UDC 37.016.2
DOI: 10.52534/msu-pp2.2025.09

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Gamification of formative assessment in primary school through the development and implementation of courses using Minecraft by future computer science teachers

Article's History:
Received: 26.01.2025
Revised: 11.05.2025
Accepted: 30.06.2025

Suggested Citation:
Riabko, A., & Ihnatenko, O. (2025). Gamification of formative assessment in primary school through the development and implementation of courses using Minecraft by future computer science teachers. *Scientific Bulletin of Mukachevo State University. Series "Pedagogy and Psychology"*, 11(2), 9-22. doi: 10.52534/msu-pp2.2025.09.

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Abstract. Gamification and formative assessment have gained increasing attention in education as effective strategies for enhancing student engagement and learning outcomes. The study aimed to determine how such an approach influences students' motivation, comprehension of key informatics concepts, and the development of digital competencies among future educators. The research involved future computer science teachers for design and implementation of interactive lessons using Minecraft to facilitate learning and assess students' progress. The study investigated the effectiveness of using Minecraft Education as a gamified tool for formative assessment in primary school informatics education. The results indicated that integrating gamified formative assessment significantly enhanced students' interest, engagement, and comprehension. Future teachers also gained valuable experience in designing student-centred learning activities using Minecraft, demonstrating improved pedagogical skills and effective use of digital tools. The results indicated that students demonstrated increased interest, engagement, and comprehension when formative assessment was embedded in a gamified environment. Additionally, future teachers gained valuable experience in designing student-centred learning activities, fostering creativity, and utilising digital tools effectively. Statistical analysis confirmed the positive impact of gamified formative assessment on learning outcomes. The study suggested that incorporation of digital game-based learning strategies into teacher education programs can significantly enhance pedagogical skills and the ability to create interactive learning experiences. The study concluded that gamification can be an innovative and effective approach to formative assessment in informatics education, providing students with immediate feedback while maintaining their motivation. The findings of this study have practical implications for primary school teachers, informatics educators, and curriculum developers seeking to integrate gamified approaches into the learning process. The results offer insights into leveraging Minecraft Education for formative assessment, which can enhance student engagement and improve learning outcomes

Keywords: informatics education; digital learning; teacher training; interactive learning; student engagement; educational technology

INTRODUCTION

Formative assessment, a dynamic and student-centred approach, is pivotal in contemporary education, fostering deeper learning by providing real-time feedback and encouraging self-reflection. However, traditional formative methods often struggle to engage modern digitally immersed learners, particularly in primary education. Gamification, especially through platforms such as Minecraft Education Edition, offers a solution by creating immersive, interactive learning environments that seamlessly integrate assessment with engaging problem-solving scenarios.

Authors M. Singh & D. Sun (2025) explored the potential of Minecraft Education Edition as a metaverse-like platform for STEM education, involving 40 students in collaborative learning tasks related to Chemistry, Coding, and AI Education. Using the Game Experience Questionnaire (GEQ) and the STEM Outcome Survey, the researchers analysed student engagement, social presence, and learning outcomes. The study revealed that Competence, Flow, and Challenge significantly enhance immersion, supporting the idea that Minecraft fosters deep learning experiences. The study concluded that Minecraft Education Edition enhances social presence, promotes behavioural involvement, and reduces negative social interactions, making it a promising educational tool for STEM learning. The authors recommend further customised Minecraft environments to improve game-based learning strategies.

E.J. Slattery *et al.* (2024) analysed experiences of teachers using Minecraft Education Edition in Irish primary schools as part of the Irish national project-based initiative Future is MINE. Through semi-structured interviews with 11 teachers, the study identified six key themes: enhanced student collaboration, increased creativity, active learning participation, inclusivity, curricular integration, and barriers to adoption. The study determined Minecraft's role in fostering 21st century skills while rendering learning more engaging and accessible. However, the study also highlighted technological barriers that hinder implementation and suggests solutions for improving Minecraft-based learning in primary classrooms.

In the study by C.L.S. Tablatin *et al.* (2023) investigated the impact of Minecraft-based STEM education through the What-If Hypothetical Implementations in Minecraft (WHIMC) project, conducted in the Philippines. Using pre- and post-STEM Interest Questionnaires (SIQ) and the Game Experience Questionnaire (GEQ), the study assessed changes in students' interest in STEM subjects. Results showed a minimal overall effect on STEM interest, though students demonstrated greater awareness of the importance of studying for STEM careers. While no significant difference was found in the overall game experience between high- and low-performers, high-performers reported higher immersion levels, indicating a more engaging and enjoyable experience. The study concluded that efficient STEM learning in Minecraft requires both engaging gameplay and well-structured educational tasks, as open-ended exploration alone can be challenging even for top-performing students.

E.J. Slattery *et al.* (2023) explored experiences of primary school students with Minecraft Education during a national project-based initiative in Ireland. The study followed a two-phase approach, where students first learned how to use Minecraft Education and then participated in a national competition to design a sustainable community. Using a mixed-methods design, the study surveyed 173 students (grades 3-6) and conducted focus group interviews with 30 sixth-grade students. Findings revealed that students found Minecraft Education engaging, easy to use, and beneficial for creativity and collaboration. Thematic analysis identified five key themes: collaboration, creativity, immersive learning, student engagement, and digital skills development. The study highlights the value of project-based learning with Minecraft in fostering 21st-century skills and enhancing student learning experiences.

Scientists M. Nkadimeng & P. Ankiewicz (2022) investigated the affordances of Minecraft Education Edition as a game-based learning tool for teaching atomic structure in junior high school. Using a qualitative approach, the study observed and interviewed 20 eighth-grade students in a South African private school, aligning the intervention with the national curriculum. Findings showed that Minecraft Education motivated students, increased engagement, and facilitated critical thinking and collaboration while rendering the atomic structure less abstract. However, not all Minecraft crafting station features promoted deep learning, highlighting the need for further research on which game elements best support conceptual comprehension. The study suggested further exploration of online Minecraft-based interventions and expand the application to other curriculum topics and diverse learning contexts.

S. Bourdeau *et al.* (2021) explored the use of Minecraft Education Edition as a simulation-based training platform for teaching agile project management. The study involved 153 university students who applied the Scrum framework to execute a simulated project within Minecraft. Findings revealed that students had a highly positive perception of their learning experience, describing it as both stimulating and challenging. The study highlights the potential of using "readymade" virtual world platforms like Minecraft for immersive, interactive, and engaging education, offering practical recommendations for educators seeking to integrate information and communication technologies (ICT) into teaching and learning.

In the study by N. Klimová *et al.* (2021) explored the use of Minecraft: Education Edition as online game-based learning tool during the COVID-19 pandemic. The study organised an online programming contest aimed at lower-secondary school pupils as part of the EU Code Week initiative in Slovakia. The contest involved ten programming tasks based on the Slovak Informatics curriculum for grades 5-6, covering topics such as case analysis, sequences of commands, loops, and debugging. The results of the contest were analysed by age and gender to assess the success of the students in solving the tasks, highlighting the effectiveness of Minecraft in engaging students with programming concepts.

Assessment is a fundamental part of the learning process, shaping not only how students comprehend and engage with educational content but also affects progress perception. Among various approaches, formative assessment can be noted as an essential tool for guiding students through their learning journey. In contrast to traditional summative assessments, which evaluate knowledge at the end of a unit or course, formative assessment is continuous, dynamic, and student-centred. It provides real-time feedback, identifying areas for improvement for students while enabling teachers to adapt instruction accordingly. This process fosters improved comprehension, encourages self-reflection, and ensures more meaningful learning outcomes. The study aimed to develop and implement a gamified course for student-teachers, which integrates teaching methodologies for primary school informatics with the use of Minecraft as a formative assessment tool. The research objectives included:

1) Development and implementation of methods for using Minecraft to create interactive and engaging lessons for primary school students.

2) Training of future teachers to integrate formative assessment into a Minecraft environment to monitor and improve student progress.

3) Evaluation of the effectiveness of gamified lessons developed in Minecraft on student engagement, learning outcomes, and the quality of formative assessment.

MATERIALS AND METHODS

Participants were divided into two groups: a control group and an experimental group. The control group received traditional methods of teaching informatics, while the experimental group underwent training focused on gamification and the use of Minecraft as an educational tool. The evaluation of the experiment focused on several criteria. Firstly, the quality of the lesson plans developed by the students was assessed, ensuring alignment with learning objectives and effective use of in-game assessment tools. Secondly, the perceived readiness of the students to apply Minecraft in their future teaching was measured, gauging their proficiency with the methodology. Additionally, the response of primary school students to the Minecraft-based lessons was examined, focusing on their level of motivation and engagement, as well as the overall learning outcomes. Lastly, the effectiveness of formative assessment was evaluated, examining student comprehension of the material before and after the lesson. Therefore, the evaluation criteria were as follows:

- Quality of developed lesson plans (alignment with learning objectives, use of in-game assessment tools).
- Readiness of students to apply Minecraft in their future teaching (level of proficiency in the methodology).
- Primary school students' response (motivation, engagement, learning outcomes).
- Effectiveness of formative assessment (students' comprehension of the topic before and after the lesson).

For data processing, a 12-point scale was used for each of the four evaluation criteria. Data collection methods included surveys, teacher observations, and testing. A total of 12 students participated in the study, with 7 in the control group and 5 in the experimental group. For statistical analysis, the Mann-Whitney U-test was applied, which is well-suited for small sample sizes, to determine any significant differences between the two groups. The Mann-Whitney U-test was used to compare the distributions of two independent groups. The test was based on the ranks of the data, and it calculates two U statistics, U_A and U_B, for the two groups.

The formula for U_A is:

$$U_A = R_A - \frac{n_A(n_A+1)}{2}, \quad (1)$$

where: R_A – sum of ranks for the control group, n_A – number of participants in the control group.

Similarly, the formula for U_B is:

$$U_B = R_B - \frac{n_B(n_B+1)}{2}, \quad (2)$$

where: R_B – sum of ranks for the experimental group, n_B – number of participants in the experimental group.

The final test statistic is:

$$U = \min(U_A, U_B). \quad (3)$$

This study employed an experimental design to investigate the effectiveness of gamified formative assessment using Minecraft Education in primary school informatics education. The research involved future computer science teachers who developed and implemented Minecraft-based lessons for primary school students. The research stages began with a theoretical preparation phase, during which participants from both the control and experimental groups studied key concepts related to gamification, formative assessment methods, and the educational applications of Minecraft. Following this, the experimental group engaged in practical training sessions, prioritising the introduction to Minecraft Education and its built-in assessment tools, such as quests, building tasks, Redstone mechanisms, and Non-Player Characters (NPCs) for feedback.

Data collection involved a combination of surveys to assess primary school students' motivation, engagement, and comprehension; teacher observations to evaluate the quality of the lesson plans and the implementation process; testing to measure students' comprehension of the material before and after the lessons. The survey was conducted as part of a broader mixed-methods approach to assess the effectiveness of using Minecraft Education Edition in formative assessment. Data collection included surveys completed by primary school students and student teachers involved in both the experimental and control groups. For primary students, the survey addressed the motivation, engagement, and perceived comprehension of the material after the lessons. Questions were phrased in age-appropriate language, and where necessary, teachers assisted students in interpreting the content to ensure reliable responses. For

the student teachers, the survey addressed the readiness to use Minecraft in the classroom, impressions of how well the game-based tools supported formative assessment, and observations of student reactions.

All surveys were conducted after the intervention, with responses collected anonymously and voluntarily to encourage honesty and minimise bias. In addition to the surveys, teacher observations and student test results were used to triangulate the findings. The data obtained from these tools were analysed both qualitatively, through thematic coding of open-ended responses and observations, and quantitatively, using the Mann–Whitney U-test to identify statistically significant differences between the control and experimental groups. This combination of student feedback, teacher reflection, pre- and post-lesson assessment provided a comprehensive picture of how gamified formative assessment affected student learning and engagement.

The collected data were analysed using the Mann-Whitney U-test to determine significant differences between the control and experimental groups, with evaluation criteria including the quality of lesson plans, student readiness to apply Minecraft, primary school student responses, and the effectiveness of formative assessment. The methods employed included Minecraft Education Edition as the primary tool for developing and implementing gamified formative assessment, the Mann-Whitney U-test as the statistical method to analyse the differences between the experimental and control groups, and qualitative methods, specifically surveys and observations, to gather feedback on student engagement and teacher implementation.

The structured approach was used for a comprehensive evaluation of the impact of Minecraft-based gamified formative assessment on primary school informatics education. The experiment unfolds in a series of stages. Initially, students from both groups underwent a theoretical preparation phase, learning key concepts such as gamification, formative assessment methods, and how Minecraft can be used in primary school settings. Afterwards, the experimental group participated in a practical session where students were introduced to Minecraft Education and learned to utilise its built-in assessment tools, such as quests, building tasks, Redstone mechanisms, and NPCs for feedback. Once students were comfortable with Minecraft, the participants from the experimental group were tasked with designing personal interactive lessons. These lessons were centred around Minecraft, incorporating elements such as signage, digital success tables, and in-game tests to provide formative assessments. The lessons were then validated by conducting open lessons in primary schools with implemented Minecraft-based learning environment, gathering feedback from primary school students on motivation, engagement, and material comprehension.

Prior to the study, ethical approval was obtained from the school. Informed consent was obtained from the parents or legal guardians of all participating primary school students. Assent was also obtained from the students themselves, where appropriate, ensuring their voluntary participation. All data was anonymised to protect the privacy of the participants, and the study adhered to the ethical guidelines and principles. All research activities were conducted following established ethical guidelines for educational research, particularly the ethical standards outlined in the Ethical guidelines for educational research (2018). The study respected participant confidentiality, ensured voluntary participation, and provided the right to withdraw at any stage without consequences. No identifying information was disclosed, and data were used solely for academic purposes.

RESULTS AND DISCUSSION

Assessment is a fundamental part of the learning process, shaping not only how students comprehend and engage with educational content but also how personal progress is perceived. Among various approaches, formative assessment is notable as an essential tool for guiding students through learning. In contrast to traditional summative assessments, which evaluate knowledge at the end of a unit or course, formative assessment is continuous, dynamic, and student-centred. It provides real-time feedback, helping students identify areas for improvement while enabling teachers to adapt instruction accordingly. This process fosters expands comprehension, encourages self-reflection, and improves learning outcomes.

At its core, formative assessment is about learning in progress, not just measuring results. It transforms the classroom into an environment where mistakes are viewed as opportunities rather than failures. As students receive immediate feedback, a sense of progress over learning is developed, gradually building confidence in the abilities. The traditional model of grading often discourages risk-taking, as students fear low scores that might impact their overall performance. Formative assessment, on the other hand, develops a growth mindset, motivating students to experiment, explore, and refine the knowledge through active participation. However, implementation of effective formative assessment strategies in primary education presents certain challenges. Many teachers struggle with integrating assessment seamlessly into lessons without overwhelming students or disrupting the flow of learning. There is also the issue of engagement – traditional formative assessment techniques, such as quizzes, written reflections, or verbal questioning, may not always captivate young learners, particularly in an era where digital technologies dominate daily experiences. This is where gamification is a notable solution, providing an engaging, interactive way to assess students in real-time while maintaining their interest and motivation.

One of the most effective platforms for gamifying formative assessment is Minecraft Education Edition. Originally designed as a sandbox video game, Minecraft has evolved into a versatile educational tool, offering a unique way to integrate problem-solving, creativity, and collaboration into the learning process. In contrast conventional educational software, which often feels restrictive and structured,

Minecraft enables students to explore, build, and interact with a dynamic world that mirrors real-life problem-solving scenarios. It provides an immersive environment where students engage with learning materials in a natural and enjoyable way. The power of Minecraft in education is determined by rendering abstract concepts tangible. Whether students are designing historical landmarks, simulating ecosystems, or programming logic-based circuits with Redstone, knowledge is constructed actively rather than passive information absorption. This level of engagement is crucial for formative assessment as it enables teachers to observe students' thought processes in action. Instead of simply grading an answer on paper, educators can view how students approach challenges, what causes struggle, and what strategies should be used to overcome obstacles.

Minecraft is particularly effective for formative assessment as it provides instant feedback loops. For example, students working on a coding challenge within Minecraft can immediately note whether their commands function as intended. If something doesn't work, the approaches can be tweaked, enabling idea verification without penalties. This aligns with the principles of formative assessment, which emphasise trial, reflection, and improvement. Moreover, Minecraft's collaborative nature enables peer assessment, where students learn from each other, exchange feedback, and refine skills together.

Another key advantage is that Minecraft naturally integrates different types of formative assessment without creating an atmosphere of a test. Teachers can monitor progress through in-game achievements, observation of student creations, or structured challenges where students demonstrate comprehension in a hands-on manner. Additionally, built-in tools such as NPCs (non-player characters) for providing hints, digital signboards for instructions, and Redstone mechanisms for interactive quizzes can be used by educators to design assessment experiences to feel as engaging adventures rather than traditional tests. In primary education, where play-based learning is essential for cognitive and social development, Minecraft provides a bridge between structured learning objectives and student-driven exploration. The open-ended nature of the game fosters critical thinking, adaptability, and perseverance – key skills that are beneficial beyond academic success. When formative assessment is embedded in such an engaging environment, students internalise learning goals more effectively, taking an active role in education rather than being passive recipients of information.

As education continues to evolve in the digital age, the need for innovative assessment approaches becomes more pressing. Formative assessment, when combined with gamification and digital tools such as Minecraft, has the potential to transform learning into a more engaging, personalised, and effective experience. By leveraging Minecraft's ability to immerse students in meaningful problem-solving scenarios, teachers can ensure that assessment is not just about measuring what students know but about assisting in development and success. Minecraft Education is more than just a game; it is an innovative educational platform that renders learning more realistic, which traditional methods could not achieve. It is built to engage students in a fun, interactive, and immersive environment where exploration, creation, and learning is done while developing critical skills. What sets Minecraft Education apart is its versatility – teachers can use it for a wide range of subjects, from math and science to history, language arts, and coding. One of the key features of Minecraft Education is the variety of educational tools. The game provides a rich variety of in-game elements that are tailored to support different learning outcomes. For instance, there are "Lesson Plans" designed to guide educators on how to efficiently incorporate Minecraft into curriculum. These plans often come with ready-made worlds, which are pre-designed environments or scenarios that students can explore. Teachers can also create worlds and crafting lessons that fit their students' needs.

Minecraft Education is beneficial in hands-on, project-based learning. For instance, students can collaborate to solve problems or complete quests, which helps develop teamwork, critical thinking, and problem-solving skills. For instance, during the "sustainable community" project, students in the experimental group collaborated to design and build virtual cities within Minecraft, requiring critical thinking to solve resource management challenges and develop collaborative strategies to achieve their goals. The quests designed for the coding lessons required students to problem-solve in real time, for example if an NPC gave a student a task to create a Redstone circuit, the student had to problem solve to make the circuit operational, and then collaborate with other students to create larger circuits. The increase in student motivation can be partially attributed to the project-based learning that Minecraft Education provides, as the students were able to collaborate, and problem solve, while working on the given tasks.

In the presented study, students were tasked with designing and constructing virtual environments that required collaboration, problem-solving, and critical thinking. For instance, during the coding lesson, the students were to collaborate on Redstone circuit creation. This active engagement in project-based tasks contributed to the enhanced student engagement and improved problem-solving skills observed in the experimental group. Furthermore, this aligns with previous research that has demonstrated the ability of the platform to improve student collaboration. The game also included tools for formative assessment, such as NPCs (non-playable characters) that can provide feedback, or digital success tables where students can track the progress. The tools not only help in teaching but also offer ways for teachers to monitor how well students are grasping concepts in real-time. Another feature is the Code Builder, which introduces students to the coding in a visual and accessible way. By using block-based programming (similar to Scratch), students can create personal in-game events and mechanisms, bringing computational thinking into learning experience. This is

especially beneficial for teaching computer science and STEM subjects, as it demonstrates abstract concepts through tangible, interactive experiences. Minecraft Education also encourages creativity, enabling students to build structures, explore historical sites, and even recreate real-world environments, rendering subjects such history and geography less abstract. It supports diverse learning styles, with visual and kinesthetic learners thriving in the hands-on approach Minecraft offers, while auditory learners can benefit from the in-game lessons and guides (Fig. 1).

Figure 1. Thematic lesson sets in Minecraft Education
Source: screenshot from Minecraft Education Edition

In terms of efficiency, research and feedback from educators have shown that Minecraft Education can significantly boost student engagement. It transforms lessons from passive activities into active experiences. Students are not just memorising facts – learned material is applied in a fun and meaningful environment. Minecraft also promotes self-directed learning, as students often must employ trial and error, which encourages resilience and improves comprehension. Minecraft Education can be efficient in formative assessment, providing real-time insights into students' understanding. One of the most engaging features in Minecraft is the use of NPCs (non-playable characters) to provide feedback. In this context, the students – future teachers – developed and implemented these NPCs as part of an interactive learning experience for teaching computer science to elementary school students. These NPCs act as virtual assistants within the game, guiding students, offering hints, and assessing their progress.

The process began with the students creating NPCs within the game world. Students placed the NPCs in various locations, such as classrooms, mazes, or simulated computer labs, where NPCs would interact with students during learning tasks. For instance, in a lesson on basic programming concepts, an NPC might be positioned near a set of blocks that students must arrange correctly to "code" an action in the game. In this study, the "World Game Code" from the Minecraft Education Edition's Computer Science lesson library was used as a foundational tool for introducing primary school students to basic programming concepts. As illustrated in Figure 2, this pre-designed world provided an interactive environment where students could visually manipulate code blocks to control in-game actions. The future computer science teachers utilised this world to design formative assessment tasks, such as challenges requiring students to sequence commands correctly to navigate obstacles or solve puzzles. This ensured real-time observation of students' problem-solving processes and immediate feedback through in-game Non-Player Characters (NPCs), enabling teachers to assess student comprehension and adapt their instruction accordingly.

Figure 2. World Game Code from the Computer Science lesson library in Minecraft Education Edition
Source: screenshot from Minecraft Education Edition

Once the NPCs were positioned, the students programmed actions using the "Agent" feature, a simple block-based coding interface that does not require extensive programming knowledge. This was used to design how the NPCs would interact with students – what dialogues would display and what actions would be done in response to students. The key to using NPCs as a formative assessment tool is in designing an interaction algorithm that provides students with immediate, personalised feedback based on performance. For instance, if the task was for students to write a simple algorithm to move a Minecraft character to a specific spot, the NPC would evaluate whether a student

used the correct commands and offer feedback accordingly. If a student wrote the correct sequence, the NPC might say, "Great job! Your code is correct. You've moved the character across the course!" If the sequence was wrong, the NPC would gently guide the student, saying, "Hmm, it looks like the character didn't move. Did you check the order of the commands? Try again!".

As the students progressed, the NPCs would offer additional guidance based on the student's struggles, such as, "Remember, in programming, the order of commands matters. What happens if you switch the jump and move commands?". This created an interactive feedback loop where the NPCs not only assessed students' work but also supported learning with helpful hints. The students also designed the learning world to reinforce coding concepts, setting it up as an obstacle course or puzzle that students needed to solve using basic programming commands. Students integrated challenges such as moving, jumping, and performing tasks such as collecting items, with NPCs acting as assessors and mentors, providing feedback based on the students' success or failure in completing each task. The world was structured in a way that challenged students' knowledge of programming concepts, such as sequencing, loops, and conditions. Each stage of the world had an NPC that assessed the students' comprehension and offered tailored feedback.

To make this system effective, the students needed access to Minecraft Education Edition, where these features are available, and knowledge of how to use the "Code Builder" and basic programming interface. This initial learning process, although requiring some effort, developed interactive lessons and formative assessment tools for students that could be used by elementary students to learn computer science concepts. Students also developed a learning objective and lesson plan that integrates the interactive features of Minecraft with the necessary core concepts to be taught. In a computer science class on learning the basics of programming, the NPCs created were used to assess how well students comprehended these concepts and provided the guidance required to succeed. Figure 3 illustrates the Non-Player Character (NPC) feature within Minecraft Education Edition, a key tool utilised by the future computer science teachers in this study. The NPC, as depicted, served as a virtual assistant within the Minecraft world, programmed to deliver instructions, provide hints, and offer real-time feedback to primary school students during their learning activities. This interactive element facilitated formative assessment by enabling teachers to observe student progress and comprehension through the NPC's responses and interactions, enhancing the dynamic and personalised learning experience.

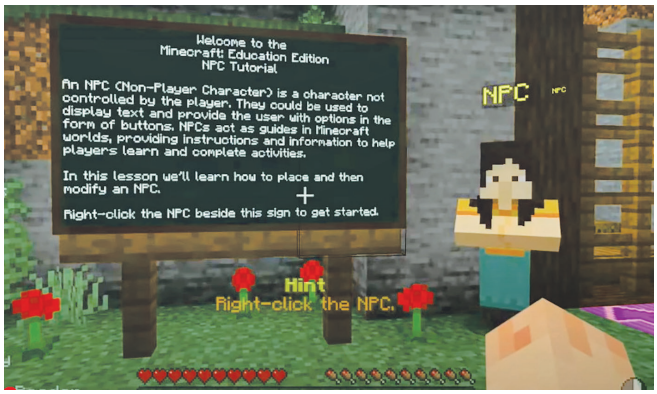

Figure 3. NPC (Non-Player Character) in Minecraft Education Edition
Source: screenshot from Minecraft Education Edition

During the training, student teachers discovered and implemented various Minecraft tools to enhance formative assessment, one of the most useful being digital progress charts. These charts were used by primary school students to track progress throughout the lesson, rendering the learning process more transparent and interactive. The student teachers designed these charts to appear within the Minecraft world, seamlessly integrating assessment into the gameplay. The process began with the student teachers incorporating digital progress charts into the lessons. These charts were designed to visually represent a student's progress as different tasks were completed in the game. For instance, if the lesson involved solving a series of puzzles or coding challenges, the chart could update in real-time to show which tasks the student had completed and which ones still needed attention. This feature provided not only immediate feedback but also the visual demonstration of personal development throughout the lesson, encouraging self-reflection and motivation. Student teachers created these progress charts using Minecraft's in-game tools, such as command blocks and signs, which could be programmed to automatically update as students achieved certain milestones.

Command blocks in Minecraft are beneficial tools that execute various in-game commands automatically when triggered. Command blocks can be used to manipulate the world, control game mechanics, and create complex interactions without manual input. These blocks can summon entities, modify player attributes, manage game rules, and alter the environment by placing or removing

blocks. Additionally, command blocks can teleport players, change weather conditions, set time, and manage inventory items. Beyond basic functions, command blocks support conditional logic, enabling command execition based on specific criteria. Command blocks can also interact with Redstone circuits, enabling automated sequences and chain reactions. In more advanced applications, command blocks can run JSON-formatted commands, display messages, and manipulate scoreboard objectives for tracking player progress. For instance, as students completed a coding task or solved a problem, the chart could reflect their achievements by showing a checkmark or a coloured progress bar. This tracked learning progress of students and provided a visual representation of content advancement.

The effectiveness of using digital progress charts was evident in the engagement of students in the learning process. As students saw their progress reflected in the game, improving motivation for further efforts and development. The progress charts not only provided a sense of accomplishment but also provided the student teachers insight into each student's learning. By tracking how students interacted with the tasks and when difficulties were present, the student teachers could adjust their approach in real-time, offering additional support or challenging students further as needed. Figure 4 demonstrates the use of command blocks within Minecraft Education Edition, specifically showcasing the application in creating interactive assessment tasks. In this example, the command block is configured to detect the presence of a diamond block, triggering an in-game event. Future computer science teachers in this study utilised such command blocks to design digital progress charts and interactive challenges, enabling real-time tracking of student progress and providing immediate feedback. This feature enabled a dynamic and engaging formative assessment approach, where students could visually monitor the achievements and teachers could gather insights into student learning.

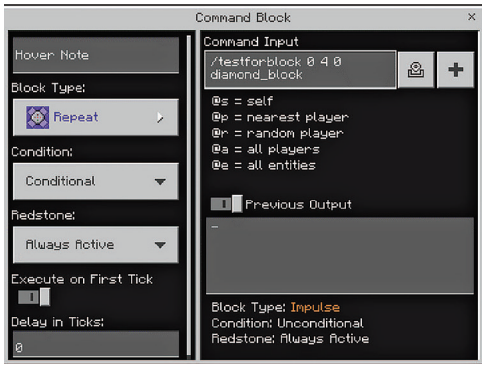

Figure 4. Example of setting up a command block – searching for a diamond block in the Minecraft world
Source: screenshot from Minecraft Education Edition

Incorporating digital progress charts into Minecraft-based lessons demonstrated the student teachers the potential of game-based learning to foster a more personalised and engaging educational environment. The charts were both motivational for students and a valuable resource for the student teachers to assess and refine teaching methods. This experience highlighted the capabilities of integrating formative assessment techniques into interactive learning environments such as Minecraft, rendering the assessment process more dynamic, transparent, and meaningful for both students and teachers.

Table 1 presented the final scores of students from both the experimental and control groups, along with respective rating positions. Students in the experimental group, who were taught using gamified formative assessment with Minecraft Education Edition, generally achieved higher scores than the control group. The sum of ranks for the experimental group is 60, while the control group's sum of ranks is 18. This suggests that students in the experimental group performed better overall compared to those in the control group, indicating a positive effect of the implemented method on student outcomes.

Table 1. Final scores of experiment participants

Student number	Scores in the experimental group	Experimental group (ranks)	Scores in the control group	Control group (ranks)
1	48	12	28	1.5
2	44	10.5	32	3.5
3	40	8	40	8
4	44	10.5	32	3.5
5	36	5.5	2	1.5
6	40	8		
7	36	5.5		
Σ		60		18

Source: original data collected by the authors during the experimental study

The ranks for the experimental and control groups are: The sample sizes are:

$$\Sigma R_A = 60, \Sigma R_B = 18.$$

The formula for the Mann-Whitney U statistic is:

$$U_A = n_A n_B + \frac{n_A(n_A+1)}{2} - \sum R_A. \quad (4)$$

$$U_B = n_A n_B - U_A. \quad (5)$$

Substituting the values:

$$U_A = (7)(5) + \frac{7(8)}{2} - 60 = 35 + 28 - 60 = 3.$$

$$U_B = (7)(5) - 3 = 32.$$

The smaller U value is:

$$U = \min(3.32) = 3.$$

Use of statistical tables or a p-value calculation for the Mann-Whitney U-test:

$$p = 0.0106.$$

For a significance level of $\alpha = 0.05$, since $p < 0.05$, the null hypothesis was rejected.

Since the Mann-Whitney U-test yielded a statistically significant result ($p < 0.05$), the study concluded that the scores in the experimental group were significantly higher than those in the control group. The results should demonstrate a statistically significant difference between the experimental and control groups, with better results in the experimental group. This indicates that the scores in the control group are systematically lower than those in the experimental group. Therefore, the experimental validation of the developed methodology has proven its effectiveness and is recommended for implementation in the educational process.

The boxplot highlights the difference in distributions, showing that the experimental group generally has higher scores. Figure 5 presented a boxplot illustrating the distribution of total scores for both the experimental and control groups. The data, summarised in the accompanying table, reveals a trend: the experimental group's scores are generally higher, with a sum of ranks reaching 60, compared to the control group's sum of ranks at 18. This visual representation highlights the significant difference in performance between the two groups, supporting the conclusion that the Minecraft-based gamified formative assessment had a positive impact on learning outcomes. The following discussion contextualises the empirical results in the existing literature and highlights the practical application. I. Sánchez-López *et al.* (2022) analysed Minecraft: Education Edition as a pioneering example of a digital learning platform within the metaverse. Using a methodology combining Multimodal Discourse Analysis, Grounded Theory, and the Constant Comparative Method, the study analysed educational potential of Minecraft, emphasising key features such as participant identity, agency, creativity, and the role of community in the learning process. The study highlighted how the platform adapts physical world elements to a connected digital environment, introducing novel aspects such as avatars, multimodal literacy, and game mechanics that foster creativity. The study concluded that Minecraft: Education Edition provides significant benefits for teachers, parents, and administrators, with the educational experience largely dependent on how these stakeholders manage and execute the platform's pedagogical possibilities.

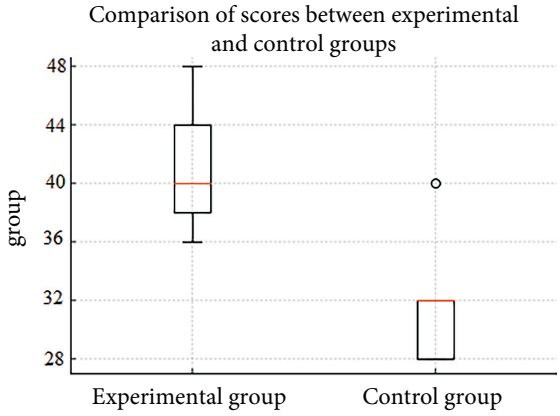

Figure 5. Boxplot with results in the experimental and control groups

Source: developed by the authors based on the study's experimental data

The research by C.I. Helvey *et al.* (2023) explored the potential of games, particularly sandbox games such as Minecraft, for experimental research in human operant behaviour. The study discussed how boredom and subject interest were long-standing challenges in traditional human operant research, where participants may lose motivation due to the repetitive nature of tasks. By incorporating dynamic, game-like experimental paradigms, researchers can minimise attrition and boredom, rendering tasks more engaging and reducing the probability of participants disengaging. Games such as Minecraft, which enable customisation with minimal or no coding requirements, present an accessible solution. These games offer flexible environments for creating controlled yet dynamic experimental tasks, enabling researchers to design experiments that are more engaging for participants.

M.K.A. Sulaiman *et al.* (2024) explored the use of Minecraft Education to teach solar photovoltaic (PV) concepts to secondary school students in Malaysia. The study determined that Minecraft Education significantly enhanced students' comprehension of solar PV technology, improving knowledge retention. The platform proved to be an engaging tool that rendered complex scientific principles more accessible, promoting active participation and critical thinking. The findings support the integration of digital

tools in science education to improve learning outcomes (Sulaiman *et al*., 2024).

The work by P. Andersen & M. Rustad (2022) analysed the use of Minecraft as an educational tool to support collaborative learning in math classes at the higher education level. The study determined that Minecraft facilitated collaborative learning processes and assisted in development of 21st-century skills in students. By combining social network analysis (SNA) and interaction analysis (IA) as research methodologies, the study demonstrated that Minecraft encouraged collaboration and subject-specific learning. These findings provide valuable insights for creating learning designs that use digital tools to enhance collaborative learning and contribute to the field of computer-supported collaborative learning (CSCL). O. Cóndor-Herrera *et al*. (2021) explored the application of Minecraft Education as a tool for pedagogical teaching. The study highlights how emerging teaching methodologies, such as gamification, are reshaping educational environments by integrating non-traditional elements such as video games. Minecraft Education promotes creativity, collaboration, and problem-solving in a digital, immersive environment, enabling teacher-student engagement on diverse lessons and projects. The study emphasised how this approach, combining gamification with STEM (Science, Technology, Engineering, and Mathematics) learning, enhances student motivation and engagement.

The study by G.K. Ming (2023) explored how Minecraft Education is integrated into teaching through digital game-based learning (DGBL). The study analysed forty lesson plans created for Minecraft Education, emphasising language, topics, skills, and student age. The findings demonstrated how teachers design lessons within the Minecraft Education Framework, aiming to foster creativity, critical thinking, problem-solving, and collaboration. The study highlighted the growing use of Minecraft Education in Malaysia, particularly in subjects such as science, mathematics, social studies, and English, demonstrating its potential to enhance student engagement and skill development. A. Crespo (2021) examined the role of lead users in the development of Minecraft: Education Edition within the game-based learning (GBL) market. The study highlights that teachers, as primary users, were the originators of the game and 90% of the significant, functionally novel innovations within the platform. These findings contrast with the role of producers, who were responsible for 100% of the dimension-of-merit innovations that improve existing user functions. A. Crespo concluded by emphasising the value of lead users in the GBL field and offers suggestions for producers to better support and learn from this vital source of innovation.

N.M. Shamsudin & T.S. Hoon (2024) explored the integration of AI copilot in Minecraft Education Edition to enhance teacher training and pedagogical practices in STEM education. The study addressed how AI copilot tools can support curriculum development, improve classroom management strategies, and engage students in interactive STEM learning activities. Using a qualitative approach, the research examined the benefits and challenges of AI copilot in teacher training programs, providing insights into its potential to foster collaborative learning environments and optimise STEM education delivery. The findings aim to offer evidence-based recommendations for educational stakeholders seeking to leverage AI to improve teaching and learning outcomes.

Therefore, Minecraft Education provides a rich, multifaceted platform that supports a wide range of subjects and offers both teachers and students a substantial tool for learning. Whether it's solving math puzzles, exploring historical events, or building virtual ecosystems, the game's flexibility and engaging environment, therefore efficient for fostering learning across various disciplines. A. Sortwell & K. Trimble (2015) conducted a systematic review of meta-analyses examining the impact of formative assessment on K-12 students' learning to understand its effectiveness and sustainability. The study reviewed 13 meta-analyses, each on formative assessment in primary and secondary education, utilising systematic literature searches from several key databases. The review found that formative assessment generally produces positive effects on student learning, ranging from trivial to large, with no negative effects identified. However, the effectiveness varied based on the type of assessment used.

Yu. Kulimova (2024) conducted a systematic literature review on formative assessment practices in secondary schools. The study identified three main themes: assessment diversity, assessment strategies, and student learning development. The study emphasised the importance of teacher professional development programs for efficient implementation of formative assessment in classrooms. Such training will help teachers integrate assessment practices to enhance student outcomes in 21st-century education. Z. Zhang & J. Crawford (2024) explored the impact of gamified formative assessment (GFA) on the motivation of EFL learners, using Quizizz as a case study. The study, based on self-determination theory, determined a strong positive correlation between the experimental and control groups' scores across stages, highlighting the role of gamification in enhancing learners' internalisation and engagement. The results demonstrated that the experimental group achieved higher accuracy (89.05%) compared to the control group (74.01%), indicating that GFA boosts motivation, performance, and language proficiency in EFL learners. This research contributes to the literature by emphasising the effectiveness of gamification in fostering student engagement and improving language skills at the elementary level.

In the study by B. Shannaq (2024) presented a model for transforming formative assessment in Omani education, particularly addressing challenges related to cultural hesitancy and low classroom participation. The model integrates digital formative assessment using the Moodle Learning System (MLS), which successfully improved student engagement and performance. The research determined that approximately 90% of students benefited from

this approach, with academic scores increasing by more than 10%. This study highlighted the effectiveness of digital formative assessment in overcoming cultural and participatory barriers, thereby enhancing learning outcomes in educational contexts with limited classroom engagement.

B.B. Ndlovu (2025) explored the role of formative assessment and constructive feedback in enhancing quality education in grade 12 Accounting classes in South Africa's Northern Cape Province. Through qualitative interviews with 15 teachers, the study revealed that teachers are aware of the importance of quality education and formative assessments but emphasise that these assessments should be tailored to address learners' challenges as necessary. The study concluded that teachers should be trained to efficiently provide feedback as part of their teaching practices to improve student performance. Future research should address the effectiveness of feedback and strategies for measuring its impact on learning outcomes. J. Moon *et al.* (2024) investigated the use of multimodal learning analytics as a formative assessment tool in mathematics teacher education. By analysing collaboration of undergraduate students, facial expressions, and emotional data, the study identifies patterns that reveal significant relationships between collaborative discourse, emotional indicators, and lesson performance. The results demonstrated that multimodal data can effectively predict learning outcomes and provide deeper insights into the learning process. This approach offered promising implications for math education, though the study also highlights its limitations and suggests future research avenues to further refine this method.

Authors J.F.P. Luzano *et al.* (2024) explored the use of Symbolab and Photomath applications as formative assessment tools in calculus studies at Bukidnon State University. Through interviews, observations, and document analysis, the study identified four key themes: learning support in mathematics, ethical use of math applications, user-friendly features, and accessibility and inclusivity. The findings suggested that these applications enhance students' learning experiences and provide teachers with valuable tools to improve calculus instruction. The study recommended that both students and teachers actively utilise these applications to deepen the expertise and awareness in the subject. C. Li *et al.* (2024) conducted a scoping review to investigate the use of gamified formative assessment (GFA) in supporting English language learning for school-aged students. The review analysed 30 articles (35 interventions) published between 2016 and 2023, determining that points and leaderboards were the most common gamification elements, and immediate, simple written feedback was the primary form of feedback. The study revealed that GFA, particularly through quizzes, significantly enhances students' academic performance in English proficiency, vocabulary, and grammar, as well as boosts their motivation, satisfaction, and engagement. However, the review highlights the need for more theory-driven, methodologically rigorous studies to expand the comprehension of GFA's impact on young learners.

S. Tirado-Olivares *et al.* (2024) investigated the use of learning analytics (LA) in primary education to enhance historical thinking. The study, involved 76 elementary students (ages 10-12), explored the impact of LA on academic achievement and self-efficacy. The findings revealed that LA particularly benefitted students with low historical knowledge, enabling the prediction of academic performance, especially in historical thinking. The study also identified a gap between students' perceived abilities and actual performance, suggesting the need for formative tasks that help students recognise limitations and misconceptions before exams. The results indicate that LA can be a valuable tool for formative assessment in history education.

The discussion of the reviewed literature underscored that Minecraft Education is a multifaceted and engaging platform supporting a wide range of subjects, offering both teachers and students a powerful learning tool. Studies consistently demonstrate its effectiveness in enhancing student engagement and knowledge retention. Furthermore, research on formative assessment emphasises positive impact on learning outcomes, with gamified approaches and digital tools such as AI copilots, learning analytics, and mobile applications proving particularly effective in boosting student motivation and performance. These studies highlight the importance of integrating digital technologies and innovative assessment strategies to improve educational practices and address contemporary learning challenges. In summary, the study demonstrated that Minecraft Education Edition significantly improved student engagement and performance in the experimental group compared to traditional methods. The results highlight the effectiveness of gamified formative assessment tools in enhancing learning. These findings suggest that game-based learning can foster more dynamic and effective educational experiences. Future research could explore the long-term impact of these methods.

CONCLUSIONS

The study highlighted the potential of gamification and formative assessment in improving informatics education for primary school students. By integrating Minecraft Education as an interactive learning tool, student-teachers were able to create engaging lessons that encouraged problem-solving, creativity, and motivation among young learners. The findings demonstrated that well-structured gamified formative assessments, such as NPC-based feedback systems and digital progress charts, not only enhance students' comprehension of key concepts but also rendered the learning process more dynamic and student-centred. Moreover, the experiment confirmed that future computer science teachers greatly benefit from hands-on experience in designing and implementing gamified lessons. Teachers not only gained technical proficiency in using Minecraft as a teaching tool but also developed essential pedagogical skills, such as fostering student engagement, adapting formative assessment strategies, and promoting a creative approach to instruction. The statistically significant results

from the study suggested that incorporation of such digital tools in teacher training programs could positively influence the way informatics is taught in primary schools.

Given the success of this approach, it would be beneficial to integrate more game-based learning strategies into teacher training curricula. Future educators should be encouraged to experiment with digital tools such as Minecraft to create interactive, student-centred learning environments. Universities and educational institutions should offer specialised courses that emphasise the use of gamification in formative assessment, ensuring that student-teachers develop the necessary skills to implement these methods effectively in real classrooms. Additionally, school administrators and policymakers should consider providing teachers with access to educational versions of popular digital tools, along with training on integration into the curriculum. Teachers should also be given opportunities to collaborate and share best practices, ensuring that gamification is not just an occasional classroom experiment but a well-supported instructional approach.

Future studies could conduct longitudinal analyses to assess the sustained impact of gamified formative assessments and explore the application of these methodologies across diverse digital platforms, thereby optimising the integration of 21st-century skills into primary education.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

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Гейміфікація формувального оцінювання в початковій школі через розробку та впровадження курсів із використанням Minecraft майбутніми вчителями інформатики

Анотація. Гейміфікація та формувальне оцінювання привертають дедалі більшу увагу в освіті як ефективні стратегії підвищення залученості студентів та покращення результатів навчання. Метою дослідження було визначити, як такий підхід впливає на мотивацію студентів, розуміння ключових понять інформатики та розвиток цифрових компетентностей у майбутніх педагогів. У дослідженні брали участь майбутні вчителі інформатики, які розробляли та впроваджували інтерактивні уроки з використанням Minecraft для полегшення навчання та оцінювання прогресу учнів. Це дослідження вивчало ефективність використання Minecraft Education як гейміфікованого інструменту для формувального оцінювання в інформатичній освіті в початковій школі. Результати показали, що інтеграція гейміфікованого формувального оцінювання значно підвищила зацікавленість, залученість та розуміння учнів. Майбутні вчителі також отримали цінний досвід у розробці навчальної діяльності, орієнтованої на учня, з використанням Minecraft, продемонструвавши вдосконалення педагогічних навичок та ефективне використання цифрових інструментів. Результати показали, що студенти продемонстрували підвищену зацікавленість, залученість та розуміння, коли формувальне оцінювання було інтегровано в гейміфіковане середовище. Крім того, майбутні вчителі отримали цінний досвід у розробці навчальної діяльності, орієнтованої на учня, розвитку креативності та ефективному використанні цифрових інструментів. Статистичний аналіз підтвердив позитивний вплив гейміфікованого формувального оцінювання на результати навчання. Це дослідження свідчить про те, що включення стратегій навчання на основі цифрових ігор у програми підготовки вчителів може значно покращити педагогічні навички та здатність створювати інтерактивний навчальний досвід. У дослідженні зроблено висновок, що гейміфікація може слугувати інноваційним та ефективним підходом до формувального оцінювання в інформатичній освіті, надаючи студентам негайний зворотній зв'язок, зберігаючи при цьому їхню мотивацію. Результати дослідження мають практичне значення для вчителів початкової школи, викладачів інформатики та розробників навчальних програм, які прагнуть інтегрувати гейміфіковані підходи в навчальний процес. Вони пропонують практичні поради щодо використання Minecraft Education для формувального оцінювання, що може підвищити залученість учнів та покращити результати навчання

Ключові слова: цифрове навчання; підготовка вчителів; інтерактивне навчання; залучення учнів; освітні технології