Fanny Litavczová
University Student
Student at J. Selye University, Faculty of Education, Komárno, Slovak Republic
litavczova.fanny@student.ujs.sk

Norbert Annuš
PhD., Doctor, Assistant Professor
J. Selye University, Department of Informatics, Komárno, Slovak Republic
ORCID ID 0000-0002-8535-2042
annusn@ujs.sk

BIOLOGY SCHOOL EDUCATION IN THE DIGITAL ERA

Abstract. This study aims to explore the specific features and challenges of biology education, with a particular focus on the shortcomings of textbooks and teaching materials, as well as the role of digital technologies such as interactive simulations, virtual reality (VR), and augmented reality (AR) in the teaching and learning process. The research examines the development and impact of digital tools in biology instruction and investigates students' and teachers' attitudes toward integrating these technologies into classroom practice. A detailed analysis is provided of the distinctive characteristics of biology as a school subject and the challenges encountered in teaching it, highlighting textbook deficiencies that could be addressed through the use of widely accessible digital resources. The study presents concrete examples of how digital technologies can be applied in biology education, with special attention to virtual models, VR and AR applications, interactive simulations, and online platforms that can enhance both the effectiveness and engagement of the learning process. As part of the research, currently used biology textbooks and workbooks were reviewed. Findings indicate an urgent need for innovation, as some institutions still rely on textbooks over two decades old, illustrated with static black-and-white drawings, to teach members of the Z and Alpha generations-students who were born into the digital era and are now learning in the age of artificial intelligence. An empirical survey was conducted among students and teachers in primary and secondary schools within the Hungarian minority community in southern Slovakia, assessing opportunities, experiences, and openness toward the use of digital tools in biology classes. The results were positive, confirming that digitalization has a clear future in biology education, extending beyond the domain of computer science instruction. Based on these findings, the study proposes recommendations for modernizing the delivery of biology curricula through more up-to-date teaching materials.

Keywords: biology education; educational technology; learning tools; virtual reality (VR); augmented reality (AR); interactive simulations and virtual models.

1. INTRODUCTION

The rapid advancement of digital technologies is exerting an increasingly profound influence on various fields of education, including the teaching of natural sciences and biology in particular. Due to its distinctive characteristics, biology education has always placed a strong emphasis on visualization and hands-on experiences. Traditional teaching methods, such as textbooks and chalkboard explanations, are often insufficient to fully convey the complexity of biological processes and systems, which can hinder students' ability to acquire and comprehend knowledge effectively. In biology education, the selected teaching methods should support not only the learning of biology, but also the understanding of the nature of biological sciences and the development of skills required to engage in scientific practice. Several biology topics require approaches that foster experimental problem-solving and the development of process-based skills. Students need both substantial scientific content knowledge and the ability to learn autonomously in order to achieve meaningful learning outcomes [1].

The problem statement. Traditional biology education has long existed in an essentially unchanged form, focusing primarily on the memorization of scientific facts and principles.

© Fanny Litavczová, Norbert Annuš, 2025.

Early studies have shown that teachers often expected students to acquire a substantial amount of scientific knowledge, largely independent of the processes of scientific inquiry [2]. Conventional methods have remained the standard instructional format in classrooms for decades, with lessons following fixed schedules that can make participation challenging for students with demanding timetables. In the absence of sufficient flexibility, students may find it difficult to balance their studies with work, family commitments, or leisure activities [3].

In Slovakia, the development of biology didactics has progressed in a relatively unstructured manner, making it one of the youngest disciplines among the didactics of the natural sciences. Perhaps the greatest challenge - requiring comprehensive analysis and systemic solutions - is the dramatic decline in interest in science and technology education. This trend raises numerous questions regarding the quality, effectiveness, and content of biology education across all school levels. The phenomenon is consistent with research findings indicating that students are generally not attracted to science subjects, and that biology is not among their most preferred disciplines [4]. Consequently, the scientific literacy of 15-year-old students in Slovakia remains at a low level, a fact repeatedly confirmed by the OECD PISA international assessments [5]. In addition to the OECD PISA results, numerous domestic studies have also shown that students tend to perceive biology and natural phenomena as abstract sciences detached from real life, and they often struggle to solve tasks of this abstract nature [6].

In biology education is so important the enhancing motivation, inspiration, and positive attitudes [7]. According to Franyó, a general problem in biology education is the decline in students' motivation and their limited openness to abstract thinking and problem-solving, which hinders effective teaching. The situation is further exacerbated by increasing class sizes and high teacher turnover. Additional challenges arise from the misalignment between the objectives of biology instruction and the requirements of final examinations. Moreover, most workbooks are of inadequate quality, a shortcoming attributable both to publishers and teachers. Many of the teaching tools necessary for instruction have not changed for decades, despite new curricula demanding updated resources. In primary schools, biology laboratories have often been discontinued, and the condition of specialized classrooms has deteriorated over time. While grammar schools and vocational secondary schools are generally better equipped, their specialized classrooms are frequently shared with other subjects [8]. Although Franyó's study was published in the early 2000s, as one of the authors reflecting on my own general and secondary school experiences over the past fifteen years, it is evident that biology education still often lacks the use of modern, interactive teaching methods that could help maintain student engagement. One of the most practical exercises remains herbarium preparation, even though biology offers much greater diversity. Traditional, frontal teaching does not provide sufficient hands-on experience and does not foster creative thinking. Furthermore, the use of digital technologies in biology education has not yet become widespread. The lack of appropriate digital tools and instructional materials impedes the implementation of modern teaching methods, and many teachers lack sufficient training to use digital technologies effectively [9].

Analysis of recent studies and publications. As early as 2006, David Warlick emphasized the importance of integrating digital technologies into education, stating: *„We need technology in every classroom and in every student's and teacher's hand, because it is the pen and paper of our time, and it is the lens through which we experience much of our world."* At that time, tools such as ChatGPT and other artificial intelligence applications existed only as science-fiction concepts [10]. Digital technologies and biologically relevant educational models could provide opportunities to make multiple lessons more practice-oriented and interactive. Nowadays, it is essential to leverage the modern technological opportunities at our disposal, including the broad use of artificial intelligence (AI) in education, as well as everyday handheld devices used by students, such as smartphones and tablets, along with wearable technologies

and robotics [11]. The effective use of digital technologies is crucial for delivering high-quality education and ensuring the smooth operation of schools, particularly in the digital age. The application of modern online educational technologies during distance learning amid the pandemic highlighted their significance and effectiveness. Previously, digital technologies and other information and communication systems available to teachers received insufficient attention and were not fully utilized [12]. Digital technologies create opportunities to support diversified learning styles, enhance accessibility and flexibility, provide personalized learning experiences, and facilitate communication and collaboration. These tools support various learning preferences, including visual, auditory, and interactive modalities [13].

Smartphones and other digital devices are extremely popular among students, making it worthwhile to leverage these tools during lessons. The “Bring Your Own Device” (BYOD) approach involves actively incorporating students’ personal devices into the teaching and learning process, thereby making lessons more effective and interactive [14].

Digital formats offer significant advantages they are non-perishable, easily accessible, and space-saving. This facilitates the digitization and easier access to natural objects, such as insects and plants. Thanks to digital tools, it is also possible to record and store information that is not visible to the naked eye, such as detailed surface textures obtained via microscopy or internal structures revealed through computed tomography (CT). Depending on the digitization method, samples can be stored in various data formats, such as two-dimensional (2D) photographs or three-dimensional (3D) surface models [15].

For generation Z and Alpha, nature is becoming an increasingly distant and less accessible reality. They have limited opportunities to engage with it directly, as truly experiencing nature often requires traveling to natural environments. Urban children, in particular, rarely encounter natural phenomena, and therefore mostly see plants and animals only through textbook illustrations. They explore the world far more frequently via the internet than in reality, navigating the virtual spaces of the digital realm long before venturing into forests, fields, or watersides. Virtual models exploit the possibilities offered by digitization and completely eliminate physical constraints. Their usefulness is enhanced by the ease with which they can be duplicated, whereas physical models have the clear disadvantage that as many copies are required as there are locations in which they are needed, making them expensive to produce. Virtual models also allow the demonstration of phenomena that cannot be observed under school conditions. They enable the illustration of large-scale or complex processes that cannot be fully monitored in reality due to size or duration, such as the development of the greenhouse effect. Furthermore, they allow the observation of extremely small phenomena invisible to the naked eye. While their use requires IT equipment, nowadays schools generally have basic IT infrastructure, and students typically have access to the devices needed to view virtual models at home. Virtual models exist in a digital space while still fulfilling the requirements expected of physical models. In biology education, virtual modeling is mainly implemented through animations and simulations [16]. Such dynamic visualizations facilitate information processing and support the learning process. Continuously changing visual elements help learners understand dynamic information and processes, reducing the risk of misunderstandings or incorrect conclusions that static representations, such as a misinterpreted image might cause. This approach also mitigates unnecessary cognitive load by helping students link separate knowledge elements, such as connections between images or schemas, thereby alleviating the strain on working memory. Students can pause, rewind, or replay visual content, making knowledge acquisition more effective [17].

Topics such as human and animal anatomy, as well as the functioning of body systems and organs, are difficult to fully understand through traditional written texts, two-dimensional diagrams, or verbal explanations alone. Therefore, the use of virtual reality (VR) as an educational tool can contribute to more effective knowledge acquisition among students [18].

Consequently, VR and augmented reality (AR) technologies have become exciting trends in education, making learning materials more interactive and presenting them in more lifelike contexts. Previous research has also confirmed that students demonstrate genuine interest in the educational use of VR, particularly in geography, biology, and history classes. These technologies typically combine sensors, devices, and software to create virtual environments where users have freedom of movement, can interact with objects, and experience scenarios that would be impossible to encounter in real life or within the confines of their educational institution [19]. These technologies also allow the integration of artificial intelligence into education, supporting personalized learning experiences and enabling experiential learning. The student transitions from a passive observer to an active participant, as the virtual environment allows users to perceive objects and all their properties, such as size, position, shape, and other visual characteristics [11]. Through these 3D models, students can explore the human body or observe cellular-level processes in real time, bridging the gap between theoretical knowledge and practical application. This shift toward experiential learning is particularly significant in biology education, where many concepts are abstract and difficult to imagine without technological support [20]. Lee and colleagues investigated the use of AR in teaching Mendelian genetics and found that students using AR-based learning materials significantly better understood inheritance patterns compared to those learning from traditional textbooks. This improvement was attributed to AR's ability to provide dynamic, interactive visualizations of genetic crosses [21]. These technologies help teachers guide students more effectively through advanced biology courses, reducing learning time and supporting comprehension of key concepts. As a result, educators can plan their curricula more efficiently and have better tools to reinforce learned content. VR-based instructional materials facilitate easier mastery of essential content, allowing students to review lessons independently outside the classroom, thereby strengthening autonomous learning skills. Additional advantages include accessibility and affordability: simpler VR headsets are now relatively inexpensive, and students can easily access educational VR content by downloading programs to their smartphones. Ultimately, ideal educational tools cannot achieve widespread adoption if they are prohibitively expensive [18].

A wide range of interactive educational tools and online platforms are available, all of which help make learning more engaging and effective. One such tool is interactive simulation, which allows students to conduct experiments or solve problems in realistic environments. Computer games encourage learning in an entertaining way while also developing problem-solving and strategic thinking skills. Interactive whiteboards enable students to engage directly with learning materials, respond interactively to questions, and deepen their understanding visually. These whiteboards can be combined with interactive simulations and online platforms. They allow lesson materials to be prepared in advance, reused later, and continuously improved [14]. Tools of this type provide students the opportunity to learn at their own pace while actively participating in the learning process. Educators have the opportunity to implement interactive teaching methods, including online presentations, interactive exercises, and videos. Digital tools facilitate the creation of collaborative learning environments, where students and teachers can easily share information, ideas, and project concepts [13].

In addition to the advantages of interactive educational tools, it is important to consider some disadvantages. Excessive use of technology may reduce personal interactions among students, which can hinder the development of social skills. Moreover, prolonged screen time can cause eye problems, such as eye strain and headaches, if adequate breaks are not taken. Technological devices, such as computers and internet access, are necessary for using interactive tools, and not all students have access to them, which may result in unequal opportunities. Furthermore, teachers' technological expertise plays a crucial role: without sufficient knowledge, they cannot fully utilize the capabilities of these tools, which can impede

the educational process. Therefore, the use of interactive tools should be balanced appropriately with traditional teaching methods [22].

The research goal. The aim of this study is to explore the specific characteristics and challenges of teaching biology, with particular emphasis on the opportunities offered by digital technologies. The research seeks to identify the difficulties faced by traditional biology instruction - especially those related to the shortcomings of textbooks and teaching materials- and to examine how digital tools, such as interactive simulations, virtual reality (VR), and augmented reality (AR), can enhance the educational process. In order to carry out the research, we involved institutions at primary and secondary education levels. We assessed the extent to which the textbooks and workbooks used in these institutions support effective biology teaching. In addition, we conducted an empirical survey to investigate students' and teachers' attitudes toward the integration of digital technologies into classroom practice.

2. RESEARCH METHODS

This study employed a mixed-methods research design, combining quantitative and qualitative approaches in order to obtain a comprehensive understanding of the use and effectiveness of digital and innovative teaching tools in biology education. Quantitative methods were primarily applied in the survey of students, while qualitative methods, supplemented with interviews, were used to gather in-depth insights from biology teachers. This approach was chosen to ensure both the statistical representation of general trends and the nuanced understanding of participants' experiences and perceptions, allowing for a richer and more holistic interpretation of the findings.

A systematic analysis of biology textbooks used in the participating schools was conducted. The evaluation criteria included: year of publication, intended grade level, covered topics, quantity and quality of accompanying visual materials, and the presence of interactive supplements.

A purposive sampling strategy was applied to target schools of different levels: primary schools, secondary schools, and grammar schools, with a specific focus on Hungarian-language educational institutions in Slovakia. The student survey was conducted with a total of N = 401 participants, while N = 22 biology teachers were involved in the qualitative part of the study. The questionnaires consisted of multiple-choice items, ranking tasks, open-ended questions, and four-point Likert-scale items designed to avoid neutral responses.

Data were collected between September 2024 and February 2025 through on-site visits to the selected educational institutions. Surveys were administered with the assistance of local coordinators and with the permission of school administrations. Participation was voluntary and anonymous; no personal data were collected from either students or teachers.

Quantitative data were analysed using descriptive statistics to identify patterns in the responses. Microsoft Excel was employed for data processing and the creation of graphical representations.

3. THE RESULTS AND DISCUSSION

In the following section, we present the results of our research, including the mapping and analysis of biology textbooks and workbooks, as well as the findings from the surveys conducted among students and teachers.

3.1. Analysis of Currently Used Textbooks

During our research, we established contact with several Hungarian-language educational institutions in southern Slovakia. This allowed us to explore a variety of textbooks and workbooks used across different regions and districts. In most of the institutions, the officially issued teaching materials were in use; however, there were also textbooks and workbooks sourced from foreign publishers, educational projects, or provided by associations of Hungarian teachers in Slovakia, which differed from the state-issued versions. The general information on the textbooks and workbooks we examined is presented in Tables 1 and 2.

Table 1

List of Textbooks

Title	Grade	Publisher	Year of publication	ISBN
Természetismeret (EN: Natural Science)	3. – PS[a]	SPN[c]	2011	978-80-10-02123-9
Természetismeret	4. – PS	SPN	2011	978-80-10-02124-6
Biológia (EN: Biology)	5. – PS	EXPOL P.[d]	2012	978-80-8091-280-2
Biológia	6. – PS	EXPOL P.	2010	978-80-8091-170-6
Biológia	7. – PS 2. – SS[b]	EXPOL P.	2017	978-80-8091-429-5
Biológia	8. – PS 3. – SS	SPN	2012	978-80-10-02143-7
Biológia	9. – PS 4. – SS	EDUCO	2012	978-80-89431-36-6
Biológia a gimnáziumok számára (EN: Biology for Gymnasiums)	2. - SS	SPN	2001	978-80-08-03095-X

a – Primary school
b – Secondary school
c – Slovenské pedagogické nakladateľstvo (EN: Slovak Pedagogical Publishing House)
d – Expol pedagogika

Table 2

List of Workbooks

Title	Grade	Publisher	Year of publication	ISBN
Természetismeret	3. – PS	SPN	2008	978-80-10-01564-1
Természetismeret	3. – PS	AITEC	2018	978-80-8146-145-3
Természetismeret	4. – PS	AITEC	2018	978-80-8146-155-2
Biológia	5. – PS	SZMPSZ[a]	2024	978-80-89919-24-6

a – Associations of Hungarian teachers in Slovakia

Our investigation revealed that today's students often still use textbooks that were published several years ago. The illustrations and textual content of these textbooks may have become outdated over time, as ongoing scientific developments mean that new discoveries and updates are not always reflected promptly in printed publications. This can be particularly problematic in rapidly evolving fields such as genetics or medicine.

The textbook illustrations we examined are either static or hand-drawn, and can be either colored or black-and-white, which may not provide the level of representation that digital tools can offer. Moreover, they lack the ability to present concepts from multiple perspectives or in three-dimensional space. Interactivity is missing, so students cannot dissect or zoom into elements. The illustrations are often simplified and stylized, reducing realism and potentially making detailed study more difficult. The level of detail is also limited, as a 2D image cannot fully capture complex biological structures. Furthermore, due to the lack of customizability, students cannot highlight or modify parts of the illustration according to their interests.

During school visits, some biology teachers even noted that these textbooks feel *„dry”* and would benefit from updates. Figure 1 presents a few examples of textbook illustrations.

Workbooks generally serve as effective tools for promoting active learning, as they allow students to complete exercises and tasks independently while mastering the material. They typically contain activities designed to develop students’ skills, deepen understanding, and provide opportunities for reviewing the content. However, a potential drawback is that repetitive, monotonous exercises may cause students to lose interest, and they may not offer an engaging learning experience for every student. Additionally, workbooks do not provide immediate, personalized feedback and do not necessarily encourage creative thinking. They are often single-use and can be costly to procure.

As shown in Table 2, one of the newest workbooks was published in 2024, making it relatively recent. Unfortunately, during our on-site visits to schools, teachers reported that these workbooks were still sitting in storage and had not yet been used.

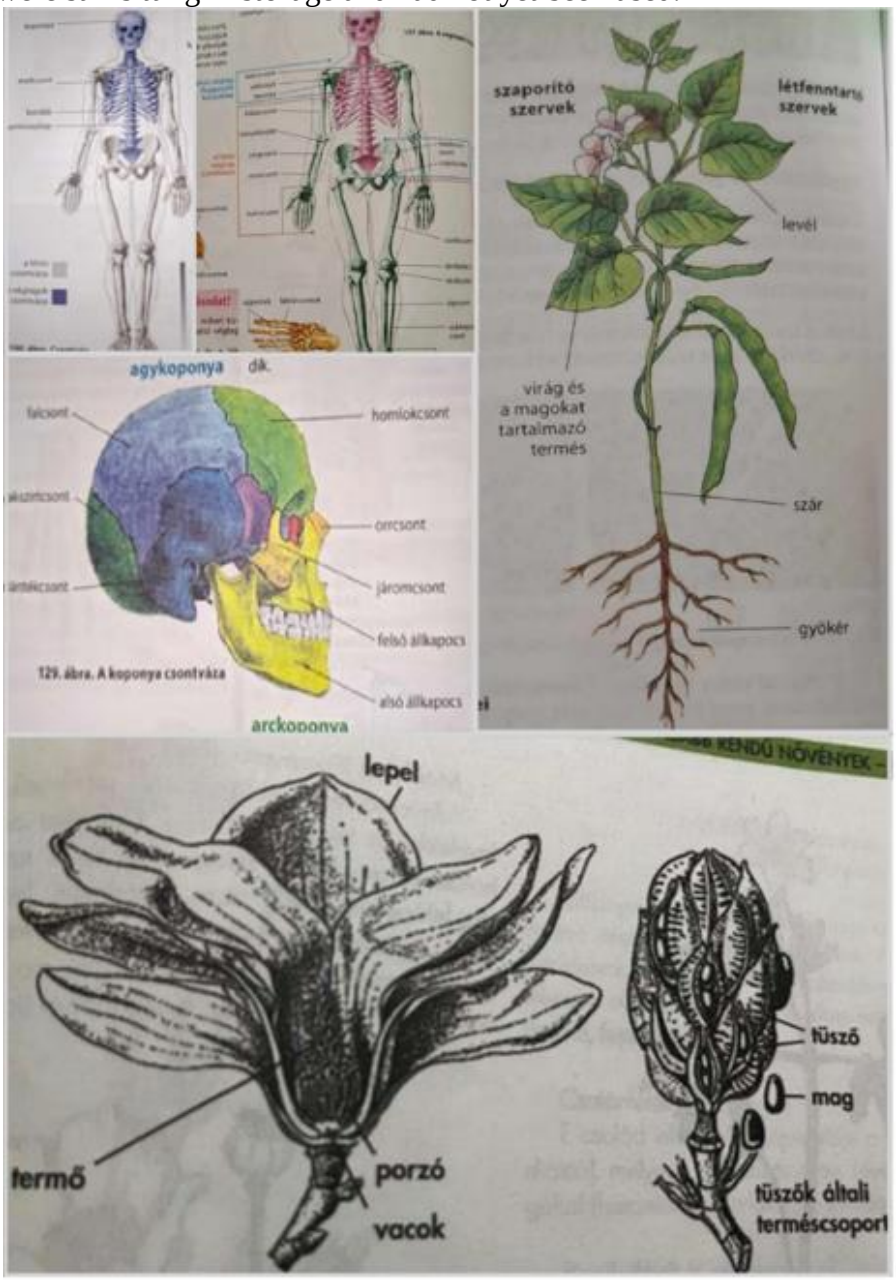

Figure 1. The images are taken from the following textbooks: Biology for Grade 7 of Primary Schools and Year 2 of Eight-Year Grammar Schools (2017 edition), Biology for Grade 6 of Primary Schools (2010 edition), and Biology for Grammar School Students 2 (2004 edition).

3.2. Students' Opinions on Digital Teaching and Learning in Biology

In this section of our survey, we aimed to examine how primary, secondary, and grammar school students evaluate visual learning materials in biology and how receptive they are to digital teaching supplements in the subject.

A total of 401 students participated in the online questionnaire, with an even distribution of 50% from primary schools and 50% from secondary schools and grammar schools.

Our primary focus was to investigate which learning styles the students prefer. This assessment was important to determine the proportion of students who favor visual learning compared to other learning styles. The results indicate that the majority of students prefer visual learning materials. This is further reflected in the fact that only 2% of respondents ranked visual materials last. The ranking of the different learning styles is illustrated in Figure 2.

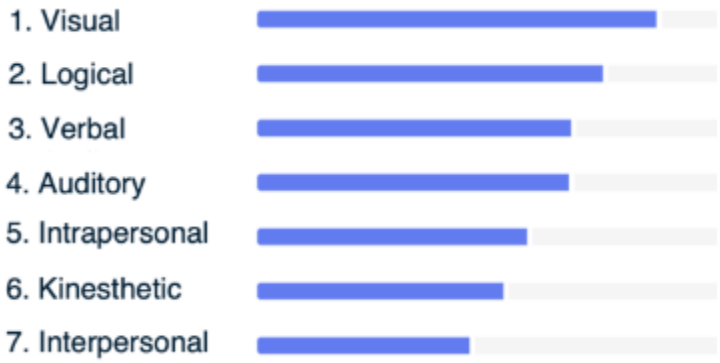

Figure 2. Frequency of Learning Styles Among Surveyed Students

Visual learning materials need to be up-to-date to meet the expectations of students from Generations Alpha and Z in the digital era. To assess this, we examined the proportion of students who have already used interactive digital learning materials in biology classes. Our results are illustrated in Figure 3, which clearly shows that biology lags significantly behind other science subjects. Interactive digital materials were most frequently encountered in computer science and mathematics lessons.

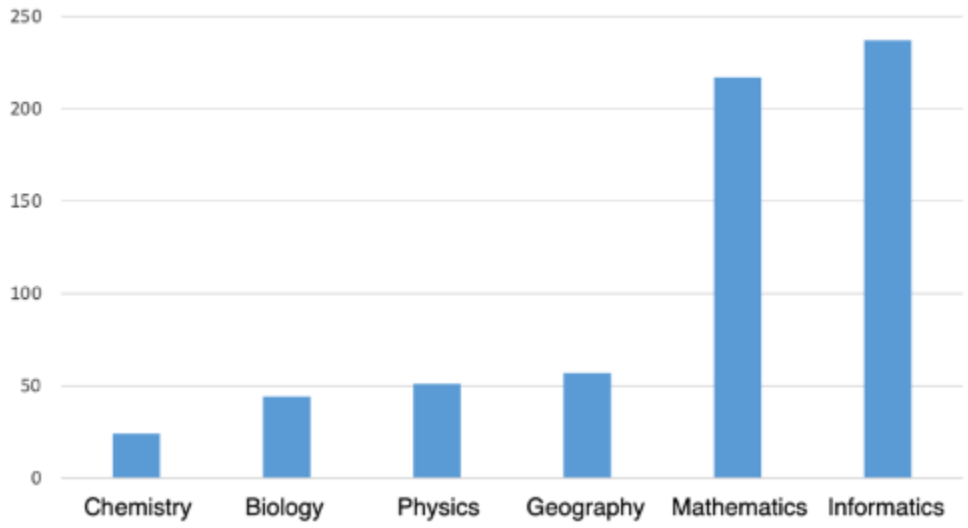

Figure 3. Use of Interactive Digital Learning Materials in Science Subjects

Consequently, responses to our subsequent questions were primarily evaluated for those students who had already used digital learning materials in biology classes a total of 44 students.

The survey results indicate that the use of interactive digital learning materials is more common among elementary school students. This suggests that current elementary students are encountering digital learning resources in biology lessons to a greater extent than their older peers did during their own elementary years.

These students were asked to evaluate the usefulness of interactive digital tools. Using a four-point Likert scale, they indicated how effective they considered this type of material for learning biology. The results show that students were almost unanimously satisfied and held a positive view of digital materials integrated into biology lessons. Notably, none of the respondents selected the “strongly disagree” option. The detailed results are presented in Figure 4.

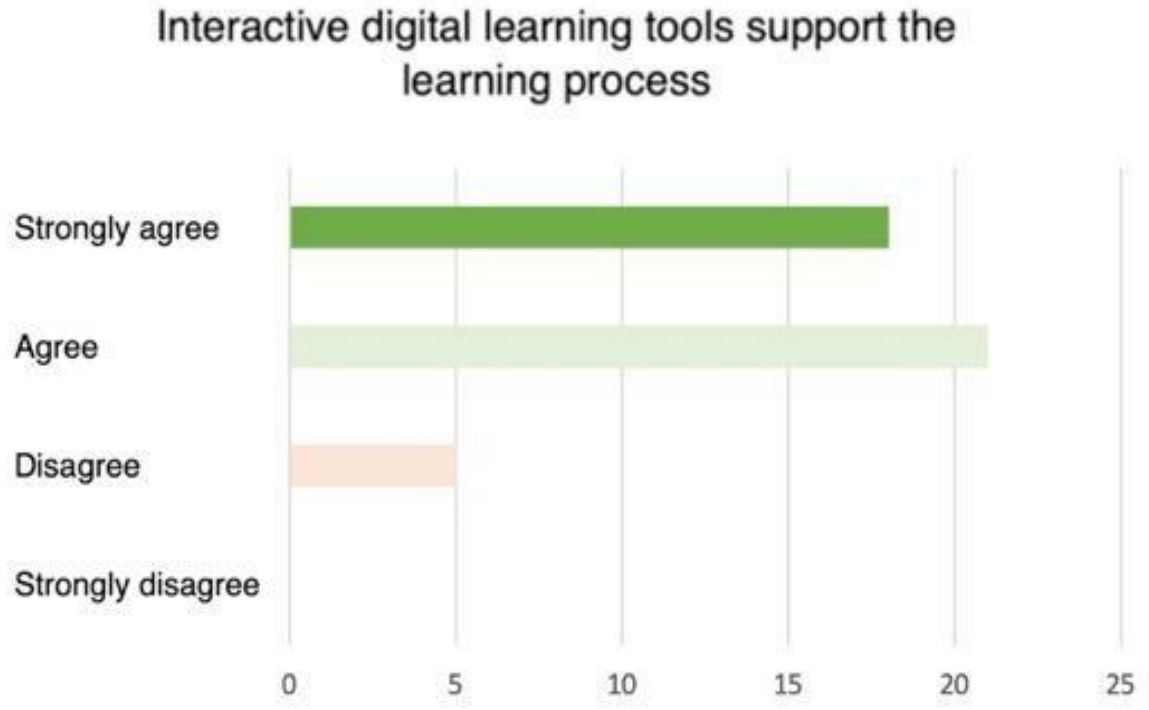

Figure 4. Students’ opinions on the effectiveness of digital learning tools

Since each student has their own learning style and individual methods for acquiring knowledge most effectively, we examined the role of interactive digital learning materials from the students’ perspective, particularly in comparison to traditional textbooks.

The results show that most students consider their own notes to be the most useful learning tool, followed by the teacher’s in-class explanations, and then the digital learning resources highlighted in our study (e.g., software, simulations, educational games). Students were asked to rank these learning tools, and the results are illustrated in Figure 5, showing the frequency of tools ranked first (Figure 5 - left) and last (Figure 5 - right). It can be concluded that traditional textbooks ranked lower than interactive digital materials in both cases.

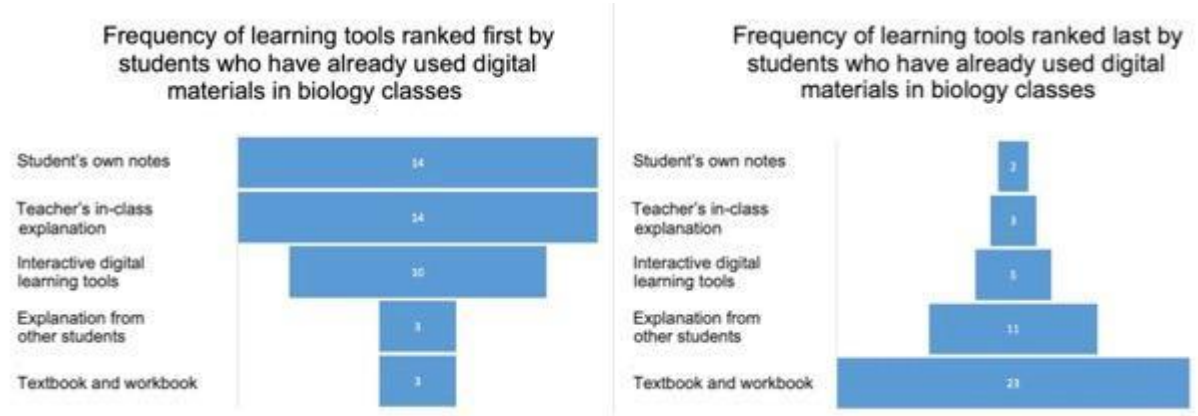

Figure 5. Frequency of learning tools ranked first and last by students who have already used digital materials in biology classes

According to the literature, one of the most frequently used digital tools in biology education is the application of VR and AR technologies. In our survey, nearly three-quarters of participants indicated that they would be open to learning with such technologies.

Furthermore, among those who responded "yes," we examined how students would envision the integration of these technologies into biology education. A positive finding was that biology was one of the most commonly selected subjects in which students would like to use such digital solutions. A total of 76 students indicated this, nearly twice the number of those who have previously experienced digital instruction in biology. This suggests that students are open to and desire up-to-date, interactive, simulation- and computer model–based biology learning materials suited for the digital age. The detailed results are presented in Figure 6.

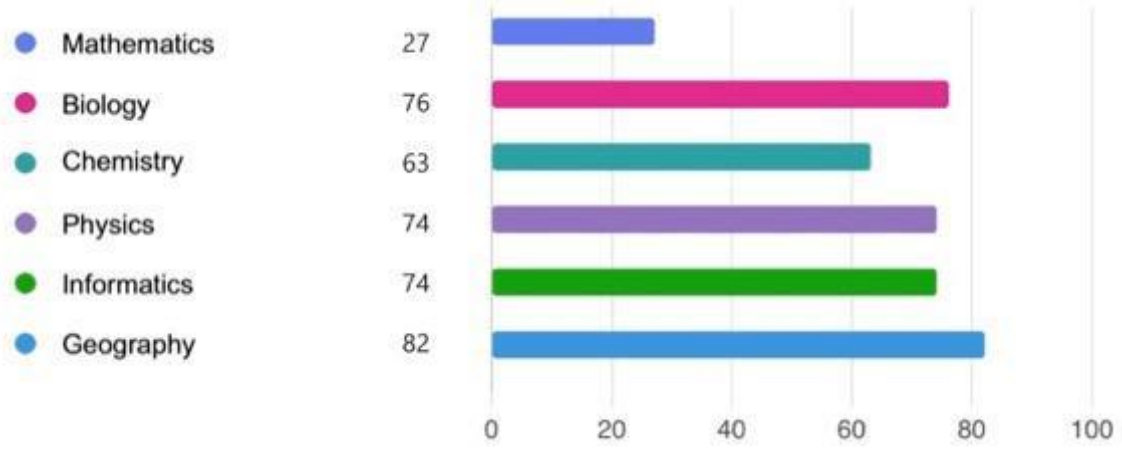

Figure 6. Students' demand for the application of VR and AR technologies in different science subjects

3.3. Teachers' Opinions on the Digital Teaching of Biology

In addition to the students, our aim was to examine how biology teachers perceive the possibilities for innovative biology education in the digital age.

A total of 22 biology teachers from primary and secondary schools participated in the survey. During the interviews, teachers were asked to evaluate the practical utility of current textbooks and workbooks in everyday classroom practice. They were also invited to consider the opportunities provided by digital technologies. Furthermore, respondents were encouraged

to critically reflect on the limitations that could negatively affect the implementation of digital learning materials in biology education.

The interviews corroborated the weaknesses identified in our survey. Several educators emphasized that textbook content is often *„dry"* and fails to sufficiently motivate students. While workbooks provide a structured framework for learning, the repetitive nature of the exercises and the lack of immediate feedback limit flexibility and reduce engagement. Consequently, maintaining student activity and interest using traditional tools remains challenging.

Interviewees acknowledged that digital resources, such as simulations, interactive software, and VR/AR applications, could serve as highly effective tools for biology instruction: *„Younger students are generally more accustomed to interactive content, making digitally enhanced lessons more engaging and potentially more effective in terms of learning outcomes"*. Nearly three-quarters of respondents (72%) expressed a positive attitude toward these educational methods, while 28% preferred to prioritize traditional teaching. The detailed results are illustrated in Figure 7.

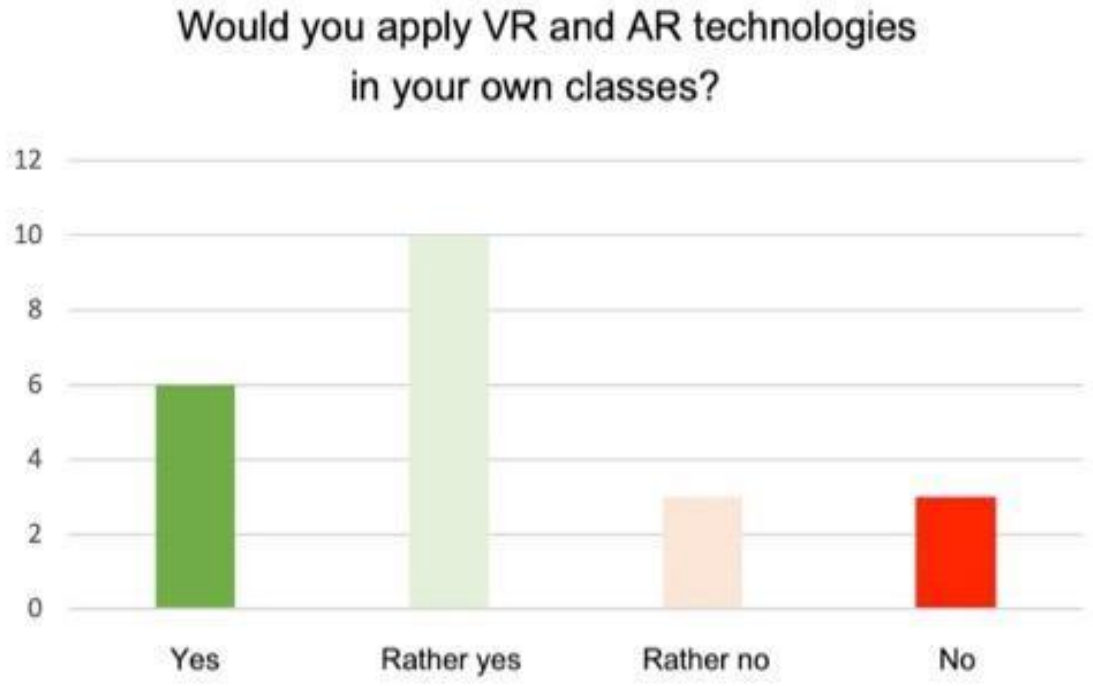

Figure 7. Biology teachers' openness to integrating VR and AR technologies into education

Teachers highlighted that successful implementation of interactive biology lessons requires classrooms equipped with computers, such as IT labs. However, logistical challenges, such as integrating biology lessons into computer-equipped rooms within existing timetables, pose a significant barrier to widespread adoption.

Interviews revealed that many educators lack sufficient digital competence and are unfamiliar with available biology-related software and platforms: *„Current curriculum guidelines and state requirements do not provide adequate, dedicated digital content for biology instruction."*. Teachers highlighted that textbook-supplied CDs are often outdated and merely reproduce the book's content in digital form rather than offering additional interactive, hands-on materials.

Teachers also expressed concerns regarding language and subject-specific knowledge. Many digital platforms and materials are in English, and limited English proficiency, both

among teachers and students can impede effective use. Additionally, understanding domain-specific terminology is crucial for supporting students' engagement with interactive content.

4. RECOMMENDATIONS FOR THE IMPLEMENTATION OF INTERACTIVE DIGITAL LEARNING MATERIALS IN BIOLOGY EDUCATION

The results of surveys and interviews indicate a clear demand from both students and teachers for innovation in biology education. While teachers acknowledge the potential of interactive digital tools, they also expressed several concerns that may hinder their everyday integration: logistical constraints, inadequately equipped classrooms, lack of familiarity with available digital content for specific topics, and language barriers.

In response to these concerns, this section aims to provide guidance on digital learning solutions that effectively address the limitations highlighted by teachers. These tools have already demonstrated success in practice by actively engaging students in lessons, enhancing motivation, and developing essential digital skills.

4.1. 3D Modeling and Visualization

The use of 3D models offers a significant innovation compared to traditional static illustrations. These models allow students to interactively manipulate and customize visual representations - for example, removing skin or ligaments from a skeleton or zooming in on specific parts of a plant. 3D models provide a superior spatial perspective, helping students understand distances and relationships between anatomical structures. Moreover, individual anatomical components can be isolated and examined, which is not possible with conventional textbook illustrations. This interactivity enhances comprehension and supports active, student-centered learning.

4.1.1. Mozaik3D

The following 3D illustrations (see Figure 8) were created using the Mozaik3D App. This versatile application provides a comprehensive view of the structure of each model. For cases where direct manipulation of the model is not desired, users can also watch an animated video walkthrough of the model, offering a clear and dynamic understanding of its components. The application is particularly useful in the teaching of natural sciences, such as biology, chemistry, geography, and physics, as it allows students to observe complex processes and structures in three dimensions. The app offers access to over 1,300 educational 3D models, which can be utilized on smartphones or tablets, making it a flexible and accessible tool for both classroom and remote learning [23].

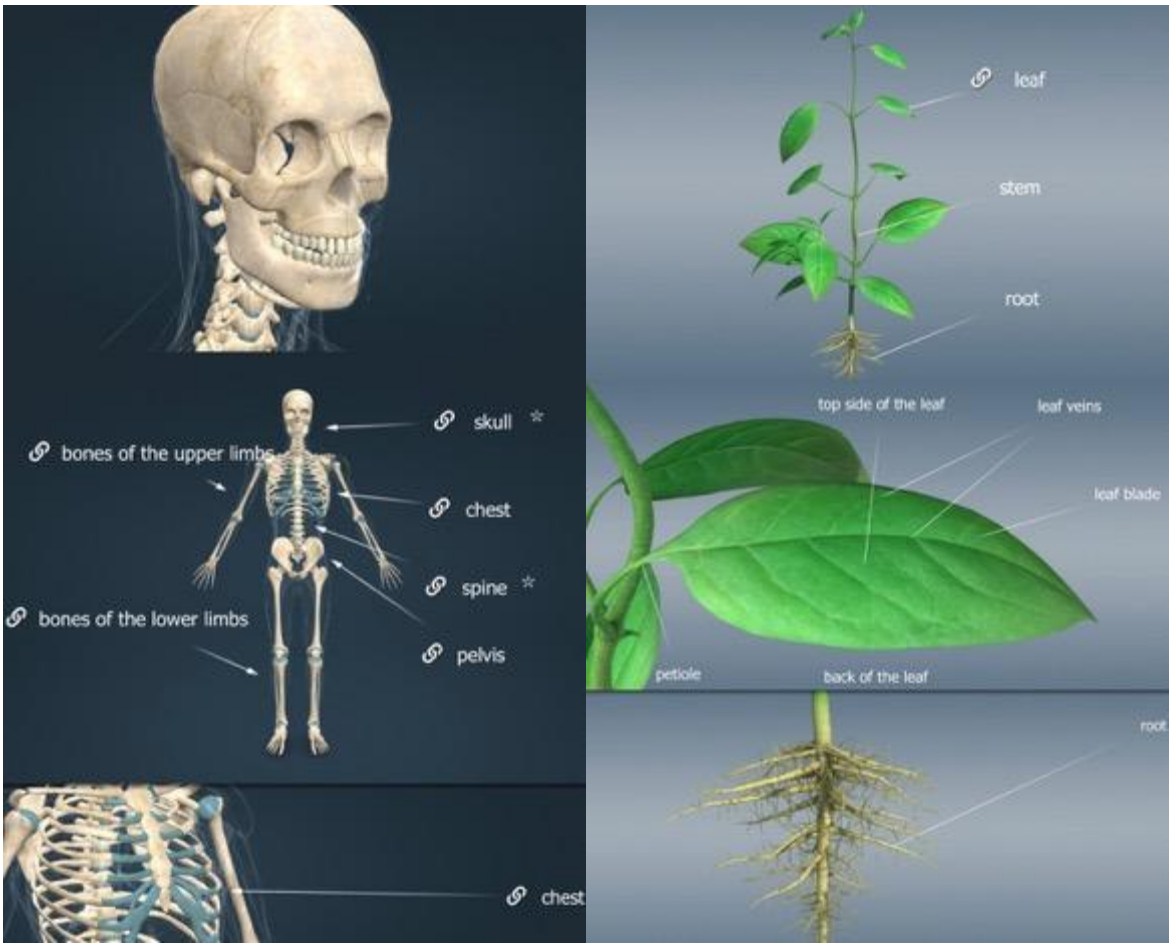

Figure 8. Mozaik3D app interface. Examples for teaching human biology and botany.

4.2. VR and AR

VR and AR technologies typically integrate sensors, hardware, and software to create immersive virtual environments. Within these settings, students can freely navigate, interact with objects, and engage in learning experiences that would be difficult or impossible to replicate in a conventional classroom or real-world context [19].

4.2.1. Sketchfab

Sketchfab provides students with the ability to examine 3D models from multiple angles, enhancing spatial understanding, particularly in biology and anatomy studies. The platform also supports the addition of animations and interactive elements, further enriching the learning experience. With its extensive library and customizable features, Sketchfab serves as a powerful educational tool, enabling students to achieve a deeper comprehension of complex subjects. Pre-service teachers generally concur that digital models, as well as VR, AR, and metaverse technologies in education, help make abstract concepts more tangible, support lasting and meaningful learning, facilitate the demonstration of experiments or cases that are otherwise difficult to perform, and enhance students' attention, engagement, and motivation [24]. Several examples of such 3D educational models are illustrated in Figure 9.

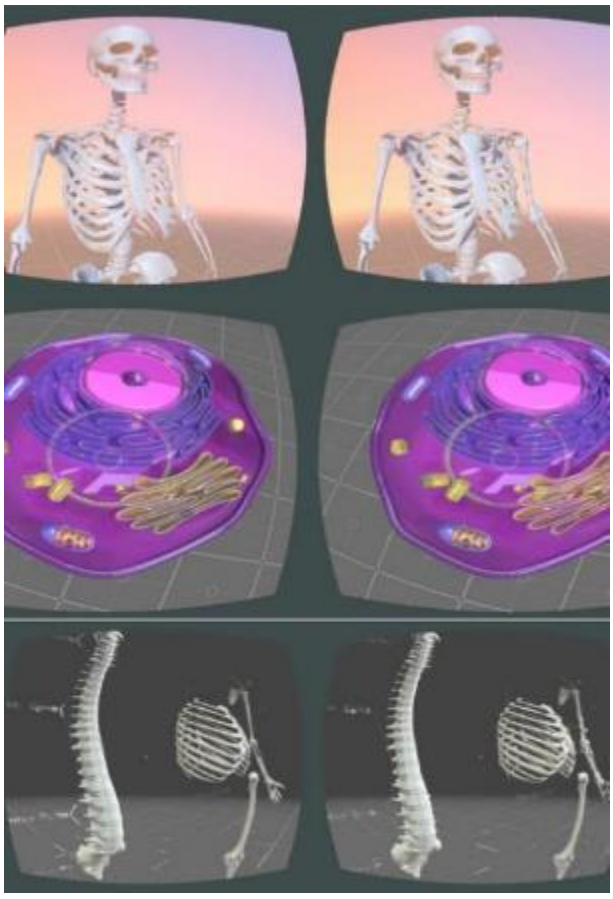

Figure 9. VR view provided by Sketchfab

Sketchfab allows users to explore individual models without requiring VR- or AR-compatible hardware. However, if the goal is to demonstrate the specific advantages of VR technology to students, affordable basic VR headsets are available from around 20€. Within the framework of a school project, classroom renovation, or educational innovation initiative, securing several of these devices for student use could be easily achievable.

4.3. Online platforms and games

The following section introduces several platforms that actively engage students in the learning process through gamified activities, quizzes, and diverse exercises. These platforms offer multilingual support and, similar to the previously mentioned examples, can be accessed via portable devices, enhancing flexibility and accessibility in the classroom.

4.3.1. Worldwall.net

WordWall is an interactive activity creation platform. Its templates can be customized according to task difficulty and problem-solving strategies, enabling the development of multiple skills and competencies. Overall, WordWall is a free or subscription-based website that can be seamlessly integrated into virtual learning environments, either as a supplement to instructional videos or as a standalone tool. The platform is accessible in multiple languages, including Hungarian. Its user-friendly interface allows educators to quickly create and implement visually engaging and interactive exercises, adding variety and motivation to the learning process [25].

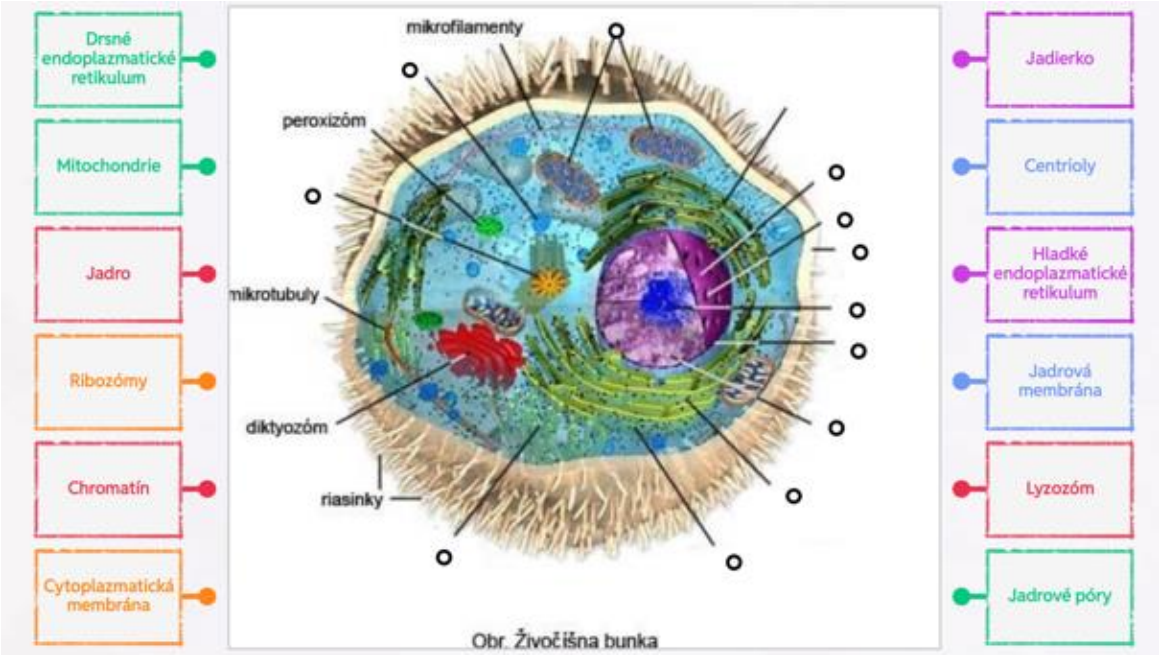

Figure 10. WordWall interface and practical examples of digital opportunities for teaching biology.

4.3.2. Kahoot!

Kahoot! is a game-based learning platform used daily by millions of learners worldwide. It supports video, image, and audio files and provides options for scoring and ranking, making learning engaging and enjoyable for students. In school settings, Kahoot! can be applied across all subjects, for any age group, and on any device, without requiring student registration. It is suitable for classroom instruction, distance learning, or blended learning environments. Its use in the classroom has been shown to positively increase student participation, enhance attentiveness, and improve learning outcomes and classroom interaction. Research indicates that game-based tools like Kahoot! can even positively impact attendance and motivation at the university level, supporting its potential adoption in higher education [26], [27].

Additionally, Kahoot! allows educators to set prerequisites for tasks, ensuring that students can progress only after mastering required knowledge, while also permitting multiple attempts during assessments. This enables individualized pacing, allowing each student to advance according to their own knowledge and abilities [13].

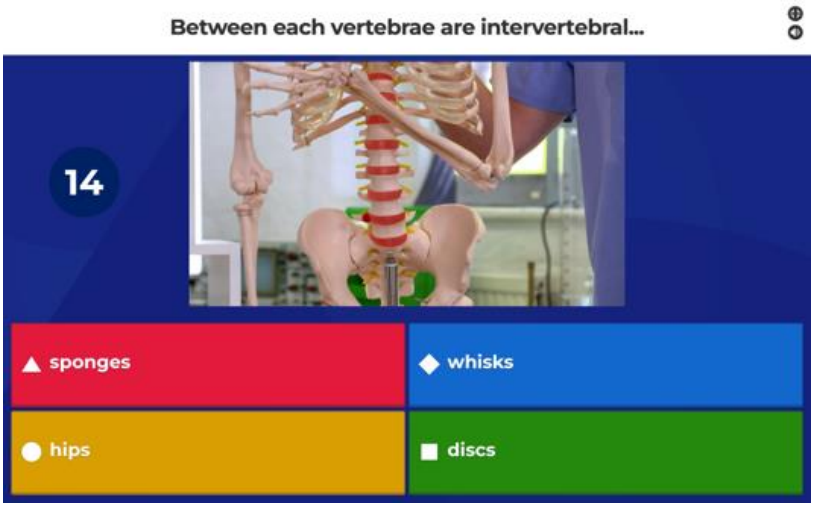

Figure 11. Quiz on human bones created on the Kahoot platform.

4.3.3. LearningApps.org

The platform LearningApps.org is designed to develop and store didactic interactive exercises, allowing teachers to shape, reinforce, and assess each student's acquired knowledge, skills, and competencies. These activities are delivered in both educational and game-based formats, thereby fostering cognitive interest, motivation for learning, critical thinking, and autonomy. Moreover, it enhances lesson effectiveness and encourages student engagement. The educational process becomes more informative, enabling students to navigate information spaces more efficiently, while the teacher assumes the role of mentor and advisor. This approach underscores the need for methodological development in biology education, particularly through the combined use of LearningApps.org and digital tools.

Figure 12 presents statements that can be categorized into two groups: Gymnosperms and Ferns. Students are tasked with classifying the statements and assigning them to the appropriate group. At the end of the exercise, feedback is provided: correct answers are highlighted in green, while incorrect responses appear in red [28].

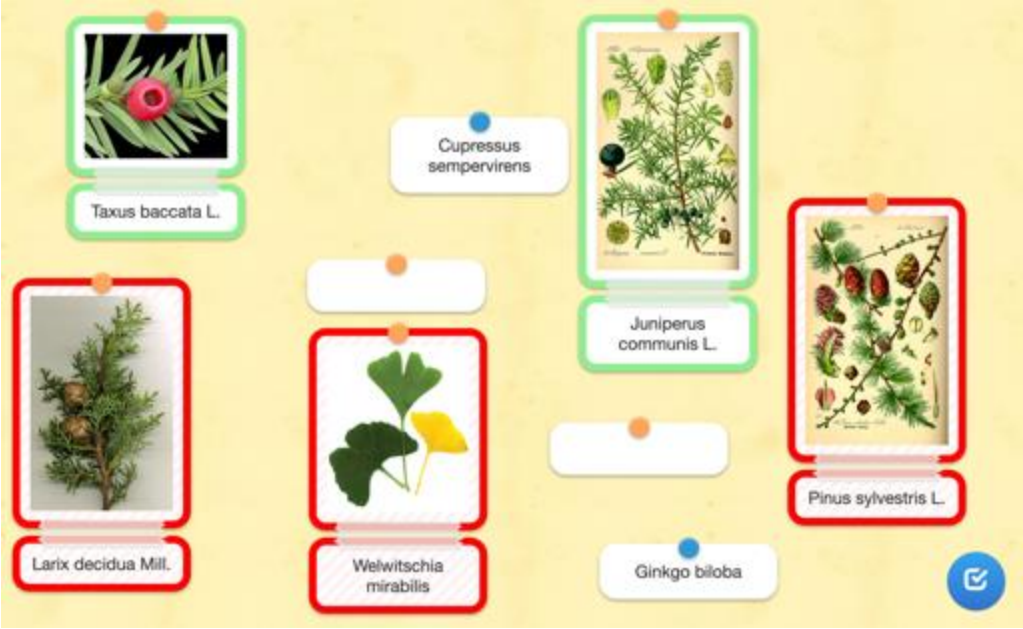

Figure 12. Practice exercises for teaching botany provided by LearningApps.org.

4.3.4. Quizlet

Quizlet is a web-based application designed to help students learn information through interactive tools and games. The content is organized into "study sets," which can be created and added to a user's account by teachers or students. When using Quizlet, students log in and select the appropriate study set for the concepts they wish to review. These sets can be generated by teachers or other users. Due to its flexibility and customizability, Quizlet can be used across all grade levels and class types. It allows for personalized learning while also incorporating collaboration and teamwork into lessons. Additionally, it offers a novel way for students to prepare for exams. Quizlet provides seven different learning modes catering to various learning needs. Students can choose from flashcards, personalized study methods, or game-based testing, ensuring that everyone finds the most suitable learning approach. Interactive games such as Match and Gravity make learning enjoyable, while traditional tools like Write and Test support effective independent practice. By combining these modes, students can prepare for assessments in a varied and engaging manner [29].

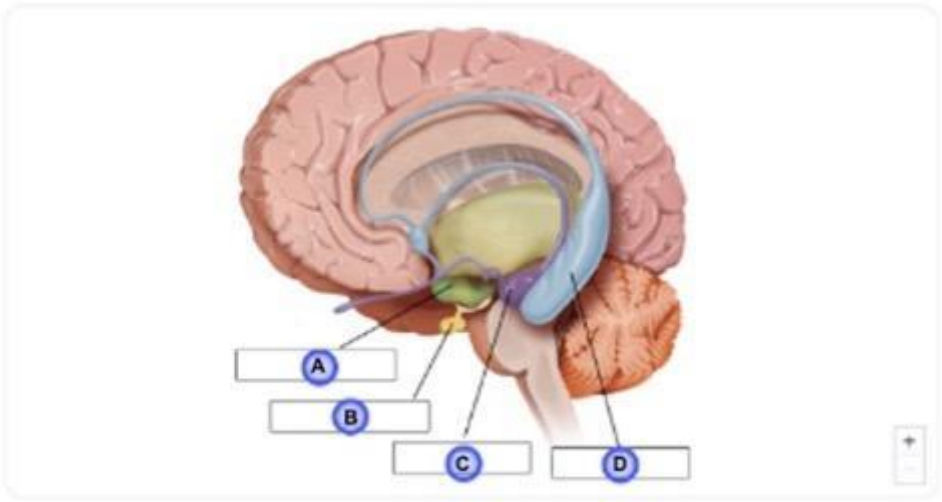

Figure 13. Quizlet activity on the structure of the human brain

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

This study explored the perspectives of both students and teachers on the integration of digital tools into biology education, with a particular focus on the potential of interactive and game-based platforms, as well as 3D, VR, and AR technologies. The findings highlight a clear demand for innovation in teaching practices. Students expressed enthusiasm for digital solutions that enhance engagement and support independent learning, while teachers recognized their motivational value but also voiced concerns about logistical challenges, limited classroom infrastructure, and their own preparedness to implement these tools effectively.

By analyzing the current use of textbooks and workbooks in contrast to digital learning materials, this research underscored the limitations of static, text-based resources when compared to interactive digital environments. Platforms such as Mozaik3D, Sketchfab, WordWall, Kahoot!, LearningApps, and Quizlet were identified as promising avenues for addressing these limitations by providing greater interactivity, accessibility, and adaptability to diverse learning styles. Importantly, the study demonstrated that such digital resources not only foster higher levels of student engagement and motivation but also contribute to the development of essential digital competencies.

Nevertheless, certain limitations must be acknowledged. The study was based on a relatively small sample of teachers and students, which restricts the generalizability of the findings. Furthermore, the focus was primarily on available platforms and teacher/student perceptions, without a longitudinal assessment of learning outcomes. Another limitation is the potential digital divide: while low-cost solutions such as basic VR headsets exist, not all schools may have equal access to the necessary technological infrastructure.

Future research should therefore expand the sample size and include diverse educational contexts to validate the findings. Longitudinal studies are particularly needed to measure the long-term impact of digital resources on student achievement, critical thinking, and motivation. Our research presents a variety of digital applications and online platforms that can support biology education. In the future, we aim to examine the actual impact of these tools within the framework of innovative biology lessons and practice-oriented laboratory activities. The leaders of the participating educational institutions have expressed openness to the implementation of such classes.

The effectiveness of digital applications will be evaluated through controlled experiments, comparing the teaching outcomes of selected curricular topics. Students' performance and their perceptions of digital tools will be assessed using questionnaire-based surveys, focusing on aspects such as usability, clarity, motivation, as well as subjective (self-reported) and objective (test-based) effectiveness.

Finally, we intend to explore teachers' perspectives through a SWOT analysis, with particular attention to the role of digital applications compared to traditional textbooks and workbooks. Our goal is to identify the strengths, weaknesses, opportunities, and potential risks that teachers associate with the practical implementation of biology lessons supplemented with digital materials. In the future, we plan to compare these findings with the results of our current research, in which we previously collected teachers' opinions on the potential of digital learning materials. Additionally, further investigation should be conducted into the training and professional development needs of teachers, ensuring that the effective integration of digital tools is supported at both institutional and policy levels.

In conclusion, while the transition from traditional to digital biology education presents challenges, it offers significant opportunities to enrich teaching and learning. By addressing infrastructural and pedagogical limitations, digital platforms can become powerful instruments in fostering active, student-centered biology education.

FUNDING

This research was supported by the national project KEGA 014TTU-4/2024 "Intelligent Animation-Simulation Models, Tools, and Environments for Deep Learning."

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to the leaders of the participating educational institutions, to the biology teachers who generously shared their insights, and to the students who actively took part in the survey. Their contributions were indispensable to the success of this research.

REFERENCES (TRANSLATED AND TRANSLITERATED)

[1] E. Jeronen, I. Palmberg, E. Yli-Panula. "Teaching Methods in Biology Education and Sustainability Education Including Outdoor Education for Promoting Sustainability—A Literature Review," *Education sciences* 7(1), 2016. https://doi.org/10.3390/educsci7010001 (in English)

[2] M. Janela. "BSCS vs. Traditional Biology," *Iowa Science Teachers Journal* 3(4), 1966. Available: https://scholarworks.uni.edu/istj/vol3/iss4/6 (in English)

[3] N. Scholar. *Biology Education: Online vs. Traditional Classes*. 2024. [Online], Available: https://disciplines.ng/biology-education-online-traditional-classes/ (in English)

[4] A. Fauzi, A. M. Rosyida, M. Rohma, D. Khoiroh. "The difficulty index of biology topics in Indonesian Senior High School: Biology undergraduate students' perspectives," *JPBI (Jurnal Pendidikan Biologi Indonesia)* 7(2), 149–158, 202. https://doi.org/10.22219/jpbi.v7i2.16538 (in English)

[5] D. Heldová, J. Kováčová, A. Galádová. *Results of the OECD PISA 2009 study focusing on reading literacy*. Bratislava, 2013. [Online], Available: https://www2.nucem.sk/dl/3479/PISA_web.pdf (in Slovak)

[6] K. Ušáková. "Reflection on the State and Perspectives of Didactics of Biology from the Perspective of the Faculty of Natural Sciences, CU in Bratislava," *Scientia in educatione* 5, 74–89, 2014. https://doi.org/10.14712/18047106.130 (in Slovak)

[7] Z. Chyleńska, E. Rybska, S. Jaskulska, M. Błaszak, B. Jankowiak. "How about the Attitudes towards Nature? Analysis of the Nature and Biology Primary School Education Curricula in Poland," *Sustainability* 14(18): 11173, 2022. https://doi.org/10.3390/su141811173 (in English)

[8] I. Franyó. “The status of biology as a subject and its development tasks” *Új Pedagógiai Szemle* 52(5), 24-37, 2002. Available: https://epa.oszk.hu/00000/00035/00060/2002-05-hk-Franyo-Biologia.html (in Hungarian)
[9] A. R. Althubyani. “Digital Competence of Teachers and the Factors Affecting Their Competence Level: A Nationwide Mixed-Methods Study,” *Sustainability* 16(7): 2796, 2024. https://doi.org/10.3390/su16072796 (in English)
[10] D. Warlick. *Curriculum is Dead*. 2006. [Online], Available: http://2cents.onlearning.us/?p=420 (in English)
[11] N. Annuš. “Education in the Age of Artificial Intelligence,” *TEM Journal* 13(1), 404-413, 2024. https://doi.org/10.18421/TEM131-42 (in English)
[12] V. Stoffová, K. Czakóová, “ Current issues in teacher training, digital transformation of teacher training,” *InfoDidac*, 215-222, 2020. Available: http://konferenciak.inf.elte.hu/infodidact/InfoDidact20/Manuscripts/SVCzK.pdf (in Hungarian)
[13] P. Ficzere. “The emergence and role of digitization in education,” *Gradus* 11(1), 2024. https://doi.org/10.47833/2024.1.ART.003 (in Hungarian)
[14] P. Kleininger. *New methods in biological knowledge acquisition. Séchenyi* 2020. [Online], Available: https://tovabbkepzes.itk.ppke.hu/content/Biologia/2019/Uj_modszerek_Kleininger_T.pdf (in Hungarian)
[15] T. Ijiri, H. Todo, A. Hirabayashi, K. Kohiyama, Y. Dobashi. “Digitization of natural objects with micro CT and photographs,” *PLoS ONE* 13(4), 2018. https://doi.org/10.1371/journal.pone.0195852 (in English)
[16] M. Nagy, D. Dancsa, J. Poráčová, R. Bernátová. “Real and virtual interactive models in biology education,” Eruditio – Educatio 16(4), 5–18 , 2021. https://doi.org/10.36007/eruedu.2021.4.5-17 (in Hungarian)
[17] M. Teplá, P. Teplý, P. Šmejkal. “Influence of 3D models and animations on students in natural subjects,” *International Journal of STEM Education* 9(65), 2022. https://doi.org/10.1186/s40594-022-00382-8 (in English)
[18] T. F. Chuang, Y. H. Chou, J. Y. Pai, C. N. Huang, H. Bair, A. Pai, N. C. Yu. “Using Virtual Reality Technology in Biology Education: Satisfaction & Learning Outcomes of High School Students,” *The American Biology Teacher* 85(1), 23–32, 2023. https://doi.org/10.1525/abt.2023.85.1.23 (in English)
[19] N. Annuš, D. Paksi, M. Csóka. “Interactivity and Animation-Simulation Tools in the Digital Presentation of Educational Material,” 17th International Technology, Education and Development Conference. IATED, Spain, 2023. 6975-6980. https://doi.org/10.21125/inted.2023.1895 (in English)
[20] W. R. Sharif, L. Narain, A. A. Ogowewo. “Impact of virtual reality and augmented reality technologies on biology education: A review,” *GSC Advanced Research and Reviews* 22(3), 159–167, 2025. https://doi.org/10.30574/gscarr.2025.22.3.0078 (in English)
[21] E. Lee, K. W. Wong, C. C. Fung. “How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach,” *Computers & Education* 55(4), 1424–1442, 2010. https://doi.org/10.1016/j.compedu.2010.06.006 (in English)
[22] İ. Ü. Yapici, F. Karakoyun. “Using Augmented Reality in Biology Teaching,” *Malaysian Online Journal of Educational Technology* 9(3), 40–51, 2021. https://doi.org/10.52380/mojet.2021.9.3.286 (in English)
[23] R. Kandikó, Á. Németh, O. Novodomszki, T. Somoskői. “Online dangers and addiction: in *Tabuk nélkül*, D. Boros, L. Czvik, E. Dorogi, Z. Hajdu, R. Kandikó, N. Káló, Á. Németh, N. Németh-Kovács, O. Novodomszki, K. Petrovics, Á. Ráczné Ördögh, T. Somoskői, K. Ötvös-Varga, A. Varga, G. Vidák, Eds. Szakmai-módszertani gyűjtemény tanároknak. Oktatási Hivatal, 236, 2020. ISBN 978-615-6256-66-9. (in Hungarian)
[24] M. Yilmaz, M. Coskun Simsek. “The Use of Virtual Reality, Augmented Reality, and the Metaverse in Education: The Views of Preservice Biology and Mathematics Teachers,” *MIER Journal of Educational Studies Trends and Practices* 13(1), 64–80, 2023. https://doi.org/10.52634/mier/2023/v13/i1/2422 (in English)
[25] K. Simon. “WordWall. How to quickly create interactive materials for online and traditional environments,” *Modern Nyelvoktatás* 26(4), 93–98, 2021. Available: https://ojs.elte.hu/modernnyelvok/article/view/2392 (in Hungarian)
[26] A. Rahman, H. A. Rony, A. Shihavuddin, M. H. Sikder, M. G. Fakir. “Kahoot: A Game-Based Learning Tool in Online Class for Effective Engagement and Formative Assessment,” *Green Uni-versity Review of Social Sciences* 2(9), 2023. https://doi.org/10.5296/ire.v9i2.18413 (in English)
[27] M. Gonzalez-Guzman, C. de Ollas, R. Perez-Clemente, A. Gomez-Cadenas, V. Arbona. “Kahoot application as a tool to track student assimilation of biology practical competences within the degree of medicine,” 11th International Conference on Education and New Learning Technologies, EDULEARN19 Proceedings, 2019. 8778-8782. https://doi.org/10.21125/edulearn.2019.2185 (in English)

[28] A. Stepanyuk, T. Olendr, I. Tsydilo, L. Mironets, M. Kormer. “Integrated Use of the LearningApps.org Resource and Information Devices in the Process of Biology School Course Studying,” Proceedings of the 1st Symposium on Advances in Educational Technology – Volume 2: AET, 2020, 452–465. https://doi.org/10.5220/0010932800003364 (in English)
[29] iCEV. *Pros & Cons of Using Quizlet in Your Classroom*. 2019. [Online], Available: https://www.icevonline.com/blog/quizlet-pros-cons (in English)

Text of the article was accepted by Editorial Team 21.08.2025

БІОЛОГІЧНА ШКІЛЬНА ОСВІТА В ЦИФРОВУ ЕПОХУ

Фанні Літавцова
студентка, Університет ім. Яноша Шеє
факультет освіти, м. Комарно, Словацька Республіка
litavczova.fanny@student.ujs.sk

Норберт Аннуш
PhD, доктор наук, доцент
Університет ім. Яноша Шеє, кафедра інформатики, м. Комарно, Словацька Республіка
ORCID ID 0000-0002-8535-2042
annusn@ujs.sk

Анотація. У представленому дослідженні за мету ставилось дослідження особливостей та викликів біологічної освіти із зосередженням особливої уваги на недоліках підручників та навчальних матеріалів, а також на ролі цифрових технологій, таких як інтерактивні симуляції, віртуальна реальність (VR) та доповнена реальність (AR) у процесі навчання та викладання. У дослідженні аналізується розвиток та вплив цифрових інструментів у викладанні біології та вивчення ставлення учнів та вчителів до інтеграції цих технологій у практику навчання в класі. Надається детальний аналіз відмінних рис біології як шкільного предмета та викликів, що виникають під час її викладання, з акцентом на недоліках підручників, які можна усунути за допомогою широкодоступних цифрових ресурсів. У дослідженні наводяться конкретні приклади застосування цифрових технологій у навчанні біології з особливою увагою до віртуальних моделей, додатків VR та AR, інтерактивних симуляцій та онлайн-платформ, які можуть підвищити ефективність та зацікавленість у процесі навчання. У межах дослідження було проаналізовано підручники та робочі зошити з біології, що використовуються на даний момент. Результати вказують на нагальну потребу в інноваціях, оскільки деякі навчальні заклади все ще використовують підручники, яким понад двадцять років, ілюстровані статичними чорно-білими малюнками, для навчання представників поколінь Z та Alpha — учнів, які народились у цифрову епоху і зараз навчаються в епоху штучного інтелекту. Серед учнів та вчителів початкових і середніх шкіл угорської меншини на півдні Словаччини було проведено емпіричне опитування з метою оцінки можливостей, досвіду та відкритості до використання цифрових інструментів на уроках біології. Результати були позитивними і підтвердили, що цифровізація має яскраве майбутнє в біологічній освіті і виходить за межі викладання інформатики. На основі цих висновків у дослідженні запропоновано рекомендації щодо модернізації викладання біології за допомогою більш сучасних навчальних матеріалів.

Ключові слова: освіта в галузі біології; освітні технології; навчальні інструменти; віртуальна реальність (VR); доповнена реальність (AR); інтерактивні симуляції та віртуальні моделі.

(cc) BY-NC-SA

This work is licensed under Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.