Integrating TinkerCad in the Flipped Classroom Method*

J. Udvaros, and I. Pšenáková

Abstract—**The rapid development of digital technologies opens up new opportunities for the renewal of educational methodologies. The aim of our study is to investigate the applicability of TinkerCad, a web-based 3D modeling and circuit simulation tool, as an educational technology within the framework of the flipped classroom method. The research was conducted using qualitative and quantitative methods, including the analysis of student feedback, observations, and comparison of learning outcomes in traditional and flipped classroom environments.**

The results show that TinkerCad effectively supports active learning, encourages the development of problem-solving skills, and increases student motivation. Combined with the flipped classroom method, it provides students with the opportunity to master prior knowledge at their own pace, while practical application and joint problem solving come to the fore during classroom work. The study presents in detail the pedagogical potential of TinkerCad and makes suggestions for its effective integration into educational environments.

I. INTRODUCTION

The educational challenges and opportunities of the 21st century are closely intertwined with the rapid development of digital technologies, which are fundamentally reshaping the traditional frameworks of learning and teaching. The integration of digital tools into education represents not only a technological innovation, but also a pedagogical paradigm shift that enables new methodological approaches. One such innovative pedagogical method is the flipped classroom model, which rearranges the traditional teaching-learning process and emphasizes the active participation and independent acquisition of knowledge by students.

The essence of the flipped classroom method is that theoretical material is mastered in the context of independent learning at home, while the emphasis during classroom work is on practical application, joint problem solving and collaboration. This approach can be particularly effective when combined with technological tools that support interactive, exploratory learning. Tinkercad, a web-based 3D modeling and circuit simulation tool, is an excellent example of how digital technologies can be put at the service of the learning process.

The aim of our study is to examine the applicability of TinkerCad as an educational technology within the framework of the flipped classroom method. The results highlight that TinkerCad effectively supports active learning, encourages the development of problem-solving skills, and increases student motivation. We present the pedagogical potential of TinkerCad and make suggestions for its effective integration in different educational environments.

II. TINKERCAD

TinkerCad is an easily accessible, online-based design and simulation platform that is widely used as a virtual laboratory, especially in the field of technical and engineering education. The tool is popular because it allows users to design, test, and simulate various electronic circuits and 3D models without the need for expensive hardware or a physical laboratory environment. This makes TinkerCad an ideal choice for both educators and students, as it helps them acquire practical skills in a flexible and cost-effective way [1].

In the field of education, TinkerCad plays a prominent role in teaching the basics of digital electronics. The platform allows you to simulate basic experiments, such as demonstrating the operation of logic gates, handling Boolean functions, and designing combinational and sequential circuits. This allows students to receive real-time feedback on their work, so they can better understand the connections between theoretical background and practical application. In addition, TinkerCad helps develop problem-solving skills, as students can test different circuit configurations, find errors, and optimize their designs without causing any physical damage [2][3].

In the article [2], the authors aimed to compare the understanding and application of programming control structures – such as if–else branches, for loops, and while and do–while loop structures – in two groups of students taught using different methods. One group (the so-called "Original Group") learned using traditional, frontal teaching methods, while the other group (the "Control Group") learned the curriculum using an online, interactive simulation platform called TinkerCad. The two groups were almost equally sized: the Original Group consisted of 21 students, while the Control Group consisted of 20 students.

During the study, students' performance was measured using four different types of programming tasks, and the results were rated on a 0–5 point scale. SPSS statistical software was used to evaluate the data. First, an independent sample t-test was used to examine whether there was a significant difference between the responses of the two groups. The results of the test showed that the standard deviation of the responses of the two groups was the same, meaning that the performance of the groups was statistically comparable. The two-sided

J. Udvaros is with the Department of Business Information Technology, Faculty of Finance and Accountancy, Budapest University of Economics and Business, Budapest, Hungary (e-mail: udvaros.jozsef@ uni-bge.hu) and with the Department of Mathematics and Computer Science, Faculty of Education, Trnava University, Priemyselná 4, 91843 Trnava, Slovakia (e-mail: jozsef.udvaros@truni.sk).

I. Pšenáková is with the Department of Mathematics and Computer Science, Faculty of Education, Trnava University, Priemyselná 4, 91843 Trnava, Slovakia (e-mail: ildiko.psenakova@truni.sk).

significance level (Sig 2-tailed) exceeded 5% for all questions examined, which means that the null hypothesis – that there was no significant difference between the two groups – could be accepted. Therefore, based on classical parametric statistical tests, no significant difference could be detected between the groups taught using the traditional and digital teaching methods. However, since the responses did not always follow a normal distribution, the researchers also performed the comparison using a non-parametric statistical method, namely the Mann–Whitney test. This test is particularly suitable for comparing data with small sample sizes and non-normal distributions. According to the results of the Mann–Whitney test, a statistically significant difference was found between the performance of the two groups only for the first and fourth questions, while there was no significant difference for the second and third questions and the total score. This suggests that the use of the TinkerCad platform resulted in better performance only in certain types of tasks, while in other cases the two types of teaching methods showed similar effectiveness.

SPSS-based statistical tests indicated that learning supported by TinkerCad did not result in significantly better results compared to the traditional method based on the entire set of tasks examined. At the same time, the Mann–Whitney test also shows that in the case of certain programming structures (e.g. simpler branches or more complex cycles), visual, simulation-based learning may have been advantageous. This means that TinkerCad as an educational tool can provide not only an alternative, but in some cases a more effective solution in teaching programming skills, especially for students who require visuality and a practical approach.

Another significant application area is supporting electronics lab activities. TinkerCad has been successfully integrated into electronics courses in post-secondary technical education. Students can use the platform to design circuits in theory and then simulate them in practice, giving them the opportunity to experiment and analyze errors in a safe environment [4][5]. The software's intuitive user interface also promotes self-directed learning, as students can easily explore different aspects of electronics at their own pace [6].

Another advantage of TinkerCad is that it offers an interactive and collaborative learning environment. Since the platform is fully online, students and instructors can work together on the same project from different locations. This is especially useful in distance learning or in situations where access to physical laboratory resources is limited. In addition, TinkerCad's constantly updated toolset and curriculum integration capabilities contribute to the modernization of education and help increase interest in STEM (science, technology, engineering, and mathematics) fields [7].

TinkerCad is not just a simple simulation tool, but a versatile educational support platform that significantly contributes to the expansion of students' practical and theoretical knowledge. With the rapid development of technology, TinkerCad's role in education is expected to continue to strengthen, as it offers flexible, innovative, and effective solutions for training future engineers and technologists.

TinkerCad has several features that make it suitable for use in the flipped classroom methodology. The essence of the flipped classroom is that students work on theoretical knowledge at home, independently, while in class they focus more on practical application, joint problem solving and project work. This requires a digital learning environment that supports independent learning, visually illustrates the material, and provides opportunities for interactive activities. TinkerCad is exactly such a platform.

Since TinkerCad is completely web-based, students can access it anytime, anywhere, without the need to install a separate program or special devices. This makes it ideal for home preparation, as students can work at their own pace. Thanks to the visual and interactive nature of the platform, students can not only learn about programming structures or the operation of electronic elements in theory, but also try them out virtually. The simulation environment provides immediate feedback, allowing students to learn from their mistakes as they experiment and discover connections on their own.

A special advantage of TinkerCad is that it offers both visual block-based programming and text-based coding, allowing students of different backgrounds to approach the material in different ways and at their own level. Beginners can work with simple visual elements, while more advanced students can write real Arduino code. This flexibility allows for differentiated instruction, which is a fundamental goal of the flipped classroom approach.

The platform also provides the ability to save, share, and reuse projects. Students can create smaller projects at home that they can present in class, analyze together, or even improve upon. This supports collaborative learning, teacher feedback, and student self-reflection. TinkerCad is therefore not only technically practical, but also pedagogically ideal for engaging students in an active and motivated learning process, while taking responsibility for their own learning.

TinkerCad's features – such as easy accessibility, interactive simulations, visual and textual programming options, and a project-based approach – are an excellent fit for the principles of the flipped classroom. Its use allows for theoretical knowledge to be acquired in a home environment, while school time is focused on active learning and practical application.

III. Flipped classroom

The flipped classroom is an innovative educational approach that fundamentally reshapes traditional teaching methods by reversing the traditional roles of lectures and homework. In this model, students learn new material at home using a variety of learning resources, such as pre-recorded video lectures, readings, podcasts, or digital materials. This allows for the application of theoretical knowledge and interactive, student-centered activities such as discussions, problem-solving exercises, and group work during school hours. The role of the teacher also changes: from being a transmitter of knowledge to being a facilitator and mentor, helping students to actively participate in the learning process and develop their critical thinking [8].

One of the most significant benefits of the flipped classroom is increased student engagement and motivation. While traditional lectures involve students as passive recipients of instruction, the flipped model encourages active participation. During lessons, students can work on real-world problems, participate in group discussions, and solve problems together, creating a dynamic and inspiring learning environment. This active engagement not only increases interest but also promotes the development of independent learning skills [9].

Another benefit is improved academic performance. Numerous studies have shown that students who study in a flipped classroom achieve better academic performance, higher test scores, and demonstrate a deeper understanding of the subject matter. Student achievement can improve while dropout rates decrease, as classes provide more opportunities for individualized feedback and immediate intervention for learning difficulties. The use of active learning methods promotes the acquisition of lasting knowledge that can be used in the long term [10].

The flipped classroom also provides opportunities for independent, self-paced learning, which is especially beneficial for complex or difficult subjects. Since students study the theoretical material at home, they can watch the instructional videos, pause, replay them, or reread the readings at any time. This flexibility allows everyone to progress at their own pace, which helps to accommodate different learning styles and abilities [11].

Another important advantage is the increased interaction between students and instructors. Traditional classes are often lecture-based, leaving little room for active dialogue and discussion of individual questions. The flipped model, on the other hand, creates opportunities for personalized support from teachers in classes, and collaboration between students is also strengthened. This type of interactive learning environment promotes deeper understanding and the development of critical thinking [12].

In addition, the flipped classroom helps to develop 21st century skills, such as problem-solving, communication and collaboration skills, and digital competences. By working with digital tools and participating in group work, students gain practical experience that can also give them an advantage in the job market.

Although the flipped classroom has many advantages, its implementation is not without challenges. One of the most significant difficulties is the need for preparation and resources. Teachers need to invest a lot of time and energy in creating or selecting high-quality pre-learning materials, such as educational videos, digital learning materials, and interactive exercises. In addition, to make lessons interactive, they need to design learning activities that truly help students apply theoretical knowledge in practice. For teachers who are used to traditional lecture-oriented methods, this shift can be initially difficult and may even require additional pedagogical training [13].

Another challenge is for students to adapt to the new learning model. The flipped classroom requires greater autonomy, which may be initially overwhelming for some students. Students must be able to manage their own time effectively, develop independent learning strategies, and take responsibility for their own learning. Students who have previously learned passively, relying on the teacher, may find it more difficult to adjust to this more active, independent form of learning. Teachers can play a supportive role in this situation, helping students develop new learning habits [14] [15].

The flipped classroom often relies heavily on technology, which can be a further challenge, especially in underfunded educational institutions or technologically disadvantaged communities. Accessing online learning materials requires a stable internet connection and appropriate digital devices. The lack of these can lead to inequalities among students, which can hinder the effective implementation of the model. In such situations, educators may seek alternative solutions, such as providing offline learning materials or utilizing school infrastructure to assist students [16].

In addition, resistance to change, which can be experienced by both teachers and students, should not be underestimated. Teachers accustomed to traditional teaching models may feel uncomfortable when implementing new methods, while students may initially experience difficulties due to independent learning and active participation. In order to reduce resistance, it is important for institutions to support teachers with appropriate training and resources, and to clearly communicate the benefits of the model to students.

The flipped classroom is an educational model that radically transforms traditional learning processes, emphasizing active, student-centered learning. By increasing engagement, improving academic achievement, providing opportunities for independent learning and facilitating interaction between teachers and students, it offers an effective alternative to traditional teaching methods. However, successful implementation requires appropriate planning, resources and a conscious management of challenges.

The flipped classroom can not only improve academic performance but also contribute to the development of students' lifelong learning skills. With the continuous development of technology and the increasing demand for educational innovations, this model is expected to play an increasingly important role in future educational practices [17].

The flipped classroom method has spread worldwide in recent years at various levels of education. TinkerCad, as a digital design and simulation tool, has been integrated into STEM (science, technology, engineering and mathematics) education in many countries, especially in engineering and technology courses. Below we present the educational practices and trends in the integration of flipped classroom and TinkerCad in some countries. In the United States, the flipped classroom method is widely used at the high school and university levels, where the integration of TinkerCad is reflected in the MakerSpace movement, project-based learning and online courses. Students master the theoretical foundations at home, while working on real-world projects in the school environment, taking advantage of the simulation capabilities provided by TinkerCad [18]. In Finland, education is based on freedom of learning and technology integration, where students work on interdisciplinary projects combining computer science, physics and mathematics, while TinkerCad's visual

simulations support independent learning [19]. In Singapore, technology-oriented education uses the flipped classroom model in preparation for robotics programs and STEM competitions, where students prepare independently and then deepen their knowledge in mentored project work at school [20]. In Germany, as part of the dual education system, TinkerCad is used in vocational training and blended learning models, where a combination of theoretical and practical learning ensures effective education [11]. In South Korea, in the field of digital learning and STEM development, students acquire theoretical knowledge at home through the integration of smart classrooms and IoT projects, and then carry out real-time simulations using TinkerCad [21].

It can be said that international experience shows that the integration of flipped classroom and TinkerCad provides a flexible learning environment that allows for a combination of independent and group learning. This approach promotes interdisciplinary thinking, as students can apply knowledge from different subjects to a single project, while developing 21st century skills such as problem solving, critical thinking, creativity and technological proficiency.

IV. INTEGRATING TINKERCAD AND THE FLIPPED CLASSROOM METHOD

Integrating TinkerCad and the Flipped Classroom Method offers many benefits, including improved learning outcomes, increased student engagement, and greater flexibility. TinkerCad's intuitive, hands-on design tools allow students to explore complex engineering and design concepts at their own pace, fostering deeper understanding through active experimentation. In the Flipped Classroom Method, students work through educational content—such as videos, tutorials, and readings—outside of class, allowing for more time in class for collaboration, problem-solving activities, and immediate feedback. This combination promotes independent learning while developing critical thinking and creativity.

However, successful implementation requires careful planning, student and instructor support, and ongoing assessment and feedback. Educators should develop well-structured curricula that align TinkerCad activities with learning objectives, ensuring a seamless connection between theoretical knowledge and practical application. In addition, it is essential to provide adequate technical support and training for both teachers and students to overcome potential technological barriers and exploit the potential of the platform.

Figure 1. Steps of integrating TinkerCad and the flipped classroom method
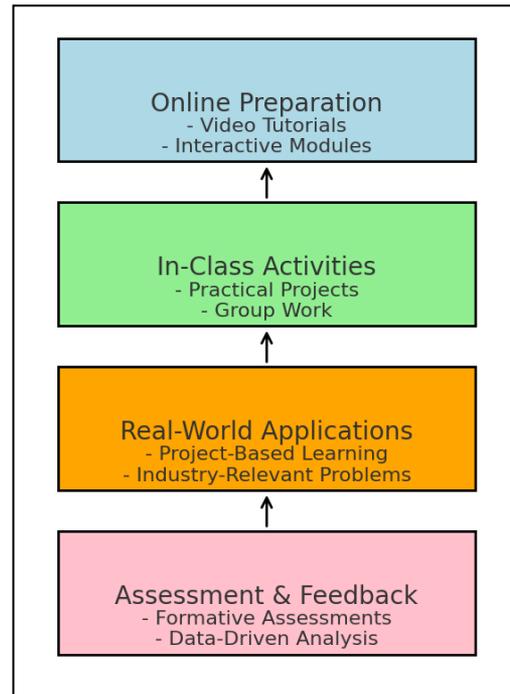
Continuous assessment plays a key role in this approach, as it allows educators to monitor student progress, identify areas for improvement, and adjust instructional strategies accordingly. Incorporating formative assessments, peer assessments, and self-reflection exercises helps reinforce learning outcomes and keeps students engaged [22].

By leveraging the strengths of TinkerCad and the flipped classroom approach, educators can create a dynamic and effective learning environment that prepares students for future challenges in engineering and design. This integrated model not only equips students with technical skills, but also develops core competencies such as problem solving, collaboration, and adaptability—qualities essential for success in today's rapidly changing technological environment.

Integrating TinkerCad into a flipped classroom model for teaching engineering involves several strategies that build on existing experiences and principles (*Fig. 1*). Let's look at some integration strategies:

A. Pre-Learning Online

- Video tutorials: Create short, focused video tutorials on TinkerCad basics and specific engineering concepts. These videos are available to students in advance, so they come to class prepared with the essential knowledge.

- Interactive modules: Develop interactive online modules where students can practice designing simple components or circuits using TinkerCad. This pre-work helps them become familiar with the software and basic concepts.

B. Active Learning in Class

- Hands-on projects: Use class time for hands-on projects where students can apply the knowledge they have gained during online learning. For example, they

can work on designing and simulating more complex components or systems in TinkerCad, promoting active learning and developing problem-solving skills.

- Group work: Encourage group projects where students work in teams to design and prototype engineering solutions using TinkerCad. This method promotes teamwork and social learning.

C. Real-world applications

- Project-based learning: Integrate TinkerCad into larger project-based learning activities. For example, students can design a product in TinkerCad, simulate its operation, and then 3D print a physical prototype.

- Industry-relevant problems: Present real-world engineering problems that students can solve using TinkerCad. This method helps students understand the practical application of what they are learning and increases engagement.

D. Assessment and feedback

- Formative assessments: Use formative assessments, such as quizzes and peer assessments, to gauge student understanding and provide immediate feedback. This can be done through TinkerCad projects, where students submit their designs for assessment.

- Data-driven analytics: Use data from learning management systems to track student progress and identify areas that need additional support. This data can help you customize lessons to address common challenges.

E. Benefits

- Increased engagement: Using TinkerCad in a flipped classroom model can increase student engagement by making education more interactive and hands-on.

- Skill development: Students develop critical engineering skills such as design thinking, problem solving, and collaboration, which are essential for their future careers.

- Flexibility: The flipped classroom model provides students with flexibility, allowing them to learn at their own pace and review material as needed, which can be especially helpful for complex engineering concepts.

F. Challenges

- Preparation time: Developing high-quality online content and interactive modules can be time-consuming for instructors.

- Consistency: Consistently applying the flipped classroom approach across different groups and instructors can be challenging, but it is essential for student success.

By incorporating TinkerCad into the flipped classroom model, educators can create a dynamic and effective learning environment that prepares students for the demands of the field.

V. CONCLUSION AND DISCUSSION

The study examines the potential of integrating TinkerCad, a web-based 3D modeling and circuit simulation tool, and the flipped classroom method in education. The TinkerCad effectively supports active learning, develops problem-solving skills, and increases student motivation. Combined with the flipped classroom method, it provides students with the opportunity to independently master theoretical knowledge, while the emphasis is on practical application and joint problem solving during classroom work.

The study presents the educational potential of TinkerCad, highlighting its advantages such as flexibility, interactivity, and cost-effectiveness. It also details integration strategies such as the use of prior online learning, practical projects, group work, and project-based learning (Fig. 2 shows a project circuit focusing on the use of the Arduino microcontroller). However, successful implementation requires careful planning, technological support for teachers and students, and ongoing assessment and feedback. The study emphasizes that this integrated approach not only develops technical skills, but also contributes to strengthening students' critical thinking, creativity, and collaboration skills.

Figure 2. Dashboard in TinkerCad
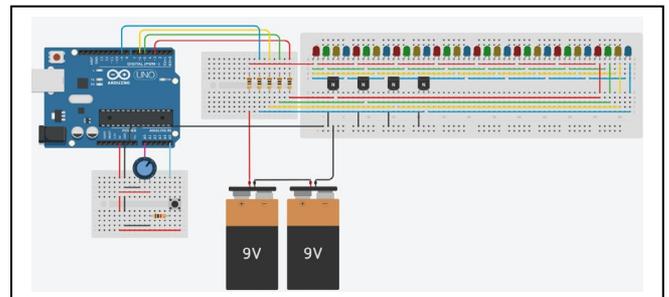
The results of the research indicate that integrating TinkerCad and the flipped classroom method can significantly contribute to improving learning outcomes, promoting active learning, and increasing student motivation. At the same time, the challenges and limitations encountered during the implementation also provide important lessons that can be taken into account to make educational practice more effective.

One of the most important observations is that while TinkerCad promotes the development of practical skills and the application of theoretical knowledge, students' technological proficiency greatly influences successful learning. Students who already had basic technical knowledge adapted to the new tool and method more quickly, while beginners needed more support and guidance. This highlights the need for educators to pay special attention to developing technological competencies before embarking on complex projects.

Furthermore, while the flipped classroom method increases student autonomy and flexibility, not all students are able to effectively handle the challenges of self-directed learning. Lack of self-motivation and time management skills may hinder the achievement of optimal learning outcomes for some

students. To address this, the study recommends ongoing mentoring and the incorporation of support mechanisms that help students develop independent learning strategies.

The transition to a new pedagogical approach can also be challenging for educators. Redesigning teaching materials, designing interactive lessons, and integrating technology tools requires a significant investment of time and resources. This is especially true in educational settings where access to digital tools is limited or where appropriate technical infrastructure is lacking.

Although the integration of TinkerCad and the flipped classroom method has many advantages, the effectiveness of the methodology depends largely on the educational environment, the preparedness of the instructors, and the technological access and learning style of the students. It is recommended that further research be conducted in different educational contexts to gain deeper insight into the long-term effects of the integration and to better understand the challenges and opportunities that arise during its implementation.

The novelty of the article lies in its unique examination of the effectiveness of the TinkerCad digital simulation platform in secondary school programming education, with a particular focus on the acquisition of control structures. While previous studies have typically analyzed the use of TinkerCad in the context of higher education or technical training, this research demonstrates through a specific example – an examination of a high school student group – that the platform can also be effectively used in the development of basic programming skills.

The special value of the research is its emphasis on visual learning and practice-oriented education. TinkerCad allows students to directly see the effect of their programs which strongly supports understanding, especially for novice programmers. This visual feedback helps to connect theoretical and practical knowledge and promotes deeper learning.

The study highlights that TinkerCad fits well with modern pedagogical methods, such as the flipped classroom model, where students can work on assignments at home and deepen their knowledge in class under the guidance of the teacher. The platform's interactive, visual nature, easy accessibility, and simulation of program codes make it suitable for both independent learning and shared analysis in class.

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