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The Effects of Non-Digital Gamification on Grade 11 Students' Mathematics Achievement and Motivation in Learning Rational Exponents

Arucha Worrawat[1], Weerayut Thongrung[2], Panyawat Haarsa[3]
[1,3]Department of mathematics, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand
[2]Triamudomsuksanomklaokunnatee School, Ratchadaphisek, Din Daeng, Bangkok 10400, Thailand

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Abstract
The study used a quasi-experimental design to examine how non-digital gamified instruction influenced the learning of rational exponents. The objectives of this study were to investigate the effects of non-digital gamification on students' mathematics achievement and to explore their motivation and engagement in learning rational exponents. The study involved 30 Grade 11 students, and both achievement and motivation in mathematics were examined. Thirty students completed six sessions of gamified mathematics activities. The course modules included gamified components such as games, rewards, peer competition, and achievement goals. The pedagogy was based on Self-Determination Theory and Constructivist Learning Theory. It highlighted autonomy, competence, and involvement. The learning outcome test comprised 15 open-ended items assessing four cognitive domains: knowledge, comprehension, application, and analysis. The data was analysed using a paired-samples t-test. Post-test scores (M = 8.19, SD = 2.80) were significantly higher than pre-test scores (M = 6.44, SD = 3.62), t(29) = 5.99, p < .001. It was an educationally meaningful improvement (effect size, Cohen's d = 0.54). Qualitative reflections confirmed the quantitative findings. Students reported that the game-based activities increased their interest and attention. They also noted better relationship-building and stronger cooperation during the lessons. Altogether, the results support the notion that classroom gamification provides an effective mechanism for enhancing students' academic achievement and motivation without relying on digital technology. The findings of this study suggest that non-digital gamification is a useful pedagogical method for advancing mathematics achievement at the upper secondary level.

Keywords Gamified Classroom Activities; Mathematics Achievement; Secondary Education; Self-Determination Theory;

Corresponding Author
Panyawat Haarsa
Srinakharinwirot University, Thailand; chaiwichith@g.swu.ac.th

INTRODUCTION

The importance of mathematical knowledge in the development of students' analytical, problem-solving, and logical reasoning skills cannot be overemphasized and is a prerequisite for survival in today's 21st century (Findell et al., 2001). Despite being an important subject, mathematics is difficult for many students worldwide, especially at the secondary level. It is well documented that the perception of mathematics (as abstract, hard, and removed from students' communities) leads to low motivation, disengagement, and underachievement in mathematical learning (Boaler, 2015; Schukajlow & Krug, 2014).

In Thailand, similar challenges have been widely reported, especially in upper secondary mathematics classrooms (Phonapichat et al., 2014). Traditional teacher-centered instruction often emphasizes procedural fluency and memorization rather than conceptual understanding, limiting students' opportunities to actively construct knowledge and develop reasoning skills (Hiebert, 2007). These instructional practices may be particularly problematic when teaching abstract topics such as rational exponents, which require both conceptual understanding and procedural competence.

Gamification as an instructional method has been used to address motivational and engagement issues in mathematics education. Gamification is the incorporation of game-design elements, including challenges, rewards, feedback, and progress systems, into non-game learning contexts to increase users' motivation and engagement (Dichev & Dicheva, 2017; Kapp, 2012). Previous studies showed that a gamified learning environment could have a positive impact on students' achievement, persistence, and attitudes towards mathematics if properly designed to align with its learning objectives (Hamari et al., 2014; Su & Cheng, 2015).

Despite the evidence for the effectiveness of gamification in mathematics teaching in previous research, these studies have some limitations. In the first place, most studies in this area are centred on digital gamification, frequently through mobile applications, learning management systems, and online platforms in general (Domínguez et al., 2013; Nah et al., 2014). Second, less such research focuses on non-digital gamification (paper-based tasks, classroom interactions, and low-tech resources), especially in secondary-level mathematics classrooms. Furthermore, to the best of our knowledge, scarce research has explored both math achievement and motivational outcomes through a single instructional innovation, especially for abstract mathematical content such as rational exponents.

RESEARCH METHOD

The study was quasi-experimental, using a one-group pretest-posttest design. This design was adopted because it enables researchers to assess the impact of an intervention on participants' learning by comparing performance before and after the treatment. In this study, the intervention was a gamification-based learning management innovation aimed at improving students' achievement in a mathematics topic on rational exponents. The purpose of the study was to examine changes in learning achievement, motivation, and self-directed learning behaviors that occurred after participants engaged in gamified learning activities.

The independent variable in this study was the gamification learning management model, which integrated game-based elements into classroom instruction, while the dependent variable was students' learning achievement in mathematics. The design was suitable for the educational setting, as it was conducted in a real classroom environment without random assignment, thereby reflecting authentic learning conditions. The conceptual framework of the study is illustrated in Figure 1 below. It presents the relationships among the key variables, showing how the gamified learning system (independent variable) is theoretically grounded in Self-Determination Theory and Constructivist Learning Theory, and how these influence the dependent variables of learning achievement, motivation, and self-directed learning behavior.

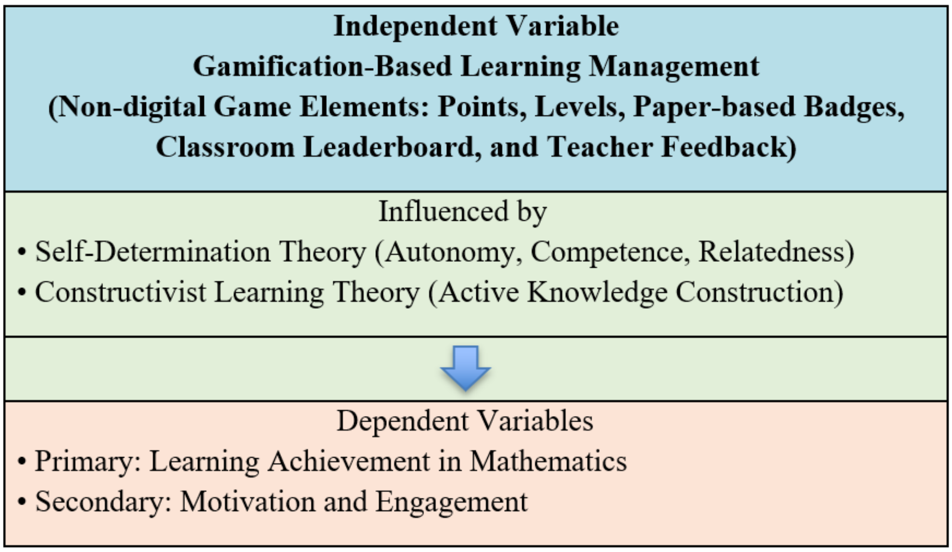

Figure 1. illustrates the conceptual framework, indicating the theoretical foundations and variable relationships of the study

Participants

The sample consisted of Grade 11 students from a secondary school affiliated with the Office of Secondary Educational Service Area 2 in Thailand. Data were gathered in the second semester of the academic year 2025. The selection of participants was based on purposive sampling at a level related to "Exponents and Rational Exponents." The participants were 30 students in a mathematics class. We chose them as representatives of the characteristics of most upper secondary learners with respect to both academic ability and their prior exposure to traditional teaching. Student participation was voluntary, and we guaranteed confidentiality, anonymity, and the right to withdraw from the study at any time.

Research Instruments

This study used three research instruments: a gamified learning plan, a learning achievement test, and a learning reflection form. We developed and validated each instrument carefully to ensure its suitability for the target population.

1. Gamification-Based Learning Management Plan

The instructional design followed core gamification principles. It used clear goals, tasks of varying difficulty, extrinsic rewards, and regular feedback. The lessons were developed according to a teaching mode that adhered to blended learning and modern instructional design models, including the pre-stage of learning (learning needs analysis), stage of learning, and post-stage of learning. The tasks were developed to promote interaction, reflection, and collaborative problem-solving. The children participated in game-based activities that involved challenges and task-oriented tasks. The students took part in game-like tasks that used challenges and goal-oriented activities. These tasks introduced friendly competition to increase their motivation. Marks were given based on learning tasks, problem-solving, and class discussion. The summed marks showed each student's progress and acted as a form of recognition in the class. This gamified approach relied on intrinsic motivation and engagement, and it did not use any digital tools. The aim was to strengthen students' motivation and involvement in learning mathematics. The unit consisted of six 50-minute lessons that emphasized both the conceptual and procedural aspects of rational exponents. All activities were designed according to the objectives of the Basic Education Core Curriculum of Thailand.

2. Learning Achievement Test

We developed a math achievement test to assess students' learning of rational exponents pre- and post-intervention. The test consisted of 15 open-ended items that measured four cognitive levels: knowledge, comprehension, application, and analysis. Test content was based on the curriculum objectives, and its validity with regard to content was assured by three mathematics education experts. The index of IOC for the items ranged from 0.67 to 1.00, indicating a good match between the exam content and the learning objectives. The test's reliability was demonstrated in a pilot sample (similar to our participants), with a Cronbach's alpha coefficient of 0.85, indicating high internal consistency. Examples of students' performance on the mathematics achievement test are shown in Figure 2, which illustrates how questions were structured to measure students' understanding and application of rational exponents.

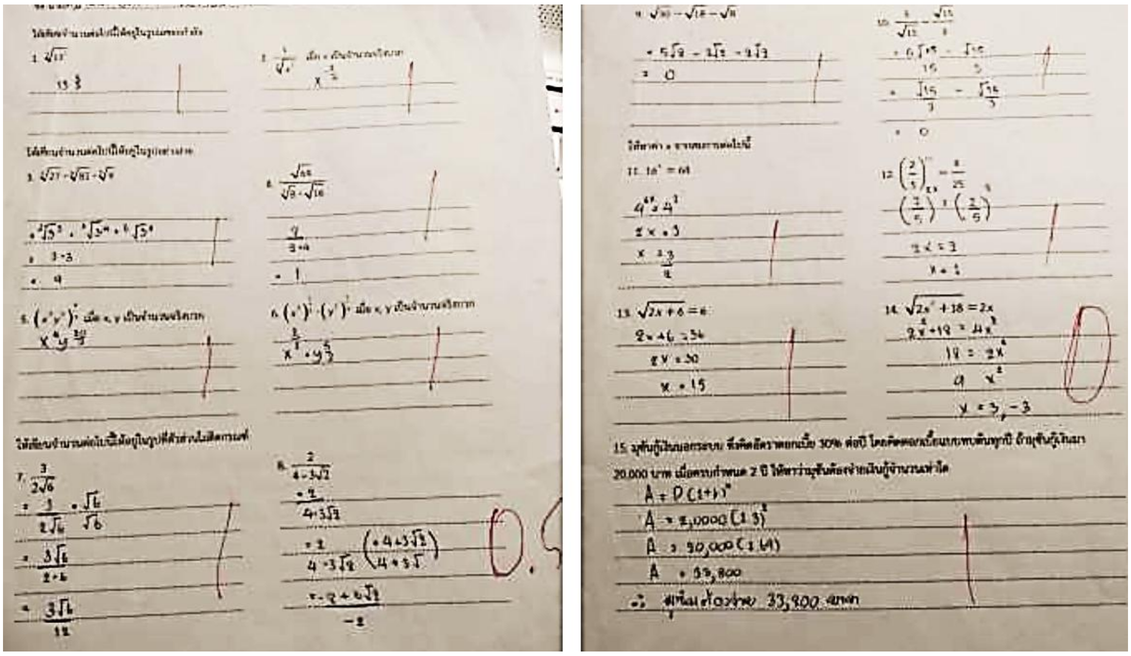

Figure 2. Examples of Students’ Responses to The Mathematics Achievement Test

Based on these results, pilot feedback, and analysis, the test was modified to improve the clarity, suitability, and accuracy of the test items before implementation. The final version of the test took about 50 min to complete. This procedure made the instrument valid and reliable for assessing students’ achievement in mathematics, specifically rational exponents.

3. Learning Reflection Form

We employed a learning reflection sheet to evaluate students’ self-consciousness and their ability to reflect on their learning. The form prompted them to report what they learned, the challenges they encountered, and ideas for change. It also recorded their “hot states,” including emotions and attitudes toward learning in a gamified setting. These qualitative reflections added some insights to the findings of the mathematics achievement test.

Research Procedures

We conducted the study over six learning sessions. The procedure consisted of three phases: the pre-experiment phase, the experiment phase, and the post-experiment phase.

1. Pre-Experimental Stage

We conducted an orientation session before the start of the game-based lessons. In this session, we described the study's purpose and the rules of the gamified learning system. All participants were then given the pre-test to assess their prior knowledge of rational exponents. Learners were also familiarized with the class award system and non-digital gamified activities used to promote participation and motivation.

2. Experimental Stage

A gamification-based learning management plan was practiced in the classroom throughout this stage. Active learning/Student-Centered instruction was used as the pedagogical model in this course. At the beginning of each session, a lecture on the topic began and was followed by activities and games for the students. Participants earned recognition for completing tasks, solving problems, and engaging in discussions. Their progress was discussed collectively to encourage motivation.

The lesson fostered student-centered learning, encouraging independence through self-selection of tasks according to readiness and ability. Figure 3 shows a student's notebook as an example of homework completed under the gamified learning system. The student selected a two-star difficulty level and reflected on the teacher's feedback, demonstrating self-evaluation and error correction during practice.

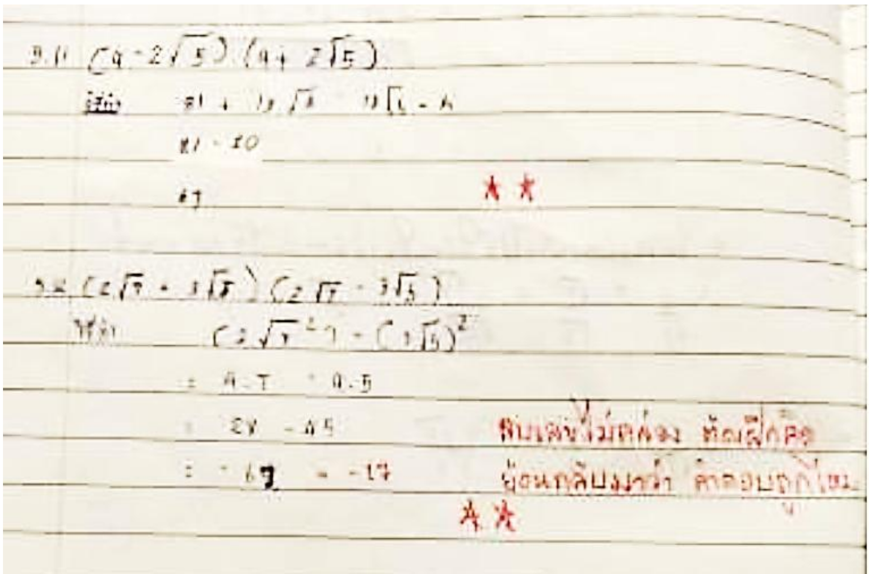

Figure 3. Example of a Student's Notebook Showing Completion of a Two-Star Level Task and a Written Reflection on Errors

Immediate feedback was provided at the conclusion of each activity to validate comprehension and direct students toward further development. Game mechanics served as a motivating influence, encouraging children to collaborate, persist, and enjoy learning mathematics. The teachers took on the role of facilitators, supporting students in the process and progression, and ensuring that the learning objectives were met.

3. Post-Experimental Stage

At the end of the intervention process, a post-test similar in structure to the pre-test was used to assess any changes or progress made by participants in learning achievement. The researcher also collected learning reflection forms to evaluate students' feelings about the gamified learning. We also conducted informal interviews for further qualitative insights. These interviews were instrumental in providing us with a better understanding of the impact of gamification on student motivation and perceptions of mathematics.

Validity and Reliability of the Research Instruments

Quantitative and qualitative data were analyzed separately but interpreted together to triangulate findings. The research instruments, including the lesson plans and achievement test, were reviewed by experts in mathematics education to ensure content validity. Revisions were made according to expert feedback, and the instruments were pilot-tested for clarity and suitability. The test's reliability, as measured by Cronbach's alpha, indicated acceptable internal consistency.

Data Analysis

The data were managed and analyzed using descriptive and inferential statistics. Means and standard deviations were used to describe the students' pre- and post-test scores. We used inferential statistics, specifically the paired-samples t-test, to compare the mean scores before and after the intervention to determine statistical significance at the 0.05 confidence level. Content analysis was used to examine the qualitative data in and across the learning reflection forms to discern patterns in motivation, engagement, and self-directed learning behaviours.

The interpretations of the statistical outputs were made in relation to the research question of whether gamification-based learning management is effective in improving students' learning achievement. Thereby, a quantitative approach was primarily employed, supported by qualitative reflections to interpret students' responses and experiences better. This approach allowed us to examine both cognitive and affective aspects of learning. It also helped us see how gamification shaped these two areas.

Ethical Considerations

We are respectful in all our actions. To ensure privacy, we used coded identification and secure data storage. Attendance was optional, and students who chose not to attend did not face academic punishment.

RESULTS AND DISCUSSION

This study aimed to examine the effects of non-digital gamification-based instruction on Grade 11 students' mathematics achievement and motivation in learning rational exponents. To address the research objectives, quantitative and qualitative data were analyzed and are presented as follows.

Students' Mathematics Achievement

Descriptive statistics indicated that students' pre-test scores were relatively low ($M = 6.44$, $SD = 3.62$), suggesting limited prior understanding of rational exponents. Following six gamified non-digital instruction sessions, students' post-test scores improved to a mean of 8.19 ($SD = 2.80$). A paired-samples t-test was applied to assess the statistical significance of differences in students' pre-test and post-test scores before and after the instructional intervention. The analysis showed a significant difference between pre-test and post-test performance, $t(29) = 5.99$, $p < .001$. This result suggests that the non-digital gamification-based learning intervention had a significant impact on students' mathematics achievement. The descriptive statistics of pre-test and post-test results are presented in Table 1, which includes the mean, standard deviation, and the level of significance from the paired-sample t-tests.

Table 1. Descriptive Statistics and Paired-Samples T-Test Results For Students' Pre-Test and Post-Test Scores

Test	N	Mean	SD	t-value	p-value
Pre-test	30	6.44	3.62	5.99	p < 0.001
Post-test		8.19	2.80		

These results indicate that non-digital gamification-based instruction is effective in supporting students' mathematics learning, as it provides deeper student involvement and active participation in classroom activities. In terms of Self-Determination Theory, the improvement observed in the current study may result from classroom practices that fostered autonomy, competence, and relatedness (thereby enhancing intrinsic motivation). Furthermore, in line with Constructivist Learning Theory, the integration of game tasks actively challenged students to build mathematical knowledge through group problem-solving. To further examine the practical significance of this improvement, an effect size analysis was conducted, as presented in Table 2.

Table 2. Effect Size (Cohen's d) of Non-Digital Gamification-Based Instruction on Students' Mathematics Achievement

Comparison	Effect Size (Cohen's d)	Interpretation
Pre-test vs Post-test	0.54	Medium effect

The observed medium effect size further reinforces the educational significance of non-digital gamification-based instruction beyond statistical significance. From a theoretical perspective, the direction and magnitude of this effect suggest that the intervention not only enhanced participants' test performance but also supported meaningful learning processes. Consistent with Self-Determination Theory, sustained motivation, facilitated by autonomy-supportive and competence-enhancing activities, may have contributed to maintaining consistent learning gains. Also, from a constructivist perspective, the sequenced flow of game-based activities allowed students to acquire mathematical 'know-how' more naturally through active participation and hands-on learning.

Students' Motivation and Engagement

We analyzed the students' learning reflections and found that they held a positive attitude toward the gamified environment. Many students said they felt more interested in mathematics and found the sessions engaging and enjoyable. They noted that the reward system, classroom recognition, and visible progress encouraged them to participate. Some students also shared that moving to more advanced levels made them feel proud and more confident, and increased their willingness to take on difficult problems.

The reflections also indicated that the gamified learning environment facilitated peer interaction and communication. Students frequently collaborated to solve problems, compare strategies, and acknowledge one another’s successes. This social dimension of the activities contributed to a supportive classroom culture in which students were comfortable expressing ideas, and failure was accepted. The findings suggest that gamification not only supports cognitive learning but also positively affects affective and social learning. These quantitative and qualitative results together indicate that non-digital gamified instruction did improve student achievement and motivation.

The findings of this study demonstrate that non-digital gamification-based instruction effectively improved Grade 11 students’ mathematics achievement and motivation in learning rational exponents. A significant difference in post-test scores and a moderate effect size imply that gamification in classroom tasks can contribute to students' conceptual learning and procedural skills in mathematics. These findings are consistent with Self-Determination Theory (Ryan & Deci, 2000), which argues that autonomy, competence, and relatedness are central components in the development of intrinsic motivation. The game-based learning environment enabled students’ autonomy by giving them the choice of tasks, timely feedback , and the possibility to collaborate with others, which fulfilled these psychological needs. Furthermore, it utilized Constructivist Learning Theory, through which students constructed learning through hands-on experience and reflection. The results generally adequately answer the research question, as they show that non-digital gamification can improve cognitive and affective outcomes in secondary school mathematics education. These findings can be interpreted through the lens of Self-Determination Theory (Ryan & Deci, 2000) and Constructivist Learning Theory (Fosnot, 2013), as the gamified learning environment supported students’ autonomy, competence, and relatedness through task choice, timely feedback, peer collaboration, and hands-on learning experiences.

Enhanced Engagement and Motivation

The students’ reflections showed that gamification shifted the classroom from passive participation to active involvement. They gained recognition and encouragement through class activities and friendly competition. These features also drew on psychological ideas such as goal-setting and reward anticipation, which helped sustain their effort. As Werbach and Hunter (2015) noted, well-designed game elements can strengthen a sense of achievement and purpose, both of which support motivation over time. While the gamified activities were non-digital, students' reflections indicated that the tangible, task-based progression maintained engagement comparable to technology-based gamified environments.

Cognitive and Social Development

Besides cognitive enhancement, gamified learning was also effective in fostering peer interaction and collaborative learning as revealed in the study (Caponetto et al., 2014; Dichev & Dicheva, 2017; Hanus & Fox, 2015). Competition and cooperation within the learning environment promoted discussion of mathematical problems, the sharing of ideas, and helping each other to progress. This result is congruent with Vygotsky's Social Constructivist Theory, which emphasizes the effect of social interaction on higher cognitive development (Vygotsky, 1978). Through group work and discussion, students can articulate their reasoning, gain new information that could amend their current understanding, and internalize it. These results highlight that gamified learning satisfied learners' psychological needs for autonomy and competence through non-digital, hands-on, task-based progression.

Additionally, gamification motivated self-regulated learning. Students were able to track their progress and assess where they fell short. This ownership over the learning feeling is also key to developing lifelong learner habits. Zimmerman (2000) suggested that self-regulated learners can set goals, use effective strategies, and be critical of their own performance, all of which contribute to academic achievement.

Comparison with Traditional Teaching Methods

Common teaching methods in mathematics include lectures, exercises, and individual problem-solving. Although such approaches can work for skill practice, they often do not sustain students' attention in the long term (Boaler, 2015; Hiebert, 2007). The gamified intervention in the present study, on the other hand, emphasized challenge, feedback, and rewards, making repetitive exercises more engaging (Landers, 2019). The change in instructional approach was expected to have played a role in the observed performance improvement. The gamified classroom also provided immediate teacher feedback and peer collaboration, which are rarely seen in traditional classrooms. (Plass et al., 2015). Therefore , misconceptions were far easier to identify and address, resulting in a more precise long-term understanding of mathematical principles (Black & Wiliam, 2009).

Integration with Literature

The findings of this study contribute to the growing body of international research on gamification in education. Prior research (Domínguez et al., 2013; Nah et al., 2014) has shown that gamification serves dual roles in both cognitive learning and social-emotional engagement. Yet its effectiveness relies on the quality of the design and the programme. Misdesigned games can lead to shallow engagement or undue stress from competition. In our research, competition was counterbalanced by collaboration so that all students would have an equal opportunity to succeed. Results indicate that gamification is most successful in the form of mastery and learning progress rather than in point-gathering activities.

Pedagogical Implications

There are several implications of these findings for educators and curriculum designers. The first is that the beneficial effects of gamification on students' achievement in learning mathematics imply that motivational strategies should be incorporated into teaching (Dichev & Dicheva, 2017; Hamari et al., 2014; Su & Cheng, 2015). Teachers may choose to include game-like features, such as immediate feedback, levelling up, and a reward system , to promote student engagement (Sailer et al., 2017). Second, the findings indicate that gamification is feasible without the need for sophisticated technologies (when relying on a simple point system and visual progression), resulting in motivation and learning gains. Lastly, the approach provides a foundation for developing the self-directed and collaborative learning skills required of learners in the twenty-first century.

Summary of Findings

The results clearly indicate that gamification-based learning management significantly improved students' achievement in rational exponents. Students not only achieved higher test scores but also developed greater motivation, confidence, and enjoyment in learning mathematics. Combining the quantitative results and the students' reflective testimonials, it is evident that this intervention addressed both cognitive and affective elements of learning. The results provide support for the importance of learning environments in meeting students' psychological needs for engagement and academic well-being. Overall, our work shows that non-digital gamification is a useful and easily applicable tool for improving mathematics education in upper secondary schools. But the study sampled only one class of 30 students, so future research could use larger sample sizes or compare digital and non-digital models of gamification.

CONCLUSION

The research problem of this study was to determine whether non-digital gamification would be an effective intervention for increasing students' achievement and motivation in mathematics in the secondary grades. The results provide empirical evidence that non-digital gamification-based instruction has a positive impact on grade 11 students' learning of rational exponents. Students achieved substantial performance gains in math and became more motivated and involved in classroom procedures. Such findings suggest that learning can be achieved in a meaningful and sustainable manner without relying on digital technology. This study contributes novel insights to the field of mathematics education by extending the scarce work on gamification to low-technology, face-to-face settings. In settings with restricted access to digital materials, non-digital gamification is a pragmatic and pedagogically defensible solution. The results also underscore how learning activities that are autonomy-supportive, competence-sustaining, and collaborative, among other things, contribute to fostering intrinsic motivation and active learning.

From a practical point of view, when following the principles discussed in this manuscript, mathematics teachers might implement non-digital gamification strategies, such as task progression, peer interaction, and structured feedback, to create a more motivating learning environment that promotes both students' cognitive and affective development. Although this research used a one-group pretest-posttest design, the findings may not be generalized. It was further argued that future research should include control or comparison groups and that the long-term effects of non-digital gamification on other mathematical topics in different educational settings should be explored.

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