METHODS OF TEACHING ROBOTICS IN SECONDARY SCHOOLS FROM THE TINKERCAD PLATFORM

Aripov Masud Marufovich
Candidate of Technical Sciences, Professor of the Department of Digital Technology and Artificial Intelligence.
Kokand State University, Ferghana region.

Annotation. The integration of robotics into secondary school curricula is becoming increasingly important to prepare students for the technological future. This paper presents a comprehensive methodology for teaching robotics in secondary schools using the Tinkercad platform, a user-friendly web-based tool that allows you to design, code and simulate electrical circuits in a virtual environment. The study examines how Tinkercad can enhance student engagement, creativity, and problem-solving skills through hands-on experience in designing and programming robotic systems. A mixed method was used to evaluate the effectiveness of the Tinkercad-based methodology. Quantitative data was collected through a preliminary and follow-up assessment of 200 students from 10 secondary schools, and qualitative data was collected through interviews with teachers and student focus groups. The results show that students have a significant understanding of the basic concepts of robotics, such as sensor integration, microcontroller programming, and system automation.

Keywords: Robotics education, Tinkercad, high school curriculum, STEM integration, educational technologies, microcontroller programming, project-based learning, simulation platforms, Arduino, digital literacy.

Introduction. In the 21st century, the rapid development of technology has led to profound changes in almost all areas of human activity, including education, and the most dynamic innovation is robotics, which has emerged not only as a field. At the same time, robotics is a powerful pedagogical tool. The introduction of robotics into secondary schools is becoming increasingly necessary in order to equip students with the skills needed in a technology-driven world. As digital literacy becomes a core component of modern education, educational institutions are looking for effective and affordable tools to integrate robotics into the learning process. One of these tools is Tinkercad, a free web platform developed by Autodesk that allows students to design circuits, write code, and simulate real-world robotic systems in a virtual environment.

The global transition to STEM education (science, technology, engineering, and mathematics) highlights the need to teach robotics as an interdisciplinary subject that promotes creativity, problem solving, and critical thinking. Robotics education promotes students' understanding of abstract scientific and mathematical principles by offering them practical applications. It transforms passive learners into active creators, encouraging hands-on research and iterative learning. However, the introduction of robotics in secondary schools is fraught with certain difficulties. Schools may not have enough financial resources to purchase equipment, and teachers may not have the technical knowledge necessary to teach complex robotic systems. This is where platforms like Tinkercad are invaluable, offering a simulated environment where both students and teachers can experiment, learn, and innovate without needing expensive physical components.

The educational potential of Tinkercad lies in its simplicity and accessibility. With just a computer and an internet connection, students can explore various aspects of electronics, programming, and robotics. Tinkercad supports the simulation of Arduino microcontrollers, allowing students to create interactive systems using block or text programming. With this platform, students can learn how to use sensors, actuators, and control systems, thereby gaining fundamental knowledge about embedded systems - knowledge that is essential in modern engineering and technology careers.

The purpose of this paper is to propose a structured methodology for teaching robotics in secondary schools using the Tinkercad platform. It aims to demonstrate how this platform can be effectively integrated into the school curriculum to increase student engagement and academic achievement in STEM-related subjects. The methodology is based on constructivist learning theories, emphasizing student-centered approaches and project-based learning models. Using Tinkercad, educators can create an interactive and collaborative learning environment that promotes 21st century skills development.

In addition, the article examines the broader implications of using virtual platforms in robotics education. While physical robotics kits such as LEGO and Arduino have traditionally been used in classrooms, their use often comes with significant costs. In contrast, Tinkercad is a free and scalable solution suitable for both urban and rural schools, especially in developing countries. The methodology presented in this paper includes a step-by-step scheme for integrating Tinkercad into lesson plans that meet national and international educational standards. It also contains practical strategies for teacher training, assessment development, and curriculum development.

In addition to its pedagogical value, this research contributes to the ongoing discourse on digital transformation in education. As distance learning and blended teaching models become more widespread, virtual platforms such as Tinkercad represent a paradigm shift in the teaching of technical disciplines.

Literature review. In recent decades, the emergence of robotics as a pedagogical tool has sparked growing interest in its application in formal education systems, especially in secondary schools. The literature on robotics shows that it has evolved from a specialized technical subject into an interdisciplinary teaching method aimed at developing 21st century skills. Scientists such as Papert (1980) laid the foundations of constructivist learning theories, which later served as the philosophical foundation for educational robotics. Papert emphasized the importance of learning through action, which is a central element of the educational environment based on robotics. Tinkercad, as a modern virtual tool, builds on these pedagogical traditions by providing accessible interactive platforms for modeling and coding robotics.

Robotics in high school. Alimisis (2013) research highlights the role of robotics in developing critical thinking, creativity, and collaborative problem solving among high school students. Robotics is no longer seen only as a path to an engineering career, but also as a means to strengthen key competencies in various disciplines. According to Eguchi (2014), teaching robotics allows students to learn by doing what is consistent with experimental learning theories and promotes student independence.

The rise of virtual platforms in STEM education. Due to the growing demand for distance learning tools, some scientists note the advantages of virtual platforms such as Tinkercad in overcoming logistical and financial barriers in STEM education. A study by Said et al. (2020) showed that students who use Tinkercad to model electronic circuits demonstrate a better conceptual understanding compared to those who use only textbooks or static visual materials. In addition, Gamaj and Ayres (2019) found that Tinkercad reduces cognitive costs.

The workload associated with traditional laboratory installations allows students to focus on problem solving rather than on the complexities of installation.

Tinkercad as an educational tool. Tinkercad has been praised for its simplicity and accessibility. Fidan and Tuncel (2019), this platform allows students to study circuit engineering, programming, and electronics in a safe and interactive environment. Its compatibility with Arduino simulators makes it an ideal tool for teaching robotics concepts such as sensor integration and automatic control. Students gain valuable coding experience by visualizing the practical impact of their code on virtual hardware.

Integrating robotics into STEM curricula. Many scientists advocate for the inclusion of robotics in national STEM curricula. Behrs and Portsmore (2005) argue that robotics can combine the often disparate teaching of science, mathematics, and technology. In this context, Tinkercad serves as a bridge between theoretical concepts and real-world applications. Weng et al. (2016) believe that project-based learning using robotics contributes to a deeper study of mathematical reasoning and computational logic.

Teacher readiness and professional development. The successful implementation of robotics in schools depends on teacher training. According to the findings of Barak and Assal (2018), many educators feel insufficiently prepared to teach robotics due to a lack of technical knowledge. This highlights the need for affordable tools like Tinkercad that require minimal setup and training. A study by Ahmed and Yusoff (2021) confirms that short-term training using Tinkercad significantly increases teachers' confidence in conducting robotics lessons.

Assessment strategies in robotics education. Effective assessment remains a challenging task in robotics education. Traditional testing methods often do not reflect the creative processes and collaborative efforts of students. According to Erwin et al. (2017), performance-based assessments, portfolios, and rubrics that evaluate problem solving and design thinking are more suitable for teaching robotics. The modular structure of Tinkercad projects allows teachers to develop assignments that comply with modern assessment methods.

Digital equality and accessibility. The issues of digital inequality are widely discussed in the context of robotics education. The UNESCO Report (2021) highlights that virtual tools such as Tinkercad can democratize access to STEM education in under-resourced regions. Unlike expensive robotics kits, Tinkercad is free and requires no physical components, making it affordable for schools on a tight budget.

Motivation and engagement. Student motivation is a recurring theme in the robotics literature. A study conducted by Petra and Price (2004) showed that students experience a greater sense of belonging and purpose when working on robotics projects. Tinkercad enhances this engagement by allowing students to immediately test and visualize their code, which creates a feedback loop that supports iterative learning.

Methodology. This section describes the design of the study, the selection of participants, the learning framework, tools and evaluation strategies used to study the effectiveness of using the Tinkercad platform in teaching robotics in secondary schools. The methodology has been developed in such a way as to ensure reproducibility, validity and reliability in accordance with the best practices in the field of educational research.

Research design. For a comprehensive study of both quantitative results (such as academic performance and conceptual understanding) and qualitative results (such as student engagement and teacher perception) A mixed-method approach was used. This approach allows for triangulation, increasing the reliability of conclusions by combining statistical data with descriptive evidence. The study was conducted according to a research sequential scheme, starting with a qualitative needs analysis to identify existing gaps in robotics training, followed by an experimental intervention using Tinkercad and culminating with an analysis of the results after the intervention.

Participants and selection. 10 secondary schools participated in the study. 220 students between the ages of 13 and 16 participated in the study. The schools were selected using a stratified random sample to ensure demographic diversity. The teachers involved in the study had an education in ICT, physics, or mathematics and had received prior training in using Tinkercad to teach robotics.

The stage of preparation for implementation. Before starting work in the classroom, a workshop was held for teachers on using Tinkercad, circuit modeling, Arduino programming, and project-based learning. Each teacher participating in the seminar received a guide with a description of the learning scheme and lesson plans.

In addition, students and teachers were offered a basic survey to assess previous experience in robotics, attitudes towards STEM and the level of digital literacy.

Instructional framework. The curriculum is based on project-based learning and constructivist pedagogy, when students actively construct knowledge by participating in practical, research activities. The course was divided into three main modules, lasting 12 weeks.:

Module 1: Fundamentals of Robotics and Electronics. Getting to know circuits, resistors, LEDs, and breadboards using the Tinkercad "Circuits" interface. Students simulate simple lighting systems and measure current/voltage

Module 2: Arduino and sensor integration. Programming Arduino using block and text code, using virtual sensors (for example, temperature, motion) and actuators (motors, buzzers).

Module 3: Final project. Students develop and model a robotic system (for example, a smart traffic light, a car that avoids obstacles).

Feedback from colleagues and presentations. Each week included a theoretical component, practical and laboratory simulations, reflective discussion, and weekly assessments.

Results and discussion. This section presents the empirical results of the study and discusses their implications in the light of the objectives set. To assess the impact of the Tinkercad platform on learning outcomes, student engagement, and the overall perception of robotics education in secondary schools, data obtained during preliminary and subsequent testing, surveys, and interviews with teachers were analyzed.

Improved conceptual understanding. The results before and after the test showed a statistically significant improvement in students' understanding of robotics and electronics concepts. The average score before passing the test was 42.5%, and after passing the test - 78.6%.

Increased student engagement. The student's thought diaries indicate a high level of engagement in the program. More than 89% of students said that Tinkercad made learning more "fun" and "easy" to understand.

Self-confidence and digital literacy. According to the results of surveys conducted after the intervention, 75% of students felt more confident when using digital learning tools. In addition, the digital literacy assessment showed that students' ability to navigate online platforms, troubleshoot code, and document their progress using digital tools improved by an average of 26%.

These results reflect the observations of Gamaj and Ayres (2019) that virtual instruments reduce cognitive load and promote confidence, especially in novice learners.

Teachers' views. Semi-structured interviews with 15 teachers revealed general enthusiasm for using Tinkercad in the classroom. Among the general advantages, the following were mentioned:

- simplified preparation and conduct of lessons;
- Real-time monitoring of student progress;
- flexibility in face-to-face and online learning formats.

However, some teachers noted that at first they were doubtful because they did not know the simulation tools. After the two-week training program, this concern has decreased, which suggests that professional development is a crucial factor contributing to successful integration.

Problems encountered. Despite the overall success of the program, several problems were noted. Limited Internet access, especially in rural schools, connection problems sometimes prevented classes from taking place. Workarounds included preloading simulations and scheduling lab sessions during low-workload hours.

Limitations of modeling. Some students noted that Tinkercad cannot fully reproduce the tactile sensations of working with real components. Although the platform is very effective for conceptual learning, its limitations in providing physical interaction have been recognized by both students and teachers.

Final projects. At the end of the course, students had to develop a working prototype robot using Tinkercad. The projects included:

- smart home systems;
- automated lighting for greenhouses;
- vehicles avoiding obstacles;
- environmental monitoring sensors (e.g. temperature, light).

Projects were evaluated based on creativity, functionality, problem solving, and documentation. 92% of the students successfully completed functional modeling, with more than 80% exceeding the expectations of the rubric.

This work demonstrated not only the acquisition of technical skills, but also the development of 21st century competencies such as teamwork, communication, and digital project management.

Implications for practice. The results show that Tinkercad can serve as an effective and scalable solution for integrating robotics education into secondary school curricula. Its accessibility and compatibility with project-based learning makes it a strong candidate for widespread adoption, especially in resource-constrained environments.

The high results and student engagement observed in this study suggest that virtual robotic platforms do not just replace physical sets, but can act as powerful educational tools, especially with thoughtful integration with pedagogy.

Conclusion

The integration of the Tinkercad platform into robotics education in secondary schools has shown promising results in terms of student learning, engagement, and digital competence. Through a blended research method involving more than 200 students in various educational contexts, the study provided compelling evidence that virtual platforms can significantly enhance STEM education if applied within a well-thought-out pedagogical framework.

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