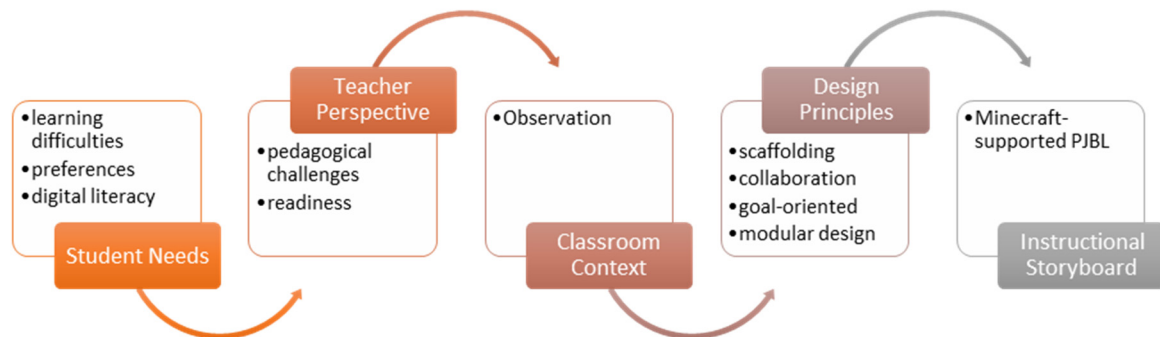


Figure 1. Conceptual Frameworks

### 3. Method

#### 3.1 Research Design

This study employs a mixed-methods exploratory approach, with a qualitative emphasis, to ascertain the learning needs of students and teachers as a foundation for developing a storyboard for Minecraft PjBL-based educational media (Creswell & Clark, 2011). This methodological choice was made because the study's focus is not on assessing effectiveness, but rather on exploring the classroom context, learning experiences, and pedagogical challenges that inform the learning design. Conceptually, this research represents the needs analysis and initial design phases within a design-based research framework, wherein empirical data is utilized to guide instructional design decisions prior to the implementation and evaluation stages (Rachmadtullah et al., 2023). In this design, quantitative data were first collected through student and teacher questionnaires to identify general patterns related to mathematics learning difficulties, digital literacy, learning preferences, and pedagogical challenges. Subsequently, qualitative data were gathered through semi-structured teacher interviews and classroom observations to better understand the contextual conditions, instructional practices, and implementation constraints. The integration of quantitative and qualitative data facilitates the identification of general trends as well as a comprehensive understanding of mathematics learning practices in elementary schools.

#### 3.2 Research Subject

The research subjects consisted of 186 elementary school students and 7 elementary school mathematics teachers selected using purposive sampling, taking into account the representativeness of the school context and readiness for digital learning integration. Students were involved to represent their mathematics learning experiences and interactions with digital media, while teachers served as key informants regarding learning practices, obstacles to PjBL implementation, and the suitability of the learning design with the curriculum (Bostley & Peters, 2023). The simultaneous involvement of these two groups enabled the triangulation of perspectives between learning experiences and teaching practices in the storyboard design process.

#### 3.3 Data Collection Techniques and Research Instruments

Research data was collected through three techniques: a student questionnaire, a critical thinking skills questionnaire, and learning observations. The student questionnaire consisted of closed-ended items measured using a four-point Likert scale (1 = strongly disagree to 4 = strongly agree), capturing dimensions such as learning difficulties, interest in mathematics, digital literacy, and preferences for project-based and game-based learning. Teacher questionnaire items were measured using a five-point Likert scale to assess pedagogical challenges, experience with PjBL, and readiness for digital integration. Non-participatory observations were conducted using structured sheets to gather data on learning methods, student engagement, barriers, and preferences for technology use (Taja et al., 2021). Classroom observations were conducted across three elementary schools, involving six mathematics classrooms. Each classroom was observed during two instructional sessions, with an average duration of 60 minutes per session, resulting in a total observation time of approximately 12 hours. The observations focused on mathematics learning activities, particularly instructional methods, student engagement, and opportunities for integrating digital media and PjBL. All observations were carried out using structured observation sheets to ensure consistency in data recording across different classroom contexts. These techniques were used to identify gaps between learning conditions and needs for developing Minecraft PjBL designs.

Table 1. Grid of Data Collection Techniques and Instruments

| Techniques                   | Data Focus                                                                                                                                                              | Instrument Format            |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| Learning Needs Questionnaire | Mathematics learning difficulties, interest and engagement, digital literacy, and project-based and collaborative learning preferences                                  | Likert Scale (4 levels)      |
| Learning Observation         | Learning method patterns (teacher-centered/drilling), student engagement, cognitive and affective barriers, opportunities for technology integration, and collaboration | Structured observation sheet |

### 3.4 Validity and Reliability of Instruments

The questionnaire instrument underwent a content validation process through expert assessment in the field of mathematics education and learning technology to ensure the suitability of the indicators with the measured constructs, including aspects of learning difficulties, digital literacy, learning preferences, and critical thinking skills based on the Facione framework. The validation results showed that all items were in the valid category, with Content Validity Index (CVI) values ranging from 0.83–1.00. Reliability testing using Cronbach's alpha showed excellent internal consistency, so the instrument was declared suitable for use in data collection on a sample of students ( $n = 186$ ). The validity of observational data was maintained through the use of structured indicators and systematic recording to ensure consistency of field findings (Abdul Raof & Musta'amal, 2021).

### 3.5 Data Analysis Techniques

Quantitative data obtained from the questionnaire were analyzed using descriptive statistics, including percentages, means, and standard deviations, to map the level of learning difficulties, mathematics interest, digital literacy, learning method preferences, and achievement of students' critical thinking skills indicators (Mustafa, 2020). The analysis results were used to identify learning gaps and critical thinking ability profiles as a basis for developing learning design specifications. Observation data were analyzed descriptively to identify dominant learning patterns, cognitive and affective barriers, and opportunities for integrating PjBL and digital media. All findings were then synthesized to formulate contextual and realistic learning design needs.

## 4. Results

### 4.1 Students' Learning Needs in Elementary Mathematics

To identify students' learning needs in elementary mathematics, a descriptive analysis was conducted on questionnaire responses from 186 students. The analysis focused on three aspects: (1) perceived learning difficulties and interest in mathematics, (2) digital literacy and attitudes toward game-based learning, and (3) preferred learning methods. The findings provide an overview of learning conditions and highlight patterns between current classroom practices and students' learning expectations. For learning difficulties and interest, most students reported challenges in mathematics, with 38.71% experiencing difficulties regularly. Additionally, 26.35% of students expressed low to very low interest in mathematics. Regarding digital literacy, most students reported familiarity with game-based environments (90.86%) and believed virtual project activities, such as those using platforms like Minecraft, could support conceptual understanding (86.03%). However, students' learning experiences were largely characterized by passive participation in teacher explanations, and only 38.7% reported enjoying self-discovery-based challenges. These descriptive patterns are summarized in Table 2.

Table 2. Analysis of Mathematics Learning Needs and Gaps

| Aspect                     | Key Data Findings                                                                                                                                          | Implications and Gaps                                                                                                                 |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Difficulties and Interests | 38.71% of students reported experiencing difficulties quite often. 26.35% of students reported little to no interest in mathematics.                       | Media that can reduce the abstraction of material (especially geometry) to make it more concrete are needed.                          |
| Digital Literacy           | 90.86% of students were accustomed to using games to learn. 86.03% believed virtual projects (such as Minecraft) could help with conceptual understanding. | There is significant potential for utilizing game-based learning technology, which has not been systematically integrated in schools. |
| Learning Methods           | Students tended to follow teacher explanations passively; only 38.7% enjoyed the challenge of independent discovery.                                       | Learning is one-way, limiting students' exploration and critical thinking.                                                            |

### 4.2 Teachers' Perspectives on Mathematics Instruction and Digital Project Learning

This subsection addresses the second research question by integrating data from teacher questionnaires ( $N=7$ ) and semi-structured interviews to capture pedagogical challenges, experiences with PjBL, and expectations regarding Minecraft-supported instruction. The combined analysis provides quantitative patterns and contextual depth regarding teachers' readiness and needs for innovative instructional design. The teacher questionnaire was used to provide indicative insights into teachers' perspectives on mathematics instruction, PjBL, and digital media integration. Given the small sample size ( $n = 7$ ), the questionnaire data are presented descriptively to complement qualitative findings rather than to support statistical generalization.

Table 3. Descriptive Statistics of Teachers' Perspectives

| Indicator                                                              | Mean | SD   | (Agree/Strongly Agree %) |
|------------------------------------------------------------------------|------|------|--------------------------|
| Challenges in Mathematics Instruction                                  |      |      |                          |
| Students struggle to connect abstract concepts to real-world contexts. | 4.57 | 0.53 | 100.0%                   |
| Maintaining student engagement during math lessons is difficult.       | 4.29 | 0.76 | 85.7%                    |
| Limited availability of contextual learning resources.                 | 4.14 | 0.90 | 85.7%                    |
| Time constraints hinder depth of conceptual exploration.               | 3.86 | 0.90 | 71.4%                    |
| Average                                                                | 4.22 | 0.77 | 85.7%                    |
| Experience with PjBL                                                   |      |      |                          |
| I have implemented PjBL in mathematics.                                | 2.43 | 1.13 | 28.6%                    |
| I feel confident designing PJBL activities for mathematics.            | 2.71 | 0.95 | 28.6%                    |
| I have received adequate training on PJBL implementation.              | 2.14 | 1.07 | 14.3%                    |
| School resources support PJBL implementation.                          | 2.29 | 0.95 | 14.3%                    |
| Average                                                                | 2.39 | 1.03 | 21.4%                    |
| Needs for Digital Media Support                                        |      |      |                          |
| Digital media can enhance students' conceptual understanding.          | 4.43 | 0.53 | 100.0%                   |
| I need digital tools that align with curriculum objectives.            | 4.57 | 0.53 | 100.0%                   |
| Interactive platforms can increase student motivation.                 | 4.29 | 0.76 | 85.7%                    |
| I require training to integrate digital media effectively.             | 4.14 | 0.69 | 85.7%                    |
| Average                                                                | 4.36 | 0.63 | 92.9%                    |
| Expectations Toward Minecraft as Learning Media                        |      |      |                          |
| Minecraft can help visualize abstract mathematical concepts.           | 4.00 | 0.82 | 71.4%                    |
| Minecraft supports collaborative problem-solving activities.           | 4.14 | 0.69 | 85.7%                    |
| Minecraft aligns with PjBL principles.                                 | 3.86 | 0.90 | 71.4%                    |
| I am willing to explore Minecraft for mathematics instruction.         | 4.29 | 0.76 | 85.7%                    |
| Average                                                                | 4.07 | 0.79 | 78.6%                    |

Questionnaire responses suggest that teachers commonly experience challenges in contextualizing abstract mathematical concepts and maintaining student engagement. These indicative patterns are supported and further elaborated through qualitative interview findings.

Thematic analysis yielded the following four themes: pedagogical tensions, barriers to PjBL implementation, digital media readiness gaps, and cautious optimism about Minecraft. Especially in geometry, teachers had difficulty illustrating abstract concepts: “When I teach volume or area, students could memorize the formula but did not know what it means in real life” (Teacher 3). This issue comes from textbook-based instruction (e.g., “math as isolated procedures”) with no real-world connection (Teacher 5). Despite benefits, systemic challenges impede PjBL uptake. In a common theme, teachers reported insufficient training (“I’ve never really received proper training on how to design projects specifically for math,” Teacher 2), curricular constraints (“If I spend two weeks designing a project, I worry about getting behind the pace guide,” Teacher 6), and lack of support at the institution level (“Our school does not have clear guidelines ... I feel like I’m experimenting alone here,” Teacher 4). These obstacles reinforce conventional teaching.

Teachers were very confident and opinionated about digital media in their classrooms but admitted they had not built up capacity: “I don’t know which apps are really good for teaching math concepts ... some seem to be more entertainment” (Teacher 1), and “I need more than just equipment—I need training and ready-to-use materials” (Teacher 7). In Minecraft, teachers were cautiously optimistic, understanding its motivational potential (“Students are very enthusiastic...if we can direct that enthusiasm into learning math, it might be a very powerful thing,” Teacher 5), while also underscoring the record-keeping aspect that they need in place (“I need... clear guidance... not just letting them play,” Teacher 5), and classroom management strategies (“How do I make sure they’re actually learning and not building random stuff?” Teacher 3), and practical integration guidance (“Can it be integrated into existing lesson plans, or does it require a completely different approach?” Teacher 6). These attitudes emphasize the necessity of pedagogically transparent instructional design that addresses practical concerns while leveraging Minecraft’s collaborative potential.

#### 4.3 Classroom Practices and Contextual Constraints

To further examine the contextual conditions of mathematics teaching, classroom observations were conducted to document dominant teaching patterns, cognitive and affective barriers, and expressed student learning preferences. This analysis aimed to identify existing teaching practices and potential entry points for integrating a more interactive, digitally supported project-based approach. The findings are summarized in Table 4.

Table 4. Results of Observation of Learning Patterns and Identification of Main Problems

| Observation Dimension            | Observation Result Indicators                                            | Percentage |
|----------------------------------|--------------------------------------------------------------------------|------------|
| Current Learning Methods         | Relying on teacher explanations in front of the class (Teacher-Centered) | 87.1%      |
|                                  | Focusing on solving routine practice problems (drilling)                 | 55.9%      |
|                                  | Lack of practical or hands-on activities                                 | < 7%       |
| Cognitive and Affective Barriers | Considering mathematics material difficult to understand,                | 76.5%      |
|                                  | Lack of opportunities to experiment or be creative                       | 24.0%      |
|                                  | Finding learning boring and irrelevant                                   | 12.0%      |
| Student Needs Preferences        | Desire to use technology/games in learning                               | 64.5%      |
|                                  | Desire to work collaboratively (in groups)                               | 50.5%      |

Observational findings indicate that mathematics learning remains teacher-centered with limited technology integration. Learning sessions predominantly use direct explanations (87.1%) and drilling (55.9%), while hands-on activities are below 7%. Questionnaire data show students experiencing learning difficulties (38.71%) and low interest in mathematics (26.35%), despite high digital literacy and preference for technology use and collaborative learning. These findings informed core design principles for Minecraft-supported PjBL in elementary mathematics, including concrete-to-abstract scaffolding, structured collaborative problem-solving, goal-oriented digital integration, and modular activities for gradual implementation. These principles translate empirical evidence into contextual design specifications for developing learning storyboards.

#### 4.4 Designing Instructional Storyboards Media

Based on various empirical findings obtained through questionnaires and observations during the learning process, a synthesis was conducted to formulate a relevant instructional design pattern. This synthesis was then systematically presented in the form of an instructional storyboard as a visual representation of the flow, activities, and integration of the developed learning components, as depicted in Figure 2.

| Visual                                                                                                                                                                                                                                                                                                                                     | Phase                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     | <p>Exploration &amp; Observation:</p> <p>Student Activity: Read instructional boards containing contextual problems (designing a carrot garden and a livestock pen) in Minecraft. Students must analyze the instructions, identify area boundaries, and understand the assigned geometric parameters.</p> <p>Teacher Activity: Provide prompt questions related to real-world spatial problems.</p> <p>Virtual Construction &amp; Math Practice:</p> <p>Student Activity: Apply calculations to a spatial 3D block shape. If the mathematical calculations are incorrect, the structure will fail to achieve precision, forcing students to revise the design and shape of the building.</p> <p>Teacher Activity: Act as a scaffolder, monitor progress, and provide technical guidance.</p> <p>Presentation:</p> <p>Student Activity: Display their mathematical design results. Articulate solution steps, justify calculation procedures, and argue rationally to defend the design argument before peers.</p> <p>Teacher Activity: Test students' logic with validation questions ("Where did this number come from?").</p> <p>Journal &amp; Group Talk:</p> <p>Student Activities: Complete a reflection sheet, discuss the efficiency of the group's collaborative workflow, identify calculation errors, and formulate improvement strategies.</p> <p>Teacher Activities: Guide the drawing of final conclusions and provide evaluative feedback.</p> |

## 5. Discussion

The findings indicate a clear mismatch between students' learning needs and classroom mathematics learning practices. More than a third of students (38.71%) reported experiencing difficulty understanding the material regularly, and 26.35% were uninterested in mathematics. At the same time, the majority of students demonstrated high digital readiness, with 90.86% accustomed to using games for learning, 64.5% expressing a desire to use technology in learning, and 50.5% favoring collaborative work. However, classroom observations revealed that 87.1% of learning was still dominated by direct teacher explanations, and 55.9% focused on routine exercises, with less than 7% of practical activities. This pattern highlights the limitations of the still-dominant procedural and teacher-centered approach, which tends to limit the development of deep conceptual understanding and connections to real-world contexts (Putrawangsa & Hasanah, 2020; Bednorz & Bruhn, 2023; Zuhri et al., 2024). This gap between students' preferences for active learning and the procedural reality of the classroom aligns with criticisms in the literature that many educational technology initiatives fail to consider the contextual conditions of the classroom, resulting in suboptimal implementation (Bösze & Devosa, 2021; Hewett et al., 2020; Nkadameng & Ankiewicz, 2022).

Overall, the results of this study confirm that the integration of digital project learning is not enough to rely solely on the potential of technology but requires instructional design that is sensitive to students' conceptual needs and aligned with existing classroom practices, reinforcing the urgency of shifting from a merely outcome-oriented approach to a contextual learning design that can be realistically implemented in elementary school mathematics learning (Ferrero et al., 2021; Loyens et al., 2023; Slaterry et al., 2025).

This study enhances design transparency in Minecraft-supported project learning by explicitly demonstrating how

classroom data is translated into concrete design specifications and instructional storyboards, rather than treating interventions as predetermined solutions. Based on student needs (e.g., high conceptual difficulties and preferences for active and technology-based learning) and classroom observation patterns that are still predominantly procedural and teacher-centered, the design process systematically generated core principles embedded in the storyboard structure. These principles include concrete-to-abstract scaffolding to address students' conceptual difficulties, structured collaboration to accommodate group work preferences, digital integration oriented toward learning goals (rather than mere entertainment), and organizing activities into flexible modules to fit within time constraints and class structure. This approach differs from much of the existing Minecraft and PjBL literature, which tends to emphasize learning outcomes while providing limited insight into how instructional design is conceptualized, contextualized, and operationalized in authentic classroom realities (Ferrero et al., 2021; Alawajee & Delafield-Butt, 2021).

By highlighting the translation of classroom evidence into design decisions, this study directly addresses calls for greater transparency and contextual sensitivity in digital PjBL research (Bösze & Devosa, 2021; Hewett et al., 2020). As such, these findings contribute to the design-based research and educational technology literature by shifting the focus from whether Minecraft-supported PjBL works to how instructional design can be systematically formulated to fit the reality of elementary mathematics classrooms, thereby strengthening the link between research evidence and practical instructional design (Slattery et al., 2025; Sauri et al., 2022). The findings of this study offer both theoretical and practical contributions to the literature on digital PjBL in elementary mathematics. Theoretically, this study asserts that instructional design serves as an epistemological mediator between technology and learning, where the educational value of a technology is not inherent in the tool itself but is constructed through design decisions responsive to classroom evidence. By demonstrating how data on student needs, including conceptual difficulties, collaborative preferences, digital literacy, and predominantly procedural learning patterns, are translated into concrete design principles, this study extends the design-based research literature by illustrating how design knowledge can be systematically generated from contextual classroom analysis. This approach directly addresses criticisms of technology interventions being treated as “black boxes” by making the conceptualization and operationalization of design transparent (Sauri et al., 2022; Loyens et al., 2023). Practically, the learning storyboards developed in this study serve as pedagogical artifacts that help elementary mathematics teachers plan and implement Minecraft-supported PjBL in a structured manner, aligning digital activities, students' conceptual needs, and the realities of classroom time and organization.

Despite these contributions, this study is limited by its focus on the design stage and a specific educational context, without examining implementation fidelity or learning outcomes. Therefore, future research should expand on this work through iterative implementation, classroom-based evaluation, and design refinement across multiple contexts to further examine how Minecraft-supported project learning can be sustainably integrated into elementary mathematics instruction (Nkadameng & Ankiewicz, 2022; Wijnia et al., 2024). Overall, this study underscores that the educational value of Minecraft-supported project learning lies not in the technology itself, but in the transparency and contextual grounding of the instructional design, which allows digital innovations to be meaningfully aligned with classroom realities in elementary mathematics.

## 6. Conclusion and Suggestions

This study concludes that the integration of Minecraft-supported PjBL into elementary school mathematics is inseparable from contextual and transparent instructional design, not simply technology adoption. Based on a synthesis of student learning needs and classroom observation findings, this study demonstrates how conceptual difficulties, preferences for active and collaborative learning, and the dominance of procedural learning practices can be systematically translated into realistic instructional design principles and storyboards. These findings confirm that digital innovations are meaningful when designed to address the real gap between learning conditions and student needs. As a design-focused study, this research does not test implementation effectiveness but rather provides an evidence-based classroom design framework as a foundation for subsequent development. Therefore, further research is recommended to conduct iterative implementation in the classroom, evaluate the learning process and impact, and adapt the design across various school contexts to test its sustainability and scalability. Practically, the resulting storyboards can be used as flexible planning tools for teachers to integrate digital PjBL in a gradual and purposeful manner into elementary school mathematics instruction.

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### Author contributions

T.H. was responsible for the study design, data collection, data analysis, and drafting of the manuscript. S. contributed to the conceptual framework, provided academic supervision, and critically revised the manuscript. R. contributed to the research methodology, validation of the findings, and manuscript revision. All authors read and approved the final version of the manuscript.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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No additional data are available.

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