IRSTI 20.01.45

10.51889/2959-5894.2025.92.4.024

Ye.H. Zhabayev[1*], M.I. Revshenova[1], A.A. Amangeldin[1]

[1]Abai Kazakh national pedagogical university, Almaty, Kazakhstan
[*]*e-mail: ermahan_zh.h@mail.ru*

THE POSSIBILITIES OF USING AUGMENTED REALITY TECHNOLOGY IN TEACHING ROBOTICS TO SCHOOLCHILDREN

Abstract

The article is devoted to exploring the potential of using game elements in teaching robotics within the context of modern STEM education. The use of gamification in the educational process enhances students' motivation, engagement, and the effectiveness of learning outcomes. An analysis of scientific research has shown that the integration of game mechanics–such as point systems, levels, virtual rewards, and narrative scenarios–has a positive impact on knowledge acquisition, the development of engineering thinking, and the formation of teamwork skills. Special attention is given to the Kazakhstani experience of integrating gamification, particularly through the implementation of the mobile application RoboBil, designed for teaching robotics to middle school students. The application combines theoretical materials, practical tasks, quizzes, and AR-based reward models, enabling personalized learning paths and strengthening the gamification effect. The research results demonstrate that the use of the RoboBil mobile application increases students' interest in robotics, improves their academic performance, and develops their problem-solving skills. Thus, gamification combined with mobile technologies opens new perspectives for the development of educational robotics and can serve as a model for introducing innovative practices in schools.

Keywords: informatization of education, augmented reality, robotics, immersive technologies, STEM.

Е.Х. Жабаев[1], М.И. Ревшенова[1] , А. Амангелдин[1]
[1]Абай атындағы Қазақ ұлттық педагогикалық университеті, Алматы қ., Қазақстан

РОБОТОТЕХНИКАНЫ ОҚЫТУДА ОЙЫН ЭЛЕМЕНТТЕРІН ПАЙДАЛАНУ МҮМКІНДІКТЕРІ

Аңдатпа

Мақала заманауи STEM білім беру жағдайында робототехниканы оқытуда ойын элементтерін пайдалану мүмкіндіктерін зерттеуге арналған. Оқу процесінде ойын элементтерін пайдалану оқушылардың ынтасын, олардың сабаққа қатысуын және оқу материалын меңгеру тиімділігін арттыруға көмектеседі. Ғылыми зерттеулерді талдау ұпайлар жүйесі, деңгейлер, виртуалды марапаттар мен сюжеттік сценарийлер сияқты ойын механикасын енгізу білімді меңгеруге, инженерлік ойлауды дамытуға және топпен жұмыс істеу дағдыларын қалыптастыруға оң әсерін тигізетінін көрсетті. Геймификацияны интеграциялаудың қазақстандық тәжірибесіне, атап айтқанда орта мектеп оқушыларына робототехниканы оқытуға арналған RoboBil мобильді қосымшасын енгізуге ерекше назар аударылады. Қолданба теориялық материалдарды, практикалық тапсырмаларды, сынақтарды және марапаттардың AR үлгілерін біріктіреді, бұл сізге жеке оқыту жолдарын жасауға мүмкіндік береді және геймификация әсерін күшейтеді. Зерттеу нәтижелері көрсеткендей, RoboBil мобильді қосымшасын қолдану мектеп оқушыларының робототехникаға деген қызығушылығын арттыруға, олардың оқу үлгерімін арттыруға және практикалық есептерді шешу дағдыларын дамытуға ықпал етеді. Осылайша, мобильді технологиялармен біріктірілген геймификация білім беру робототехникасын дамытудың жаңа перспективаларын ашады және мектептерде инновациялық тәжірибелерді енгізуге үлгі бола алады.

Түйін сөздер: білім беруді ақпараттандыру, толықтырылған шындық, робототехника, иммерсивті технологиялар, STEM.

Е.Х. Жабаев[1], М.И. Ревшенова[1] , А. Амангелдин[1]
[1]Казахский национальный педагогический университет имени Абая, г.Алматы, Казахстан

ВОЗМОЖНОСТИ ПРИМЕНЕНИЯ ИГРОВЫХ ЭЛЕМЕНТОВ В ОБУЧЕНИИ РОБОТОТЕХНИКЕ

Аннотация

Статья посвящена исследованию возможностей применения игровых элементов в обучении робототехнике в условиях современного STEM-образования. Использование игровых элементов в образовательном процессе способствует повышению мотивации учащихся, их вовлеченности и эффективности усвоения учебного материала. Анализ научных исследований показал, что внедрение игровых механик, таких как система баллов, уровней, виртуальных наград и сюжетных сценариев, положительно влияет на усвоение знаний, развитие инженерного мышления и формирование навыков командной работы. Особое внимание уделено казахстанскому опыту интеграции геймификации, в частности внедрению мобильного приложения RoboBil, созданного для обучения робототехнике учащихся средней школы. Приложение сочетает теоретический материал, практические задания, тесты и AR-модели наград, что позволяет создавать персонализированные траектории обучения и усиливает эффект геймификации. Результаты исследования демонстрируют, что использование мобильного приложения RoboBil способствует повышению интереса школьников к робототехнике, улучшает их академическую успеваемость и развивает навыки решения практических задач. Таким образом, геймификация в сочетании с мобильными технологиями открывает новые перспективы для развития образовательной робототехники и может служить моделью для внедрения инновационных практик в школах.

Ключевые слова: информатизация образования, дополненная реальность, робототехника, иммерсивные технологии, STEM.

Introduction

This study investigates how incorporating game elements can enhance robotics education within modern STEM programs. In the context of rapid technological advancement and the increasing importance of digital literacy, educators face the challenge of engaging students in complex technical subjects such as robotics. Effective STEM education today requires innovative teaching approaches that make learning not only informative but also interactive, engaging, and enjoyable.

Robotics as a discipline integrates engineering, programming, mathematics, and problem-solving. While this interdisciplinary nature provides rich learning opportunities, it can also pose challenges for students who may find these topics abstract or difficult to relate to real-life applications. As a result, maintaining consistent motivation and interest becomes a key task for educators.

Gamification–defined as the application of game design elements in non-game contexts–offers a promising pedagogical approach to addressing these challenges. By introducing features such as points, levels, leaderboards, virtual rewards, and storytelling, gamification transforms the learning process into an experience that stimulates curiosity, engagement, and a sense of achievement [1,2]. When thoughtfully integrated into the curriculum, these elements not only sustain students' attention but also make the assimilation of complex engineering and programming concepts more accessible. Moreover, they help to cultivate essential 21st-century skills, including logical reasoning, creative problem-solving, collaboration, and perseverance [3-5].

Recent research and data from academic databases such as Scopus and Google Scholar reveal a growing interest in applying gamification to technical and engineering education [6]. Numerous studies report that combining traditional instruction with digital tools and gamified learning environments significantly improves student performance, enhances retention of knowledge, and promotes self-directed learning.

Within this context, the main objective of the present study is to examine the impact of game-based elements on the effectiveness of robotics learning. Specifically, it aims to identify which gamification strategies–such as point systems, AR-based rewards, or progress tracking–most effectively contribute to improving students' motivation, comprehension, and practical skills in robotics. The study also seeks to propose a model for integrating gamification into STEM curricula,

highlighting its potential to personalize learning trajectories and increase accessibility to technical education for students of different ability levels.

Research Methodology

The study began with an evaluation of how game elements can be applied in robotics education under modern STEM frameworks. We focused on identifying methods that maximize learning outcomes. We conducted a comparative review of scientific publications from Scopus and Google Scholar (2023-2025) covering gamification in STEM. Practical examples were also examined, including our mobile app RoboBil, which combines theoretical content, hands-on exercises, quizzes, and AR robot models used as rewards. The study was conducted on the basis of an analysis of existing educational programs incorporating game mechanics, as well as through practical experiments with middle and high school students. Within the framework of the experiment, the following game-based elements were employed:

-Competitions and tournaments (robot programming contests, robotics challenges).

-Achievement systems (levels, rewards, and rankings for successful task completion).

-Storylines and missions (thematic assignments related to robotics).

-Simulation environments (virtual laboratories where students can test programming solutions prior to applying them on physical robots).

Results of the study

The incorporation of game-based elements into robotics education within the framework of contemporary STEM learning significantly enhances instructional effectiveness by increasing the clarity and interactivity of educational materials. The analysis of the outcomes of implementing game-based elements revealed the following key trends, which are illustrated in Figure 1:

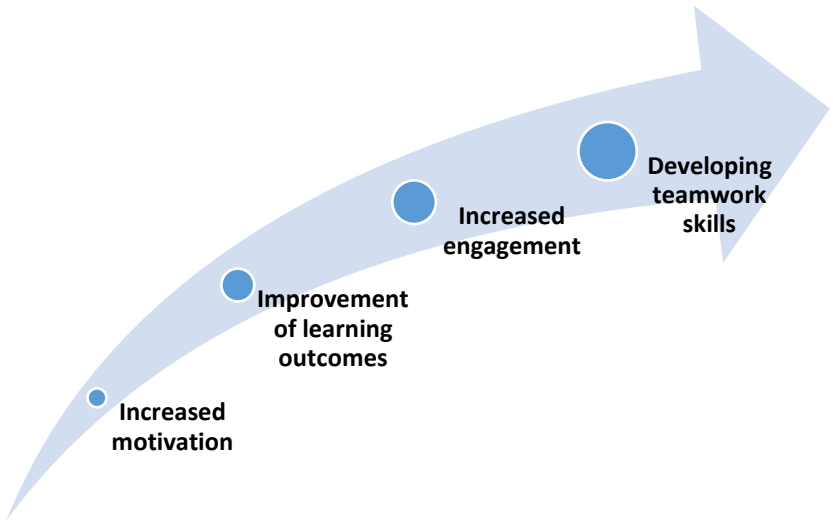

Figure 1. Key Trends in the Implementation of Game-Based Elements

During the experiment, 87% of students reported that the game-based format increased their interest in learning robotics. Learners engaged in the gamified environment acquired basic concepts of programming and robot mechanics more rapidly. Classes incorporating game elements attracted a broader range of students, including those who had previously shown little or no interest in robotics. Team competitions contributed to the development of communication and leadership skills. Nevertheless, several limitations were also identified:

- Excessive focus on the game – in some cases, students concentrated more on the gaming aspects than on the actual learning process;
- Need for additional teacher preparation – the successful implementation of game-based elements requires thorough methodological development and adequate technical resources.

The use of game-based elements in teaching robotics within the context of modern STEM education provides a number of advantages. First and foremost, a game-based approach enhances students' motivation and engagement in the educational process, as learning is perceived not as a routine activity but as an engaging and dynamic game. Game mechanics such as point systems, rankings, virtual rewards, and storyline-based tasks stimulate cognitive activity and foster a sustained interest in technical disciplines (see Fig. 2).

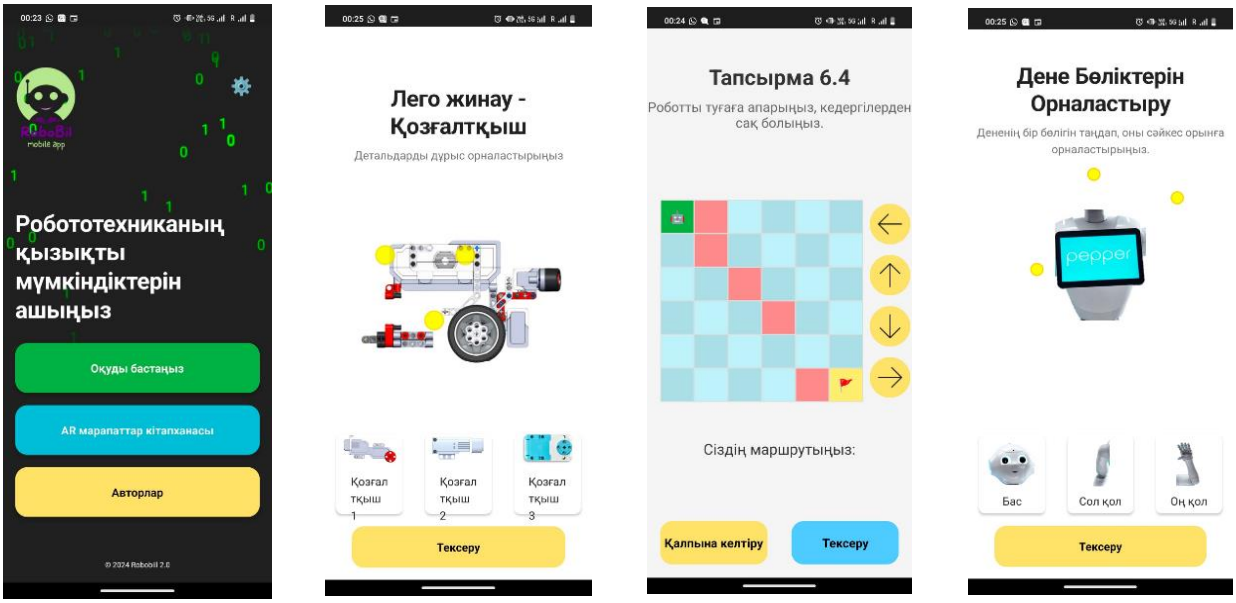

Figure 2. Game-Based Elements in the RoboBil Mobile Application

Moreover, the application of gamification contributes to the development of critical thinking, problem-solving abilities, and teamwork skills, which are among the key competencies of STEM education. In the context of project-based work, students learn to analyze, experiment, and generate creative solutions, while the game-based format reduces stress and alleviates the fear of making mistakes.

An important advantage also lies in the potential for personalized learning: game elements make it possible to adapt tasks to the learner's level of preparedness, ensuring a gradual increase in complexity and supporting an individualized trajectory of development.

Thus, the integration of game-based elements into robotics education not only enhances the effectiveness of learning outcomes but also fosters a sustained motivation among school and university students to engage with engineering and digital technologies, thereby preparing them for the challenges of the contemporary educational and professional environment.

A considerable body of research confirms that the integration of game-based elements into the educational process – particularly in the teaching of robotics and other STEM disciplines – has a positive impact on students' academic performance.

Based on the results of the conducted experiments, it was established that the use of game-based elements in the educational process has a positive impact on students' academic performance. In particular, learners engaged in gamified methodologies demonstrate higher levels of motivation, engagement, and cognitive activity compared to those taught within the framework of traditional pedagogical approaches. These findings are consistent with a number of international studies, which emphasize that gamification contributes to the development of critical thinking, the improvement of problem-solving skills, and the cultivation of a sustained interest in the disciplines under study. In a meta-analysis by Zeng et al. [7], which encompassed 22 experiments conducted between 2008 and 2023, a moderately strong positive effect of gamification on academic performance was observed, with a significant effect size of Hedges's $g = 0.782$ ($p < 0.05$) [8]. Similarly, the systematic review

by Jaramillo-Mediavilla et al. [9] confirms that the integration of game-based elements enhances both motivation and learning outcomes, further substantiating the influence of gamification on academic achievement.

Moreover, game mechanics create favorable conditions for the individualization of the learning process, allowing for the consideration of each student's level of preparedness and pace of knowledge acquisition. Therefore, the integration of game-based elements into robotics education within the framework of modern STEM learning can be regarded as an effective tool for improving the quality of education and fostering the key competencies of the 21st century.

Discussion

The application of game-based elements and mobile technologies, such as RoboBil, reflects global trends in the digitalization of education. Unlike traditional teaching methods, the application integrates learning, practice, and play within a single environment, which aligns with the principles of contemporary pedagogy and the digital transformation of education [10].

Moreover, RoboBil addresses the challenge of localizing educational technologies, as it is specifically designed for Kazakhstani school students and takes into account the national context. This serves as an example of how international approaches to gamification can be effectively adapted to the conditions of a local educational system.

The integration of gamification opens new perspectives for the advancement of personalized learning, which is particularly relevant for technical disciplines such as robotics. By combining game-based elements with intelligent algorithms, it becomes possible not only to enhance learners' motivation and engagement but also to ensure a flexible adjustment of the educational process to individual student needs. The Kazakhstani experience in this field demonstrates that the implementation of such approaches contributes to an increased interest in STEM disciplines, the development of sustainable learning habits, and the cultivation of independent learning skills.

At the same time, it is necessary to take into account the potential risks associated with the excessive or improper application of gamified practices. Among these are phenomena such as motivational fatigue (when constant exposure to external stimuli leads learners to lose intrinsic interest in the subject), a decline in academic focus (when attention is directed primarily toward the gaming component rather than the content), and the emergence of social pressure resulting from competition or comparison of achievements with peers. These factors may negatively affect both the quality of knowledge acquisition and the level of psychological well-being of school and university students.

Therefore, the integration of gamification into the educational process requires an ethically sound, scientifically grounded, and adaptive approach. Such an approach should include:

-the use of diverse game elements and mechanics (e.g., points, levels, scenarios, exploratory tasks, and cooperative missions),

-regular monitoring of the impact of game-based technologies on learners' motivation, academic performance, and emotional well-being,

-a flexible system of rotating game tools, which helps to prevent the "habituation effect" and sustain interest throughout the entire course,

-a balance between game mechanics and the substantive content of learning, ensuring that gamified practices serve not as a distraction but as a means of consolidating knowledge and fostering competencies.

Thus, a well-designed combination of gamification and artificial intelligence can not only enhance the effectiveness of teaching robotics and related disciplines but also foster learners' skills in self-organization, critical thinking, and teamwork. However, the key condition for successful implementation remains sustained attention to the psychological, pedagogical, and ethical dimensions of applying these technologies.

The results of the study confirm that the use of game-based elements in robotics education has a significant impact on students' motivation, academic performance, and the development of key skills.

The use of gamification makes the learning process more engaging and dynamic. A comparative analysis demonstrated that the level of motivation under traditional instruction was 62%, whereas with the integration of game-based elements it increased to 85%. This growth can be explained by the implementation of game mechanics (points, levels, virtual rewards), which provide students with an additional sense of engagement.

Table 1. The level of motivation of students

Teaching methods	*Average motivation level (%)*
Traditional education	*62*
With gamification	*85*

Gamification also has a positive effect on the effectiveness of knowledge acquisition. Student's academic performance increased from 68% under traditional instruction to 88% when gamification was applied. Importantly, the use of the RoboBil mobile application–which includes theoretical materials, tests, practical tasks, and AR-based rewards–not only reinforces learning outcomes but also helps to form individualized learning trajectories.

Table 2. Student performance

Teaching methods	*Students' academic performance (%)*
Traditional education	*68*
With gamification	*88*

Particular attention should be given to the development of teamwork, engineering thinking, and problem-solving skills. Without the use of gamification, the level of these competencies remained at 55–60%, whereas the application of game-based methods increased them to 80–85%.

Table 3. Developing key skills

Skills	*Without gamification (%)*	*With gamification (%)*
Teamwork	*55*	*80*
Problem solving	*60*	*82*

Thus, it can be argued that gamification in robotics education not only enhances students' motivation but also contributes to the improvement of their academic performance. In addition, it strengthens the development of teamwork and engineering skills, while simultaneously opening new perspectives for the integration of mobile technologies into the educational process.

The Kazakhstan experience of implementing the RoboBil mobile application demonstrates that the combination of game mechanics and digital technologies serves as an effective tool for improving the quality of STEM education and can be scaled to other academic disciplines.

Conclusion

In conclusion, game-based elements represent an effective means of teaching robotics within the context of modern STEM education. For the Republic of Kazakhstan, the introduction of gamification offers the opportunity to increase students' motivation, foster a sustained interest in engineering and technical disciplines, and create a learning environment that is both interactive and engaging. The use of game mechanics not only facilitates better knowledge acquisition but also promotes the development of critical thinking, teamwork skills, and creativity.

Scientific research and practical case studies–ranging from Kazakhstani schools to international projects–demonstrate that gamification improves learning outcomes, fosters the development of digital literacy, and makes the acquisition of complex technical concepts more accessible. In contexts where robotics laboratories cannot always be fully equipped, game mechanics serve as an alternative tool for engaging and sustaining students' attention.

A special role is played by the RoboBil mobile application, developed for Kazakhstani schools. It integrates theoretical materials, practical tasks, and game-based elements (points, levels, rewards, AR models), enabling the incorporation of robotics into the educational process even under limited resource conditions. The use of such applications extends the possibilities of gamification, ensuring access to digital tools for all students regardless of their region or the material resources of their schools.

Mobile applications for robotics with augmented reality (AR) support on students' personal devices provide the most effective means of scaling such tools across all schools in the Republic of Kazakhstan. Depending on the learning objective and technical capabilities, AR can be applied either through the addition of a virtual object (in cases where physical models and prototypes are unavailable) or through the addition of an informational layer (when objects are available but have a complex structure or limited functionality).

At the same time, it is necessary to take into account the emerging challenges: the need to prepare teachers for the use of game-based technologies, the development of high-quality instructional materials, and the provision of technical support for schools. When applied appropriately, game elements become not a form of entertainment but a full-fledged didactic tool that complements textbooks, practical activities, and digital platforms.

For Kazakhstan's innovation-oriented education system, the further development of gamification and educational mobile applications such as RoboBil may represent an important step toward modernization. The creation of teacher networks, the exchange of methodological solutions, the implementation of pilot projects, and government support for educational initiatives will contribute to the consolidation of game-based practices in school education. It can be anticipated that in the coming years, game elements will take a firm place in the teaching of robotics, while the Kazakhstani experience will serve as an example of the effective integration of digital technologies into the educational process.

Acknowledgements

This article was prepared with the financial support of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan within the framework of the grant-funded research project №AP19579496 «Development of a Mobile Application for Teaching Robotics to Students of Kazakh Secondary Schools».

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