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LEVERAGING GAME-BASED LEARNING IN MATHEMATICS EDUCATION: ENHANCING ENGAGEMENT AND EFFICIENCY THROUGH MANAGEMENT INFORMATION SYSTEMS

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Abstract: The integration of game-based learning (GBL) into mathematics education has emerged as a promising approach to enhance student engagement and understanding of complex concepts. Simultaneously, the use of management information systems (MIS) offers an innovative framework for monitoring and optimizing the implementation of such educational methods. This study explores the intersection of GBL and MIS, focusing on their combined potential to improve teaching and learning outcomes in mathematics. By leveraging MIS, educators can collect and analyze data on student performance, customize learning experiences, and address individual needs effectively. The article also discusses challenges in integrating these technologies and provides recommendations for further development. This research highlights the transformative potential of combining GBL and MIS in fostering a more interactive and data-driven approach to mathematics education.

Keywords and phrases: Game-Based Learning, Information Systems, Education, Technology, Optimization

MSC 2010 Classification: 97U50, 97C30, 97D40, 68N01.

1 Introduction

The rapid advancements in technology have reshaped the educational landscape, introducing innovative approaches such as game-based learning (GBL) to enhance student engagement and learning outcomes [1]. By incorporating elements of gamification, such as challenges, rewards, and interactive storytelling, GBL has proven effective in fostering motivation and enhancing cognitive engagement among learners [2]. Studies show that gamified environments stimulate curiosity and encourage active participation, making learning a more enjoyable and immersive experience [3]. Mathematics, often perceived as one of the most challenging and abstract disciplines, holds a pivotal role in shaping critical thinking and logical reasoning while forming the foundation for various fields, including science, technology, engineering, and mathematics (STEM) [4]. However, traditional teaching methods frequently fail to address the diverse learning needs of students, resulting in disengagement and poor performance [5]. Innovative teaching strategies, such as GBL, are essential to transform mathematics education into an engaging and interactive process [6]. By incorporating visualizations, simulations, and real-world problem-solving scenarios, GBL can demystify complex mathematical concepts and make them accessible to learners of all backgrounds [7]. In parallel, management information systems (MIS) have become an essential tool for enhancing the effectiveness of educational technologies, including GBL [8]. MIS provides a structured framework for collecting, managing, and analyzing data related to educational processes, enabling educators to track student progress, provide real-time feedback, and tailor learning experiences to individual needs [9]. Additionally, MIS supports resource allocation, curriculum management, and performance assessment, ensuring that GBL platforms are optimized for maximum effectiveness [10]. By integrating MIS with GBL, education systems can foster a data-driven approach that not only streamlines administrative tasks but also improves learning outcomes [11]. This article explores the intersection of GBL and MIS, focusing on their potential to revolutionize mathematics education. It aims to examine the effec-

tiveness of GBL in enhancing learning outcomes, investigate how MIS can support and optimize GBL, identify challenges associated with integrating these technologies, and propose practical solutions [12]. Through this exploration, the article seeks to contribute to the growing body of research on innovative educational methodologies and provide actionable insights for educators, policymakers, and developers.

2 Literature Review

2.1 Game-Based Learning in Mathematics

Game-based learning (GBL) has emerged as a dynamic and interactive teaching methodology that integrates game elements into educational contexts, transforming the traditional learning experience into an engaging and motivational process [1]. In mathematics, GBL has proven particularly effective in enhancing student engagement and understanding by fostering an active learning environment where abstract concepts are simplified and contextualized. Through the use of simulations, puzzles, and interactive challenges, students are encouraged to develop problem-solving and critical-thinking skills while gaining a deeper understanding of mathematical concepts.

Numerous studies highlight the benefits of GBL in mathematics education. For example, digital platforms like DragonBox and Prodigy Math utilize gamified techniques to teach foundational mathematical principles, offering students immediate feedback and adaptive learning paths [2]. These tools have demonstrated significant improvements in student performance, particularly in areas such as algebra and arithmetic. Similarly, research on educational games like Math Blaster shows that integrating gameplay with curriculum-aligned content enhances knowledge retention and builds mathematical confidence [3]. Beyond improving academic outcomes, GBL creates a sense of achievement and reduces the anxiety commonly associated with mathematics, making it an appealing alternative to traditional methods [4].

2.2 Management information systems in education

Management information systems (MIS) play a pivotal role in modern education systems by providing a structured framework for the efficient management and analysis of educational data [5]. As schools and universities increasingly adopt technology-driven approaches, MIS serves as the backbone for planning, organizing, and monitoring educational processes. By integrating data collection, storage, and analysis capabilities, MIS enables administrators and educators to make informed decisions and optimize resource allocation.

One of the primary applications of MIS in education is the tracking of student performance and learning progress. Systems such as Moodle and Blackboard collect detailed data on student participation, assessment scores, and engagement levels, offering insights that help educators identify learning gaps and customize interventions [6]. Furthermore, MIS supports curriculum management, streamlines administrative tasks, and facilitates real-time communication between students, teachers, and parents. In higher education, MIS tools like PowerSchool and Canvas have been instrumental in enhancing institutional efficiency, improving academic outcomes, and fostering a data-driven culture [7].

2.3 Intersection of GBL and MIS

The integration of game-based learning with management information systems represents a powerful synergy capable of transforming mathematics education. MIS enhances GBL platforms by enabling the collection and analysis of data generated through gameplay, allowing educators to track student progress, measure engagement, and assess learning outcomes [8]. This data-driven approach empowers educators to make informed adjustments to the curriculum and tailor the gaming experience to individual student needs.

Several studies and applications have explored the intersection of GBL and MIS. For instance, platforms like Kahoot! and Quizizz combine game-based activities with analytics tools to monitor student performance in real-time [9]. These platforms provide actionable insights, such as identifying frequently missed questions or trends in learning behavior, which can be

used to refine teaching strategies. Similarly, research on personalized learning environments demonstrates how MIS can support adaptive GBL systems by analyzing individual learning patterns and dynamically adjusting the level of difficulty or content to match student capabilities [10].

The integration of GBL and MIS also enhances scalability and accessibility, allowing educators to implement game-based approaches across diverse educational settings while maintaining consistent quality and impact. Despite these advantages, challenges remain, including the need for robust infrastructure, data privacy concerns, and the alignment of GBL content with educational standards [11]. Nevertheless, the intersection of GBL and MIS holds immense potential for advancing mathematics education, offering a data-driven, student-centered approach that fosters engagement, understanding, and academic success.

3 Methodology

This study employs a mixed-methods approach, combining both quantitative and qualitative research methodologies to comprehensively explore the integration of game-based learning (GBL) in mathematics education and the role of management information systems (MIS) in optimizing its implementation. The quantitative component involves the collection and analysis of numerical data, such as student performance metrics, engagement levels, and system usage statistics. The qualitative component includes interviews and surveys with educators and students to gather insights into their experiences, perceptions, and challenges related to GBL and MIS integration.

3.1 Tools and platforms for game-based learning in mathematics

The study utilizes several established game-based learning platforms, including Prodigy Math, Kahoot!, and Quizizz, which are widely recognized for their gamified approach to teaching mathematics. These platforms offer interactive problem-solving exercises, adaptive difficulty levels, and real-time feedback, making them ideal for fostering engagement and improving mathematical proficiency. Each platform is aligned with curriculum standards to ensure the content meets educational objectives. Additionally, these tools are equipped with analytics capabilities that enable tracking of student performance and engagement patterns.

3.2 Role of MIS in data collection and analysis

Management information systems play a pivotal role in the study by supporting data collection, storage, and analysis processes. The selected platforms integrate seamlessly with MIS tools such as Moodle and Google Classroom, which serve as centralized systems for managing educational data. MIS collects detailed records of student interactions with the game-based learning platforms, including task completion rates, error frequencies, and time spent on activities. This data is analyzed using statistical software to identify trends, measure the effectiveness of GBL interventions, and assess student progress. Moreover, MIS facilitates real-time monitoring and reporting, providing educators with actionable insights to refine instructional strategies. Qualitative data from interviews and surveys is analyzed thematically to complement the quantitative findings, offering a holistic understanding of how GBL and MIS integration impacts mathematics education. By combining these approaches, the study aims to deliver robust and evidence-based conclusions regarding the effectiveness and potential of GBL and MIS in transforming the teaching and learning of mathematics.

4 Results and discussion

4.1 Effectiveness of game-based learning in mathematics

This study involved 60 students, divided into two groups: an experimental group that utilized game-based learning (GBL) platforms for mathematics education and a control group that followed traditional teaching methods. Pre-test and post-test scores, along with engagement metrics, were collected to evaluate the effectiveness of GBL.

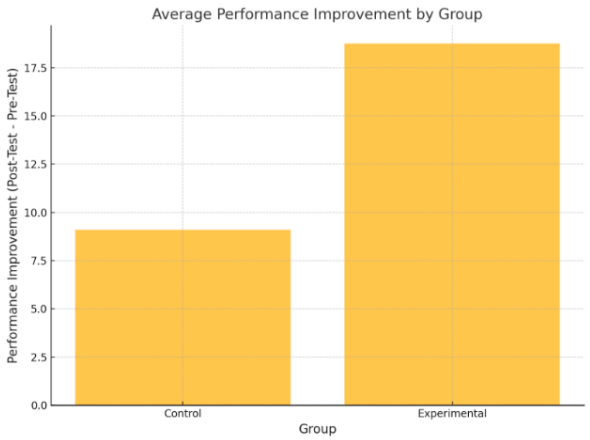

Figure 1. Average performance

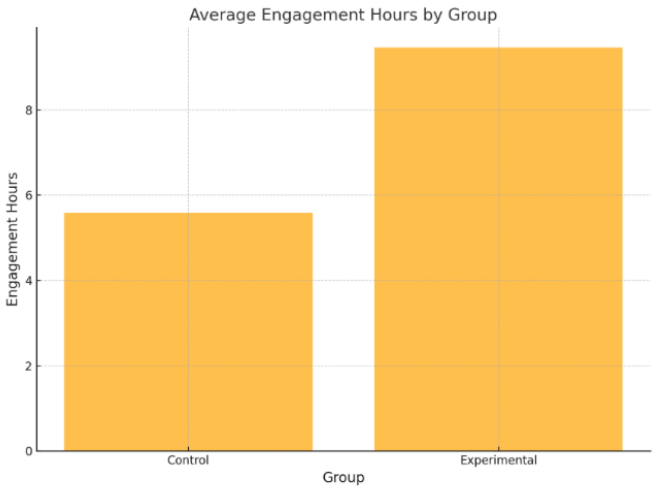

Figure 2. Engagement hours

The experimental group showed significant improvement in performance compared to the control group. On average, the experimental group achieved a performance improvement of 18.76 points, nearly double the improvement observed in the control group (9.10 points). This indicates that GBL platforms effectively enhanced students' mathematical understanding and problem-solving abilities. Additionally, engagement hours were notably higher in the experimental group, averaging 9.46 hours, compared to 5.58 hours in the control group. This highlights the motivational aspect of GBL, as students spent more time interacting with the content.

Key Insights Derived from Statistical Analysis

Table[tab:summary] summarizes the key findings, and the accompanying bar charts visually depict the performance improvement and engagement hours for each group.

4.2. Contribution of MIS in Optimizing GBL

The integration of management information systems (MIS) played a critical role in facilitating data collection, organization, and analysis throughout the study. MIS tools enabled the efficient

GROUP	PRE_TEST_SCORE	POST_TEST_SCORE	ENGAGEMENT_HOURS	PERFORMANCE_IMPROVEMENT
CONTROL	53.68	62.77	5.58	9.1
EXPERIMENTAL	55.79	74.55	9.46	18.76

Table 1. Summary of Key Results by Group

tracking of student engagement metrics, pre-test and post-test scores, and overall performance improvements. These systems provided real-time insights, allowing for a detailed comparison between the experimental group using game-based learning (GBL) platforms and the control group following traditional methods. The centralized data storage and reporting capabilities of MIS streamlined the evaluation process, ensuring that trends and patterns could be easily identified.

Analysis of the data revealed a strong correlation between engagement hours and performance improvement in the experimental group. Students in the experimental group, who spent an average of 9.46 hours engaging with GBL platforms, demonstrated an average performance improvement of 18.76 points—nearly double the improvement seen in the control group, which averaged 5.58 engagement hours and a performance improvement of 9.10 points. This highlights the effectiveness of MIS in uncovering critical insights, such as the impact of sustained engagement on learning outcomes. Furthermore, MIS-supported analytics allowed educators to monitor individual student progress and tailor interventions to address specific learning gaps, thus optimizing the educational experience.

In addition to providing actionable insights, MIS enhanced the scalability and efficiency of the study. Automated data visualization tools enabled quick identification of areas where GBL was most effective, such as problem-solving and critical-thinking tasks. By leveraging MIS, educators were equipped with a robust framework for evaluating and refining teaching strategies, ensuring that game-based learning was not only engaging but also impactful. This underscores the transformative potential of MIS in optimizing educational technologies and driving data-informed decision-making in mathematics education.

Statistical Analysis for Contribution of MIS in Optimizing GBL

Table [tab:analysis] shows the statistical analysis results comparing the experimental and control groups across various metrics.

METRIC	EXPERIMENTAL MEAN	CONTROL MEAN	T-STATISTIC	P-VALUE
PRE-TEST SCORE	55.7931	53.67742	0.937747	0.352266
POST-TEST SCORE	74.55172	62.77419	4.568821	2.83E-05
ENGAGEMENT HOURS	9.456552	5.581613	6.23569	1.16E-07
PERFORMANCE IMPROVEMENT	18.75862	9.096774	8.06167	3.34E-10

Table 2. Statistical Analysis Results for Experimental and Control Groups

Key Insights Derived from Statistical Analysis

(i) **Pre-Test Scores:** The mean pre-test scores for the experimental group (55.79) and control group (53.68) were not significantly different ($p = 0.352$), indicating that both groups started at a similar performance level.

(ii) **Post-Test Scores:** The experimental group showed a significantly higher mean post-test score (74.55) compared to the control group (62.77). The difference is statistically significant ($t = 4.57$, $p < 0.001$), demonstrating the positive impact of game-based learning (GBL) on mathematics performance.

(iii) **Engagement Hours:** The experimental group reported a significantly higher average engagement time (9.46 hours) than the control group (5.58 hours), with a strong statistical significance ($t = 6.24$, $p < 0.001$). This highlights the motivational aspect of GBL, where students spent more time interacting with the material.

(iv) **Performance Improvement:** The experimental group experienced a substantially higher average improvement (18.76 points) compared to the control group (9.10 points). This difference is highly significant ($t = 8.06$, $p < 0.001$), underscoring the effectiveness of GBL in enhancing learning outcomes.

Role of MIS in Data Collection and Insights

The use of Management Information Systems (MIS) facilitated the collection and analysis of these key metrics, providing detailed comparisons between the experimental and control groups. The statistically significant differences in post-test scores, engagement hours, and performance improvement validate the effectiveness of GBL. MIS provided real-time monitoring of engagement hours and dynamically generated reports on student performance, enabling educators to identify and address individual learning gaps. These actionable insights highlight the critical role of MIS in optimizing teaching strategies and enhancing the learning process. The statistical results and the insights derived from MIS analytics emphasize the transformative potential of integrating GBL and MIS in mathematics education.

Recommendations

The integration of game-based learning (GBL) and management information systems (MIS) in mathematics education has demonstrated significant potential to enhance student engagement, performance, and overall learning outcomes. To maximize this potential, the following recommendations are proposed for educators, policymakers, and developers:

5.1 Recommendations for Educators

Educators play a pivotal role in successfully integrating game-based learning (GBL) and management information systems (MIS) into mathematics education, and several practical steps can enhance this process. First, it is essential to adopt GBL platforms that align with national or institutional curriculum standards, ensuring seamless integration with teaching objectives and reinforcing students' learning of key mathematical concepts [17]. These platforms should be carefully selected to complement the existing curriculum while providing an engaging and interactive learning environment. Second, educators should leverage MIS dashboards to monitor student progress effectively and use the insights gained to tailor instruction to individual strengths and weaknesses. This data-driven approach allows teachers to identify learning gaps, provide timely interventions, and offer additional support where necessary, enhancing the overall learning experience. Additionally, investing in professional development is critical for educators to understand and utilize GBL platforms and MIS tools effectively. Training programs can equip teachers with the technical expertise and pedagogical strategies needed to integrate these technologies into their classrooms seamlessly. Lastly, incorporating blended learning models that combine traditional teaching methods with GBL and MIS offers a balanced and flexible approach to mathematics education. This hybrid model allows educators to maximize the benefits of technology while retaining the proven advantages of face-to-face instruction, creating a comprehensive and effective learning framework. By implementing these strategies, educators can harness the transformative potential of GBL and MIS, fostering a more engaging, personalized, and impactful mathematics learning environment. Some works in this area can be found in detail in works [12]-[17].

5.2 Recommendations for policymakers

Policymakers have a crucial role in creating an enabling environment for the successful integration of game-based learning (GBL) and management information systems (MIS) into mathematics education. A fundamental step is to promote infrastructure development, ensuring that schools have reliable internet connectivity and adequate hardware to support the implementation of these technologies. This includes providing access to modern devices, such as computers and tablets, and establishing robust networks to facilitate seamless interaction with GBL platforms and MIS tools. Additionally, policymakers should allocate sufficient funding for technology

integration, prioritizing the purchase and maintenance of GBL platforms and MIS solutions, particularly for under-resourced schools and communities where access to such resources may be limited. Financial support is critical to bridging the digital divide and ensuring equitable access to innovative educational tools. Furthermore, policymakers must standardize data privacy and security measures by developing clear policies that protect sensitive student information collected through MIS. Compliance with ethical and legal standards is essential to build trust among stakeholders and ensure the responsible use of data in educational settings. Finally, fostering collaboration between educational institutions, technology providers, and researchers is vital to drive innovation in integrating GBL and MIS. Policymakers should facilitate partnerships that encourage the exchange of knowledge, resources, and best practices, ensuring that these technologies are effectively utilized to enhance teaching and learning outcomes. By addressing these recommendations, policymakers can lay the foundation for a technology-driven, equitable, and secure educational ecosystem that supports the transformative potential of GBL and MIS.

5.3 Recommendations for developers

Developers play a critical role in ensuring the effectiveness and accessibility of game-based learning (GBL) platforms and management information systems (MIS) by focusing on user-centric design and advanced functionalities. First, it is essential to design user-friendly platforms with intuitive and engaging interfaces that cater to users with varying levels of technical expertise. Both educators and students should find the systems easy to navigate, with clear instructions and features that enhance the overall user experience. This approach ensures that technology does not become a barrier but rather an enabler for improved education. Second, developers should incorporate adaptive learning features into GBL platforms, using algorithms that adjust content difficulty based on real-time performance. This personalization caters to diverse student needs, ensuring that learners are appropriately challenged and supported, which maximizes the impact of the educational content. Third, enhancing data analytics capabilities within MIS is crucial to providing educators with actionable insights. Advanced analytics and reporting tools can reveal trends in student behavior, identify performance gaps, and highlight areas requiring improvement, enabling educators to make informed decisions. Finally, developers must ensure scalability and compatibility by designing systems that can be easily scaled across different institutions and seamlessly integrated with existing educational technologies. This flexibility allows GBL platforms and MIS tools to accommodate growing student populations and adapt to evolving technological ecosystems. By addressing these recommendations, developers can create innovative, accessible, and impactful solutions that support the integration of GBL and MIS, ultimately transforming the way mathematics education is delivered and experienced.

5.4 Areas for further research

Further research is essential to fully understand and maximize the potential of integrating game-based learning (GBL) and management information systems (MIS) in mathematics education. First, longitudinal impact studies are needed to investigate the long-term effects of these technologies on mathematics learning outcomes, retention rates, and student attitudes. Such studies would provide valuable insights into how sustained use of GBL and MIS influences academic success and whether these benefits persist over time. Second, cross-cultural applications should be explored to adapt GBL and MIS for diverse cultural and educational contexts. Particular attention should be given to low-resource settings, where tailored solutions could bridge educational gaps and provide equitable access to innovative learning tools. Third, research on emerging technologies such as artificial intelligence (AI) and virtual reality (VR) offers exciting possibilities for enhancing GBL platforms and MIS functionalities. AI could enable deeper personalization of learning experiences, while VR could create immersive environments for mathematics education, making abstract concepts more tangible. Lastly, a cost-effectiveness analysis is crucial to evaluate the economic feasibility of implementing GBL and MIS in different educational environments. This research would guide budget allocation and policy decisions by identifying the most efficient ways to achieve desired outcomes with limited resources. By addressing these areas, researchers can contribute to the development of evidence-based strategies that ensure the

sustainable and impactful integration of GBL and MIS in education.

6. Conclusion

This study underscores the significant impact of combining game-based learning (GBL) and management information systems (MIS) in transforming mathematics education. The findings reveal that GBL fosters higher levels of engagement and improved performance among students by delivering interactive and gamified learning experiences that make abstract mathematical concepts more accessible and enjoyable. Students in the experimental group demonstrated substantial improvements in post-test scores and spent significantly more time engaging with learning materials compared to their peers in the control group, showcasing the motivational power of GBL. Moreover, the integration of MIS proved instrumental in collecting, analyzing, and interpreting data on student progress, enabling educators to make informed decisions, provide personalized instruction, and address individual learning needs effectively. The combined use of GBL and MIS holds immense potential to revolutionize traditional approaches to mathematics education. While GBL captivates and inspires learners, MIS offers a robust framework for monitoring outcomes, identifying challenges, and optimizing teaching strategies through data-driven insights. Together, these technologies create a dynamic, student-centered learning environment that not only improves academic outcomes but also cultivates critical skills such as problem-solving and adaptability. By embracing the synergy between GBL and MIS, educators and policymakers can pave the way for a more innovative, equitable, and impactful future in mathematics education, ensuring that students are better prepared to thrive in a technology-driven world.

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