ISSN 2712-0562
Original Research

Sustainable Engineering and Innovation
Vol. 5, No. 2, December 2023, pp.261-280
https://doi.org/10.37868/sei.vi.id233

From traditional to digital: The impact of drones and virtual reality technologies on educational models in the post-epidemic era

Jiaxin Lu[1*], Ahmad Yahya Dawod[1], Fangli Ying[1]
[1] International College of Digital Innovation, Chiang Mai University, Thailand

*Corresponding author E-mail: jiaxinlu4353@outlook.com

Received Nov. 1, 2023
Revised Dec. 18, 2023
Accepted Dec. 26, 2023

Abstract

Employment of various innovative tools for education in the post-epidemic era is an urgent issue of improving the quality and efficiency of education and the relevance of educational material. The study aims to investigate the impact of the use of drones and virtual reality in educational models of student learning in the post-pandemic period. The study was conducted using a quantitative method, a sociological survey, a pedagogical experiment, and mathematical processing of the results. The study involved fourth-year students (n=748) studying in the following specialties: geography and ecology (n=119), engineering, robotics (n=135), architecture and urban planning (n=120), agriculture, agronomy (n=118), information technology (IT) (n=139), journalism (n=117), and teachers (n=258) with more than 5 years of experience. For the educational process of students of each specialty, the scope of application of drones and virtual reality has been developed. Classes with the use of drones and virtual reality were held 2 times a week for one academic semester. Afterward, students were interviewed using an adapted questionnaire to study their attitudes toward virtual reality technologies and drones for learning. Students of all specialties positively evaluated various aspects of the use of drones and virtual reality in their educational process. The use of drones helps to improve student engagement and visual attention and has a positive impact on learning efficiency and student satisfaction with the learning process. Teachers approve of the use of drones and virtual reality in teaching but point out that further development of the methodology for training stakeholders in the educational process, infrastructure, improvement of curricula, and consideration of various aspects of technology use is needed to further effectively implement drones and virtual reality in the learning process. The practical significance of this study is to present aspects of the use of drones in teaching students of certain specialties and to study the impact of the effectiveness of the use of these technologies on the opinions of students and teachers.

Keywords: Unmanned aerial vehicles, Educational process, Fourth-year students, Learning efficiency, Interactive learning

1. Introduction

The coronavirus pandemic has contributed to the introduction and multidisciplinary use of digital technologies in education, and to rethinking the organization of learning in general. Traditional learning models have been the predominant model for centuries, but they have several limitations, and after the pandemic, they are simply forced to transform. The emergence of virtual reality and artificial intelligence technologies is forcing changes in approaches and methods of teaching at different levels [1]. The use of digital resources requires changes to complement traditional learning to teach students the ability to navigate the digital world and to use different opportunities to develop their knowledge and skills.

After the pandemic, the educational process involves a much wider use of digital technologies in education, which are constantly being improved and supplemented. In particular, the use of drones in the educational process allows for high-quality aerial photography, and virtual reality allows for realistic images of various objects that are pedagogically difficult to present in normal conditions. These technologies can optimize the learning process in various fields and increase the level of digital literacy of students so that they learn not only to perceive but also to create, critically reflect, and analyze information. These skills are powerful abilities for future professionals in various fields. At the same time, the use of technology in education requires a detailed study of its impact on the learning process and various aspects of effectiveness.

The use of drones and virtual reality in education is a fairly new technology that requires further research to explore the feasibility and costs of its use [2] and is associated with a range of technical and pedagogical challenges [3]. Nevertheless, the use of these technologies will optimize the student learning process. Studies have shown that the use of virtual reality has had a positive impact on student behavior and, as a result, on learning outcomes [4], [5]. Another study pointed out the need for software improvements when using virtual reality (VR) technologies [6] and that the use of this technology is still in its early stages of development [2]. Positive feedback has been received on the use of drones by students, in particular for the educational process of future architects [7]. The use of drones in the educational process is sometimes unprofitable since when studying in urban environments, it is not always acceptable to fly a drone while studying in terms of safety and other factors. To solve this problem, experts have proposed using virtual reality to teach drone control [8]. Experts have proposed promising areas for further research on the use of drones and virtual reality in education, increasing access to technology, the interaction between the physical and virtual environment, and introducing new proposals to update the foundations of learning theory, but the practical use of these technologies requires further study and research [9]. Another limitation of the traditional learning model is the limited access to learning resources, and the use of technology can significantly expand this access, especially for students from different regions. At the same time, pupils and students must have equal access to technology, as inequality of access only widens the gap between different groups. The study aims to investigate the effectiveness of using drones and virtual reality in the educational process of students. Goals/tasks of the study:

- to study changes in educational models as a result of the use of digital technologies, including virtual reality and drones;
- to investigate the impact of the use of drones and virtual reality on the engagement of students and students with educational material;
- to study the readiness of teachers and educators to use drones and virtual reality in the educational process;
- to explore the positive and negative aspects of using drones and virtual reality in education;
- to evaluate the impact of the integration of drones and virtual reality in the educational process of students of different specialties.

2. Literature review

There is currently little research on the use of drones in education, and their use in the school environment is practically non-existent [10]. The use of drones in education allows us to explore certain phenomena from a new perspective, gain practical experience with advanced technologies, and visually observe and study various phenomena [11]. Drones can be used to collect data and conduct various studies. The development of drone applications has also expanded the possibilities of using them in education, creating a unique and engaging learning experience [12]. According to the study by [13], it is proposed to conduct training and retraining of teaching and non-teaching staff to ensure the proper use of drones in student learning. According to a study by [14], seven opportunities for using drones in education have been identified: programming with blockchain languages, recording from a height, viewing places that cannot be seen from the ground or other viewing points, streaming photos and videos in real-time, and gamification. At the same time, four limitations were identified: the need for teacher training, time constraints on drone operations, infrastructure data, and personal skills and abilities. Studies of the use of virtual reality in the educational process show an increase in the interest of scientists and the number of scientific publications on the topic, as well as a positive impact on the training of certain specialties [15], [16]. Even before the pandemic, interest, in and use of virtual reality in some higher education institutions was at a high level [17]. In particular, a study conducted by [18] shows an increase in the number of students who visited teaching laboratories equipped with Oculus Rift headsets, most often used by students studying at the Faculty of Engineering. At the same time, students noted the negative aspects of using virtual reality and their reluctance to use it in the future educational process due to complexity, lack of convenience, and other reasons. However, despite this, the authors recommend the use of virtual reality in the future when improving this technology for learning. The use of virtual reality allows students to better understand complex concepts, and to work with information or observe phenomena or conditions that are difficult to create in the classroom [19]. Virtual reality can be used to simulate and enable students to practice skills and solutions in a safe and controlled environment. Such conditions are especially valuable for such specialties as medicine and engineering [20]. [21] showed that learners and students perceive virtual reality better from desktop virtual reality applications than from head-mounted devices. To improve the effectiveness of virtual reality, active learning methods should be incorporated, which can shift the focus to the learning-relevant aspects of the virtual reality learning environment. Other authors have studied the effectiveness of learning using virtual reality and combining it with educational games [22], [23]. The use of virtual reality and drones allows for a better understanding of complex concepts and improved skills in environments that are as close as possible to the actual working conditions or the object of observation. However, more research is needed on the effectiveness of virtual reality and drones, student and teacher perceptions, and other aspects.

3. Research method

The study was conducted using a quantitative method. The study involved 748 fourth-year students studying various specialties in Chinese higher education institutions, which were considered in the survey results to assess the impact of the use of drones and virtual reality for students of these specialties. A detailed description of student characteristics is presented in Table 1.

Table 1. Demographic characteristics of the students who took part in the study

Specialty	Number of students, average age	
	Males	Females
Geography and ecology	87 (20.5±1.8)	32 (20.82±1.35)
Engineering, robotics	94 (21.35±1.9)	41 (19.95±1.55)
Architecture and city building	97 (21.22±1.15)	23 (20.86±1.85)
Agriculture, agronomy	63 (19.96±1.96)	55 (20.55±1.92)
Information technology (IT)	76 (20.22±1.54)	63 (21.16±1.75)
Journalism	55 (20.65±1.88)	62 (19.54±1.65)
Total (n=748)	472 (20.65±1.75)	276 (20.48±1.77)

A description of the tasks using drones and VR that were used in the educational process of students of different specialties is presented in Table 2.

Table 2. Use of drones and virtual reality in the educational process of 4th-year students of different specialties

Specialty	Drone employment	Virtual reality employment
Geography and ecology	Geographic landscape study, aerial photography, ecosystem monitoring, and analysis of landscape features	1. Geospatial visualization. 2. Travel and virtual tours. 3. Virtual modeling of climate change. 4. Assessing the impact of certain factors on the environment in virtual reality.
Engineering, robotics	Studying the features of engineering structures, designing, and constructing drones for various applications	1. Training based on simulation modeling. 2. Digital prototyping. 3. Remote research laboratories. 4. Create an environment for co-design. 5. Programming and control of robotics. 6. Professional development and learning.
Architecture and city building specialists	Studying the features of structures, surveying construction sites, assessing building structures, and creating 3D models of architectural projects	1. Visualization of architectural structures and their design. 2. Urban planning modeling. 3. Virtual analysis of a certain area for further modeling of structures. 4. Architectural presentations and excursions. 5. Historic buildings tour. 6. Sustainable design research.
Agriculture, and agronomy	Studying the possibilities of using drones, and practical applications to study the peculiarities of agriculture, crops, and soil conditions	1. Agricultural simulations, and crop modeling to understand the peculiarities of growing crops in different conditions. 2. Livestock management modeling. 3. Maintenance and operation of agricultural machinery. 4. Pest control stimulation. 5. Greenhouse agriculture stimulation. 6. Research in soil science and crop nutrition.
IT	Programming drone movement using different programming languages, different drone movements, sensors, and image quality settings	1. Cybersecurity training sessions. 2. Network configuration and troubleshooting. 3. Cooperation on software development. 4. IT project management simulation. 5. Virtual IT laboratories for skill development. 6. Stimulating cloud computing. 7. Planning of virtual IT infrastructure. 8. Learning new technologies.
Journalism	Use of drones for news filming and investigative journalism	1. Immersive storytelling experience. 2. Virtual newsrooms and joint reporting. 3. Virtual journalism with an overview of the environment. 4. Virtual reporting from remote locations. 5. Interactive news presentations. 6. Creating documentaries in virtual reality. 7. Stimulating ethical decision-making. 8. Audience engagement and feedback in virtual reality.

The student's classes were held during the second academic semester of 2022/2023, in the amount of two classes using drones and two classes using virtual reality per week for students of each specialty. During the classes, the Ryze DJI Tello Edu, Sky Viper e1700, and Parrot Mambo fly drone models were used. VR training sessions were conducted using head-mounted devices in specially designed laboratories in educational institutions. Each lesson with the use of drones and virtual reality lasted for 1.5 hours for all participants of the pedagogical experiment. After the completion of the training experiment, students were surveyed to study their perceptions of the use of drones and virtual reality using a questionnaire developed by [24], which was adapted for this study. The questions given to students after the semester are presented in the results. In addition, to assess the impact of the use of drones and virtual reality, after the experiment, students were interviewed using the author's questionnaire, the questions from which are presented in the supplementary materials (Table 3). Students evaluated certain aspects of the use of drones and virtual reality in the educational process on a Likert scale, from 1 – disagree to 5 – fully agree.

Table 3. Surveying students on aspects of drone use and VR in the educational process

Question	Answer variant	Geography, ecology	Engineering, robotics	Architecture, city building	Agriculture	IT	Journalism
Have you had any experience with drones before using them in your studies?	Yes	66.39% (n=79)	65.19% (n=88)	81.67% (n=98)	63.56% (n=75)	89.93% (n=125)	72.65% (n=85)
	No	33.61% (n=40)	34.81% (n=47)	18.33% (n=22)	36.44% (n=43)	10.07% (n=14)	27.35% (n=32)
Average score (max 5)							
How comfortable were you flying the drone during the training?	3.72±0.46	3.77±0.34	3.69±0.55	4.1±0.31	3.66±0.43	3.56±0.65	3.56±0.34
On a scale of 1 to 5, how interesting were the drone training activities?	3.9±0.38	3.97±0.41	3.87±0.49	3.96±0.42	3.78±0.29	3.78±0.54	4.05±0.25
Do you think that drone training has a positive impact on the understanding of educational material?	4.02±0.32	4.32±0.34	4.21±0.45	3.78±0.54	3.86±0.29	4.05±0.34	3.87±0.34
In your opinion, does the use of drones enhance your learning experience compared to traditional methods?	3.79±0.38	3.88±0.42	3.75±0.57	3.69±0.67	3.59±0.61	3.79±0.56	4.06±0.35
Do you think drones contribute to a better understanding of theoretical concepts?	3.72±0.54	3.76±0.58	3.87±0.62	3.36±0.75	3.76±0.67	3.56±0.76	3.98±0.45
Do you think drone training improves the efficiency of group projects?	4.13±0.45	4.54±0.34	4.06±0.38	4.12±0.41	4.11±0.37	3.98±0.77	3.96±0.56
Do you think the use of drones improves communication and teamwork skills in the learning environment?	3.95±0.56	3.87±0.45	3.76±0.61	3.85±0.48	3.95±0.43	4.11±0.39	4.15±0.34
Do you think the use of drones helps you apply theoretical knowledge in practical scenarios?	4.04±0.35	4.06±0.43	3.86±0.56	4.12±0.34	3.95±0.41	3.92±0.35	4.35±0.33

Teachers (n=258) from professionally oriented disciplines who participated in the experiment, i.e., used drones and VR in teaching were also interviewed to assess the effectiveness and certain aspects of using drones and VR in the educational process. For this purpose, the author's questionnaire was developed, which is presented in the supplementary materials (Appendix A). Teachers evaluated some aspects of the use of drones and VR in the educational process using the Likert scale to understand the further development of the use of these technologies in education. The mathematical processing of the survey results was carried out using SPSS Statistics, the presence of a normal distribution of the results and the level of consistency between the scales of the author's questionnaire were studied, with the deduction of the Cronbach Alpha coefficient.

Students of other specialties, such as medicine, pharmacology, and pedagogy, did not participate in this study. Only fourth-year students took part in the study. The study was conducted with generalized ways of using drones and VR, which can be further refined in in-depth research with students of certain specialties, at different stages of study, and for different purposes (improving communication skills, gaining practical experience, solving practical problems, and many others).

4. Results

A pedagogical experiment was conducted during one academic semester to study the effectiveness of using drones and virtual reality in teaching students of different specialties. After the training experiment, a student survey was conducted to study student satisfaction with the use of drones and virtual reality in the educational process. The supplementary materials show the questions for the student survey based on the author's questionnaire (Appendix A).

A survey of students shows that students of different specialties have a positive opinion about the use of drones and virtual reality in the educational process and assess the effectiveness of their use. In particular, a percentage of students studying geography and ecology had previous experience with drones. Students reported a high level of comfort with drones and virtual reality and expressed a significant interest (from 3.87 to 4.05 points) in educational activities using drones. This interest in the use of drones and virtual reality, and the increase in engagement, shows that they can be used effectively for future educational models. Students also indicated that they felt a positive impact on their understanding of the educational material using drones and virtual reality.

Students studying engineering and robotics had sufficient experience with drones before the experiment (65.19-89.93% of students had experience), which creates the preconditions for incorporating best practices in teaching. Students reported a high level of comfort and skill in flying drones, which facilitates the use of in-depth study on the use of drones and virtual reality. Students reported a high level of enthusiasm for learning with drones, which contributes to the effectiveness of using them as innovative tools to solve educational problems. The perceived impact on understanding (ranging from 375 to 4.21) indicates that drones can be integrated to improve understanding of concepts in engineering and robotics.

Future professionals in the field of architecture and urban planning positively assessed the comfort and skill of using drones and virtual reality in the training of specialists in this field, and their readiness to use these technologies in education. Students also report a high level of interest and engagement in educational activities. The survey of students studying agriculture and agronomy, IT specialists, and future journalists shows similar results, with students having some unprofessional experience of flying drones and using virtual reality before the experiment, which explains their interest in using such technologies in the educational process. Students reported a sufficient level of comfort with flying drones and using virtual reality in the educational process, which can be explained by the detailed selection of tools for using these technologies in classrooms by teaching staff, and ultimately by the influence of curiosity and leveling of various possible discomforts due to students' interest and motivation to learn how to use innovative tools in education. Students also noted the perceived positive impact on their understanding of the subject matter, as the use of virtual reality allows them to "immerse" themselves in a particular activity, rather than just studying theoretically about certain phenomena in education. Similarly, the use of drones, in addition to providing an immersive learning experience, allows for a detailed study of certain phenomena.

As can be seen from the results of the student survey, students positively assess their comfort and interest in conducting classes using drones and virtual reality in the learning process, believe that the use of drones improves communication and teamwork skills in the learning environment and the use of theoretical knowledge in practical scenarios. Also, according to statistical calculations, there is no significant difference between the scores of students studying in different specialties. A survey of students on the adoption of technology in the educational process after using drones and virtual reality shows the following (Table 4).

Table 4. Student survey on technology acceptance after using drones and VR [24]

Sub-scales and questions	Geography, ecology	Engineering, robotics	Architecture, city building	Agriculture	IT	Journalism	Cronbach Alpha
Perceived usefulness	3.94±0.61	3.9±0.45	3.86±0.54	4.07±0.45	3.87±0.44	4.01±0.45	0.899
PU-1	3.98±0.12	3.99±0.67	3.67±0.35	3.79±0.34	3.69±0.65	4.12±0.38	
PU-2	3.68±0.29	4.02±0.45	3.78±0.65	4.56±0.36	4.04±0.54	3.94±0.76	
PU-3	4.03±0.49	3.79±0.65	3.98±0.38	3.97±0.45	3.98±0.65	4.11±0.65	
PU-4	4.07±0.56	3.78±0.72	4.01±0.26	3.97±0.45	3.78±0.37	3.88±0.56	
Perceived simplicity	3.98±0.54	4.03±0.45	3.91±0.98	3.92±0.36	4±0.46	3.96±0.77	0.798
PS-1	4.11±0.34	3.89±0.38	3.97±0.56	4.03±0.48	4.03±0.37	3.98±0.56	
PS-2	3.97±0.45	4.21±0.45	3.78±0.53	3.69±0.65	3.97±0.56	4.1±0.34	
PS-3	3.95±0.56	4.04±0.33	3.98±0.45	3.89±0.55	4.02±0.48	3.98±0.76	
PS-4	3.9±0.43	3.98±0.54	3.89±0.43	4.05±0.35	3.98±0.36	3.78±0.56	
Self-efficiency	3.97±0.45	3.81±0.47	3.92±0.76	3.99±0.27	3.92±0.55	4.1±0.33	0.898
SE-1	3.98±0.39	3.78±0.65	3.88±0.34	4.11±0.46	3.98±0.39	4.24±0.34	
SE-2	4.03±0.55	3.95±0.54	4.09±0.45	3.87±0.57	3.75±0.61	3.98±0.65	
SE-3	3.89±0.47	3.69±0.43	3.78±0.38	3.98±0.39	4.02±0.45	4.08±0.55	
Perceived satisfaction	4.11±0.56	3.88±0.66	3.92±0.34	3.98±0.46	3.94±0.66	3.95±0.43	0.887
PS-1	3.77±0.54	3.69±0.46	3.97±0.55	3.88±0.57	3.89±0.34	4.09±0.45	
PS-2	4.76±0.65	4.06±0.38	4.02±0.23	3.98±0.48	3.95±0.66	3.78±0.39	
PS-3	3.87±0.39	3.99±0.76	3.78±0.44	4.01±0.66	4.02±0.54	3.95±0.76	
PS-4	4.05±0.44	3.79±0.35	3.89±0.38	4.05±0.47	3.88±0.65	3.98±0.64	
Perceived cyber risk	3.84±0.65	3.95±0.35	3.95±0.61	3.96±0.37	3.96±0.59	4.04±0.56	0.865
PCR-1	3.69±0.54	4.02±0.54	3.79±0.45	3.98±0.45	3.89±0.62	3.95±0.39	
PCR-2	3.98±0.45	3.87±0.66	4.11±0.35	4.01±0.44	4.02±0.64	4.12±0.37	
Personal innovation in using new technologies	3.92±0.44	4.02±0.45	3.93±0.56	3.98±0.88	4.02±0.55	3.98±0.55	0.855
PINT-1	3.98±0.34	3.98±0.36	3.98±0.54	3.79±0.37	3.98±0.58	3.98±0.88	
PINT-2	3.69±0.76	4.12±0.34	3.69±0.45	4.02±0.46	4.04±0.39	3.89±0.65	
PINT-3	4.11±0.45	4.04±0.55	4.15±0.39	4.12±0.36	4.12±0.36	4.07±0.49	
PINT-4	3.9±0.53	3.93±0.43	3.89±0.33	3.98±0.55	3.95±0.55	3.98±0.65	
Behavioral intent	4.04±0.34	4.05±0.39	4.1±0.37	3.88±0.54	3.87±0.37	3.87±0.44	0.798
BI-1	4.06±0.62	4.32±0.64	4.12±0.37	3.98±0.77	3.79±0.65	3.97±0.59	
BI-2	3.98±0.37	3.95±0.55	4.11±0.34	3.89±0.67	3.98±0.46	3.85±0.38	
BI-3	4.09±0.56	3.89±0.67	4.06±0.45	3.78±0.47	3.84±0.77	3.78±0.75	

The survey conducted on the approval of technologies in the educational process after the pedagogical experiment shows a high level of perception by students of different specialties, and the absence of statistically significant differences between the assessment of the perception of technologies by students of different specialties. The experiment with the use of drones and virtual reality in the educational activities of students of different specialties showed, firstly, the absence of statistically significant differences between the assessments of the usefulness, simplicity, and other factors by students of different specialties, and secondly, a positive perception of the use of drones and virtual reality in the educational process of students of those specialties who took part in this experiment.

To evaluate the effectiveness of the use of drones and virtual reality in the educational process, an author's questionnaire was developed to survey teachers about their experience of using these tools. The results of the survey show that teachers are generally positive about the use of drones and VR in the educational process, but certain aspects of the use of these technologies need to be improved. The results of the survey are presented in Table 5.

Table 5. The results of a teacher survey on the use of drones and VR in the educational process of students of different specialties

Subscales	Geography and ecology	Engineering, robotics	Architecture and city building	Agriculture, agronomy	IT	Journalism
Overall perception	3.98±0.43	3.67±0.58	3.87±0.66	3.45±0.75	3.52±0.87	3.37±0.85
Pedagogic influence	3.54±0.56	4.03±0.65	4.05±0.54	3.76±0.38	3.77±0.57	3.65±0.55
Drone and VR use efficiency in teaching a particular specialty	3.77±0.45	4.07±0.46	4.02±0.64	3.78±0.56	4.05±0.67	4.02±0.55
Opportunities to improve the perception of educational material using VR and drones	3.55±0.78	3.47±0.67	3.65±0.88	3.82±0.54	3.59±0.56	3.89±0.47
Professional development	3.78±0.46	3.67±0.55	3.76±0.65	3.76±0.39	3.75±0.48	3.29±0.48
Drone integration challenges in education	3.87±0.76	3.85±0.76	3.67±0.93	3.77±0.85	3.96±0.65	3.67±0.56
Engaging and interacting with students	3.97±0.85	3.67±0.76	3.67±0.85	3.72±0.47	3.88±0.58	3.76±0.66
Specific considerations for the use of drones and VR in the educational process of certain specialties	2.98±0.76	2.98±0.87	2.88±0.76	2.67±0.98	3.08±0.67	3.12±0.65
Updating and improving the use of drone and VR technologies in the educational process	2.56±0.77	2.63±0.86	2.37±0.73	2.47±0.87	2.78±0.36	2.56±0.67
Overcoming the challenges of using drones and VR in education	2.98±0.43	3.02±0.56	2.77±0.45	2.39±0.76	2.39±0.56	2.76±0.47

The results of the survey show that teachers positively assess such aspects of the use of drones and VR in education as general perception, pedagogical impact, effectiveness of use in the study of a particular specialty, opportunities to improve the perception of educational material using VR and drones, qualitative impact on professional development, level of engagement and interaction with students. At the same time, teachers rated below the specific considerations for using drones and VR in the educational process of certain specialties, updating, and improving the use of drone and virtual reality technologies in the educational process, and overcoming challenges in using drones and VR in teaching. This indicates the need to improve approaches to learning material using drones and VR, a higher level of teacher training, and better assimilation of learning material using technology.

Given the possibilities of using drones and virtual reality in the educational process in the post-epidemic era, it can be stated that educational models are significantly transforming. Educational models are aimed at moving from passive learning to active learning, when students do not just passively receive the information, they are given, but critically evaluate it and draw certain conclusions. Educational models are becoming more resilient to possible disruptions in the learning process, and with certain support, students can study the material in different ways and at different times. The possibilities of individualized learning paths for students of different specialties are increasing. The ability of virtual reality to create an environment as close as possible to real working conditions, and of drones to observe certain phenomena in real time, improves the ability to gain real-world experience. Teachers also highly appreciated the potential of using drones and VR to teach interdisciplinary skills and to help students acquire versatile skills, communication, and collaboration. The creation of virtual platforms greatly improves the ability to collaborate. Students can work together on projects in a virtual space, overcoming the obstacles of physical presence at certain facilities.

Based on the results of a survey of teachers, drones and VR have been shown to enable adaptive learning, meaning that students can understand the subject matter of their studies much more deeply, predict different ways of solving problems, consider the problem from different angles, conduct in-depth research, and identify interdisciplinary connections between the problem and ways to solve it.

5. Discussion

The educational process after the pandemic is characterized by a much more frequent use of digital technologies in education, which are constantly evolving and supplemented [25] education, as the use of digital tools provides wide access to student learning, provided that they are accessible [26], [27]. Digital transformation requires large-scale changes, a common vision of the participants in the educational process, and work on the effectiveness of the use of digital technologies in the educational process [28], [29], [30]. Further research is needed to better understand the impact of virtual reality technologies and the use of drones, including the study of the impact on the psychological and pedagogical aspects of the learning process.

The use of drones in the educational process allows for high-quality aerial photography, while virtual reality training sessions allow for realistic images of various objects [7], [31], [32]. These technologies can optimize the learning process in various fields and increase students' digital literacy so that they learn not only to perceive but also to create, critically reflect, and analyze information [33], [34]. These skills are powerful abilities for future professionals in various fields. At the same time, the use of such technologies in the education of future specialists in various fields requires a detailed study of their impact on the learning process and research into various aspects of efficiency. The rational and effective use of VR requires a significant change in curricula and training programs at the national level, and at this stage, such implementation is taking place at the level of experiments by interested scientists or educational institutions [23], [35], [36], [37]. It is important to study the requirements for the need to expand the infrastructure for the effective use of drones and virtual reality in the educational process in various fields of study, as the use of technology can vary dramatically depending on the specialty studied by students [38], [39], [40]. Further discussions and research are needed on the duration of the use of VR and drones in student education to prevent possible misuse of technology and ensure sufficient efficiency of technology use.

The development of drone technology is leading to the use of drones in various fields, including education [2], [41], [42], [43]. However, this necessitates training to ensure quality use and to consider the learning and perception of children of different ages. The introduction and use of virtual reality in the educational process is also increasing [44], but further research is needed on the effectiveness of certain teaching methods using virtual reality for students of different specialties. At the same time, it is necessary to consider students' abilities to fly drones, as the results of the study [45], [46], [47] show that students' skills and abilities in flying drones are not uniform. To address this issue, [48] and [49] proposed an approach to teaching drone use using virtual reality. In the study, most students had experience with using drones, and they were fourth-year students, so before the experiment, students were able to fly the drone to meet the conditions of the experiment. For the effective use of drones and VR in different countries and educational institutions of different types, it is necessary to take into account previous experience and the availability of training in drone flying and VR, as [28], and [50] investigated the effectiveness of using VR to teach drone flying in primary school, which is a predictor of a high level of skills in using these technologies, while in other countries or educational institutions, such classes may not have been implemented due to various factors [51], [52]. Therefore, further research and experimental programs should address the factor of students' readiness to use drones for learning, as the level of students' skills may vary significantly.

The Technology acceptance model, which is the most widely used and valid model for predicting and adopting various technologies in the educational process, was used to survey the acceptance of technologies for the educational process [53], [54], [55], [56]. The results obtained indicate a high level of acceptance of technologies for use in the educational process, and adaptability to the use of technologies, which practically indicates readiness for effective use in education. According to [11], [57] immersive learning experiences have been found to lead to favorable outcomes and motivation compared to traditional learning experiences. The results of the study confirm that the use of VR and drones has a positive impact on student engagement in classrooms. [58], [59], [60] also found that the use of virtual reality technology can help optimize student learning, allowing students to access various visual and audio cues, which can increase interest in academic subjects. [61] and [62] found that the use of drones in education helps to increase student engagement and develop critical thinking, coding skills, and analysis of various information. For the effective use of IT technologies, it is necessary to implement an effective infrastructure of applications used in education [63], [64], [65], [66], [67].

The study complements the findings of [61] and [28] that the use of drones in education allows effective the development of critical thinking skills, engages students in the learning process, and improves spatial visualization skills and sequence of actions. According to [68], [69], [70], the use of drones in education is effective for students of different specialties, but for the specifics of each, it is necessary to develop certain plans for their use in the educational process. Many experts have studied the impact of drones and virtual reality on the educational process, and most of them positively assess this impact in special schools [5], and other educational institutions of various levels [71], [72].

This study presents the results of the impact of the use of drones and virtual reality on the learning process of students of certain specialties and the positive assessment of students regarding the use of these technologies in their educational process. Further research can be aimed at developing longer-term programs for the use of drones and virtual reality in the educational process of students from the first year of study and for students of different specialties. Earlier studies on the value of virtual reality learning environments show an increase in the number of learning environments that use virtual reality specifically for certain specialties such as agronomy and agriculture, geography, and ecology [73], [74], [75], [76], [77]. This study has revealed the effectiveness of VR and drones in the fields of IT technology, architecture and urban planning, engineering, robotics, and journalism. The same results on the positive impact of using VR and drones in education were obtained in the study by [78], [79], [80]. In addition, different possibilities of using drones and VR in education contribute to the development of a fairly wide range of skills, in addition to the overall effectiveness of developing professionally important skills, and the development of intercultural communication [20] in comparison to the specifics of activities in different countries (for example, urban planning, ecology) [81], [82].

The survey of teachers revealed a generally positive attitude to the impact and effectiveness of teaching with the use of VR and drones, but a desire to improve the methodology of use, develop infrastructure, and increase their level of preparedness to use VR and drones in the educational process. It is also important to involve other participants in the educational process in evaluating the use of VR and drones and to conduct further, long-term observations of the impact of these technologies on students' learning.

6. Conclusions

The integration of virtual reality and drones into the educational process of students has a positive effect, despite the types of specialties, students equally appreciated their effectiveness in their studies. The use of virtual reality allows for a deeper understanding of complex concepts in the topics studied by students, thanks to the ability to view certain phenomena from different perspectives, creating conditions as close to real life as possible, which allows for a deeper understanding of certain nuances of the educational material. All of this makes the learning process interesting and engaging for students, allows them to develop various skills and abilities, and learn more about the essence of their future work. In the post-epidemic era, these skills are becoming increasingly important for future professionals and are therefore essential for their professionalism. It also contributes to the development of digital literacy and the ability to use various technologies for future professional activities. The results of this study demonstrate the versatility of using drones and VR in student education. Improving the experience of observing certain phenomena, designing architectural projects, and numerous other benefits contribute to the efficiency of gaining practical experience by students and other important skills for future professional activities. The student survey shows a positive attitude of students towards the use of drones in education and a high assessment of the actual effectiveness of the use of drones and VR in education. The survey of teachers shows a similar attitude, but at the same time, they also wish to improve the methodological framework, technological support, and other aspects.

The obtained results demonstrate the universality of the use of drones and VR in the educational process of students of different specialties. To assess the effectiveness of various aspects of the use of drones and VR in education, questionnaires for students and teachers have been developed, and the survey confirms their validity. These questionnaires can be further adapted to a survey for an in-depth analysis of the use of VR and drones in the teaching of students of different specialties, with a longer time of use of these technologies in the educational process, and in the teaching of students of other specialties. Thus, the transition from traditional to digital educational models using drones and VR significantly improves the acquisition of practical skills by students, which is insufficient in distance learning and other forms of electronic communication. Future research could focus on an in-depth study of educational strategies using drones and virtual reality, comparative analysis, and the impact of using drones and VR on the interaction between teachers and students.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

Author contribution

Conceptualization, J. Lu; methodology, A. Yahya Dawod; software, F. Ying; investigation, J. Lu, A. Yahya Dawod and F. Ying; resources, A. Yahya Dawod; data curation, Jiaxin Lu; writing – original draft preparation, J. Lu; visualization, A. Yahya Dawod and F. Ying.

Funding information

No funding was received from any financial organization to conduct this research.

Abbreviations and acronyms

IT Information Technology

VR Virtual Reality

References

[1] J. Chen and M. Zhang, “Exploration and research on industry-education integration of vocational education in AI era,” *Advances in Vocational and Technical Education,* vol. 4, no. 3, pp. 41-47, 2022.

[2] Z. Zhao and W. Wu, “The effect of virtual reality technology in cross-cultural teaching and training of drones,” in *Proceedings of the 14th International Conference “Cross-Cultural Design. Applications in Learning, Arts, Cultural Heritage, Creative Industries, and Virtual Reality”*. P.-L. P. Rau, Ed. Cham: Springer, pp. 137-147, 2022. https://doi.org/10.1007/978-3-031-06047-2_10

[3] J. Jiang, L. Zhi and Z. Xiong, “Application of virtual reality technology in education and teaching,” in *2018 International Joint Conference on Information, Media and Engineering (ICIME)*. New York: IEEE, pp. 300-302, 2018. https://doi.org/10.1109/ICIME.2018.00070

[4] X. Ding and Z. Li, “A review of the application of virtual reality technology in higher education based on Web of Science literature data as an example,” *Frontiers in Education,* vol. *7,* p. *1048816*, 2022. https://doi.org/10.3389/feduc.2022.1048816

[5] J. D. Espinola, J. E. Ignacio, J. P. Lacaden, C. B. Toribio, and A. Y. Chua, “Virtual simulations for drone education of Senior High School students,” *International Journal of Engineering and Advanced Technology*, vol. 8, no. 6s3, pp. 220-226, 2019. https://doi.org/10.35940/ijeat.f1036.0986s319

[6] J. Luisier, S. Yooyen, and S. Deebhijarn, “Perceptions of Thai aviation students on consumer grade VR Flight experiences,” *Proceedings*, vol. 39, no. 1, p. 8. https://doi.org/10.3390/proceedings2019039008

[7] J. Rábago and M. Portuguez-Castro, “Use of drone photogrammetry as an innovative, competency-based architecture teaching process,” *Drones*, vol. 7, no. 3, p. 187, 2023. http://dx.doi.org/10.3390/drones7030187

[8] H. Cardona-Reyes, C. Trujillo-Espinoza, C. Arevalo-Mercado, and J. Muñoz-Arteaga, “Training of drone pilots through virtual reality environments under the gamification approach in a university context,” *Interaction Design and Architecture(s),* vol. 49, pp. 64-83, 2021. https://doi.org/10.55612/s-5002-049-004

[9] A. Scavarelli, A. Arya, and R. J. Teather, “Virtual reality and augmented reality in Social Learning Spaces: A literature review,” *Virtual Reality*, vol. 25, no. 1, pp. 257-277, 2020. https://doi.org/10.1007/s10055-020-00444-8

[10] I. Yepes, D. A. Barone, and C. M. Porciuncula, “Use of drones as pedagogical technology in STEM disciplines,” *Informatics in Education*, vol. 21, no. 1, pp. 201-233, 2021. https://doi.org/10.15388/infedu.2022.08

[11] G. Makransky and R. E. Mayer, “Benefits of taking a virtual field trip in immersive virtual reality: Evidence for the Immersion Principle in multimedia learning,” *Educational Psychology Review*, vol. 34, no. 3, pp. 1771-1798, 2022. https://doi.org/10.1007/s10648-022-09675-4

[12] F. A. Phang *et al.*, “Integrating drone technology in Service Learning for Engineering Students,” *International Journal of Emerging Technologies in Learning (iJET),* vol. 16, no. 15, pp. 78-89, 2021. https://doi.org/10.3991/ijet.v16i15.23673

[13] I. O. Muraina, S. N. Lameed, and O. M. Adesanya, “Pedagogical skeptics and challenges towards the application of drones in teaching and learning sciences,” *Shodh Sari – An International Multidisciplinary Journal*, vol. 2, no. 3, pp. 413-424, 2023. http://dx.doi.org/10.59231/SARI7616

[14] T. Sivenas and G. Koutromanos, “Exploring the affordances of drones from an educational perspective,” in *2022 International Conference on Advanced Learning Technologies (ICALT)*. New York: IEEE, pp. 90-94, 2022. https://doi.org/10.1109/ICALT55010.2022.00035

[15] J. Kasperiuniene and F. Faiella, “Bibliometric analysis of virtual reality in school and university contexts,” in *Computer Supported Qualitative Research: World Conference on Qualitative Research (WCQR2023)*. A. Pedro Costa, A. Moreira, F. Freitas, K. Costa and G. Bryda, Eds. Cham: Springer, pp. 72-92, 2023. https://doi.org/10.1007/978-3-031-31346-2_5

[16] G. Al Farsi, *et al.*, “The general view of virtual reality technology in the education sector,” in *Proceedings of International Joint Conference on Advances in Computational Intelligence*. M. Shorif Uddin and J. Chand Bansal, Eds. Singapore: Springer, pp. 295-303, 2023. https://doi.org/10.1007/978-981-99-1435-7_25

[17] D. Hamilton, J. McKechnie, E. Edgerton, and C. Wilson, “Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design,” *Journal of Computers in Education*, vol. 8, no. 1, pp. 1-32, 2020. https://doi.org/10.1007/s40692-020-00169-2

[18] B. Marks and J. Thomas, “Adoption of virtual reality technology in higher education: An evaluation of five teaching semesters in a purpose-designed laboratory,” *Education and Information Technologies*, vol. 27, no. 1, pp. 1287-1305, 2021. https://doi.org/10.1007/s10639-021-10653-6

[19] N. Elmqaddem, “Augmented reality and virtual reality in education. myth or reality?” *International Journal of Emerging Technologies in Learning (iJET)*, vol. 14, no. 3, p. 234, 2019. https://doi.org/10.3991/ijet.v14i03.9289

[20] B. M. Kyaw *et al.*, “Virtual reality for health professions education: Systematic review and meta-analysis by the digital health education collaboration,” *Journal of Medical Internet Research*, vol. 21, no. 1, p. e12959, 2019. https://doi.org/10.2196/12959

[21] J. G. Cromley, R. Chen, and L. Lawrence, “Meta-analysis of STEM learning using virtual reality: Benefits across the board,” *Journal of Science Education and Technology*, vol. 32, no. 3, pp. 355-364, 2023. https://doi.org/10.1007/s10956-023-10032-5

[22] Kuang, Y., Yang, S., Jiang, J. 2023. The research on the challenges confronted by the combination of virtual reality technology and educational games. In: *Computer Science and Education* (pp. 29-41). Singapore: Springer. https://doi.org/10.1007/978-981-99-2443-1_3

[23] M. A. Rojas-Sánchez, P. R. Palos-Sánchez, and J. A. Folgado-Fernández, “Systematic literature review and bibliometric analysis on virtual reality and education,” *Education and Information Technologies*, vol. 28, no. 1, pp. 155-192, 2022. https://doi.org/10.1007/s10639-022-11167-5

[24] A. S. Al-Adwan *et al.*, “Extending the technology acceptance model (TAM) to predict university students’ intentions to use metaverse-based learning platforms”,” *Education and Information Technologies*, vol. 28, no. 11, pp. 15381-15413, 2023. https://doi.org/10.1007/s10639-023-11816-3

[25] C. Rapanta, L. Botturi, P. Goodyear, L. Guàrdia, and M. Koole, “Balancing technology, pedagogy and the new normal: Post-pandemic challenges for Higher Education,” *Postdigital Science and Education*, vol. 3, no. 3, pp. 715-742, 2021. https://doi.org/10.1007/s42438-021-00249-1

[26] A. M. Maatuk, E. K. Elberkawi, S. Aljawarneh, H. Rashaideh, and H. Alharbi, “The COVID-19 pandemic and e-learning: Challenges and opportunities from the perspective of students and instructors,” *Journal of Computing in Higher Education*, vol. 34, no. 1, pp. 21-38, 2021. https://doi.org/10.1007/s12528-021-09274-2

[27] A. Groza and N. Siddelev, “Nonlinear surface polaritons near the interface between a magneto-optical substance and a nonlinear metamaterial with a permittivity close to zero,” *Scientific Herald of Uzhhorod University. Series "Physics"*, no. 51, pp. 24-29, 2022. https://doi.org/10.54919/2415-8038.2022.51.24-29

[28] P.-N. Chou, “Smart technology for sustainable curriculum: Using drone to support young students’ learning,” *Sustainability*, vol. 10, no. 10, p. 3819, 2018. https://doi.org/10.3390/SU10103819

[29] S. Karabayev, K. Nurgaliyeva, A. Kredina, M. Bekturganova and Y. Aimagambetov, “Relationship between determinants of higher education and economic development: The case of Kazakhstan,” *Problems and Perspectives in Management*, vol. 21, no. 1, pp. 336-351, 2023. https://doi.org/10.21511/ppm.21(1).2023.29

[30] D. Fernandez, O. Dastane, H. Omar Zaki and A. Aman, “Robotic process automation: bibliometric reflection and future opportunities,” *European Journal of Innovation Management*, 2023. https://doi.org/10.1108/EJIM-10-2022-0570

[31] A. Mazakova, S. Jomartova, T. Mazakov, T. Shormanov and B. Amirkhanov, “Controllability of an unmanned aerial vehicle,” in *ENERGYCON 2022 - 2022 IEEE 7th International Energy Conference, Proceedings*. Riga: Institute of Electrical and Electronics Engineers, 2022. https://doi.org/10.1109/ENERGYCON53164.2022.9830244

[32] O. Horbachova, Yu. Tsapko, S. Mazurchuk and O. Tsapko, “Mobile technology of thermal modification of wood,” *Ukrainian Journal of Forest and Wood Science*, vol. 13, no. 3, pp. 22-31, 2022. https://doi.org/10.31548/forest.13(3).2022.22-31

[33] G. Kozhasheva, M. Maltekbassov, T. Baidildinov, A. Sakhipov and Y. Gavrilova, “Distance learning technologies with blockchain elements in the system of continuous education,” *Cypriot Journal of Educational Sciences*, vol. 17, no. 9, pp. 3277-3288, 2022. https://doi.org/10.18844/cjes.v17i9.7474

[34] V. G. Prokopov, N. M. Fialko, G. P. Sherenkovskaya, V. L. Yurchuk, Yu. S. Borisov, A. P. Murashov and V. N. Korzhik, “Effect of coating porosity on the process of heat transfer with gas-thermal deposition,” *Powder Metallurgy and Metal Ceramics*, vol. 32, no. 2, pp. 118-121, 1993.

[35] G. Kassenova, A. Zhamiyeva, A. Zhildikbayeva, R. Doszhan and K. Sadvakassova, “Digitalization of the company's financial resources (by the example of Air Astana JSC),” *E3S Web of Conferences*, vol. 159, p. 04021, 2020. https://doi.org/10.1051/e3sconf/202015904021

[36] L. Rubino, D. Iannuzzi, G. Rubino, M. Coppola and P. Marino, “Concept of energy management for advanced smart-grid power distribution system in aeronautical application,” in *2016 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles and International Transportation Electrification Conference, ESARS-ITEC 2016*. Toulouse: Institute of Electrical and Electronics Engineers, p. 7841322, 2016. https://doi.org/10.1109/ESARS-ITEC.2016.7841322

[37] H. Lukashchuk, Ia. Onufriv and S. Tupis, “Green space and planning structure optimisation ways in parks and monuments of landscape architecture,” *Architectural Studies*, vol. 9, no. 1, pp. 23-35, 2023. https://doi.org/10.56318/as/1.2023.23

[38] L. Nykyforova, N. Kiktev, T. Lendiel, S. Pavlov and P. Mazurchuk, “Computer-integrated control system for electrophysical methods of increasing plant productivity,” *Machinery & Energetics*, vol. 14, no. 2, pp. 34-45, 2023. https://doi.org/10.31548/machinery/2.2023.34

[39] B. Zholmagambetova, T. Mazakov, S. Jomartova, A. Izat and O. Bibalayev, “Methods of extracting electrocardiograms from electronic signals and images in the python environment,” *Diagnostyka*, vol. 21, no. 3, pp. 95-101, 2020. https://doi.org/10.29354/diag/126398

[40] G. Abdikerimova, A. Shekerbek, M. Tulenbayev, S. Beglerova, E. Zakharevich, G. Bekmagambetova, Z. Manbetova and M. Baibulova, “Detection of chest pathologies using autocorrelation functions,” *International Journal of Electrical and Computer Engineering*, vol. 13, no. 4, pp. 4526-4534, 2023. https://doi.org/10.11591/ijece.v13i4.pp4526-4534

[41] M. Aliaskar, T. Mazakov, A. Mazakova, S. Jomartova and T. Shormanov, “Human voice identification based on the detection of fundamental harmonics,” in *ENERGYCON 2022 - 2022 IEEE 7th International Energy Conference, Proceedings*. Riga: Institute of Electrical and Electronics Engineers, 2022. https://doi.org/10.1109/ENERGYCON53164.2022.9830471

[42] R. Dinzhos, N. Fialko, V. Prokopov, Yu. Sherenkovskiy, N. Meranova, N. Koseva, V. Korzhik, O. Parkhomenko and N. Zhuravskaya, “Identifying the influence of the polymer matrix type on the structure formation of microcomposites when they are filled with copper particles,” *Eastern-European Journal of Enterprise Technologies*, vol. 5, no. 6-107, pp. 49-57, 2020.

[43] K. G. Sadvakassova, A. Z. Nurmagambetova, G. E. Kassenova, Z. S. Kazbekova, D. Jamshidi, “Development of an Investment Management Model for Air Carriers,” *International Journal of Computing*, vol. 22, no. 3, pp. 319-327, 2023. https://doi.org/10.47839/ijc.22.3.3226

[44] R. Zadorozhniuk, “UAV data collection parameters impact on accuracy of Scots pine stand mensuration,” *Ukrainian Journal of Forest and Wood Science*, vol. 14, no. 1, pp. 39-54, 2023. https://doi.org/10.31548/forest/1.2023.39

[45] J. Hayes *et al.*, “Identifying early predictors of learning in VR-based drone training,” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 66, no. 1, pp. 1872-1876, 2022. https://doi.org/10.1177/1071181322661254

[46] A. Belgibayeva, O. Denissova, M. Kozlova, I. Savchenko, A. Tleubayev and G. Siximbayeva, “Analysis of Sustainable Development of SMEs in Agriculture,” *Journal of Environmental Management and Tourism*, vol. 13, no. 3, pp. 681-694, 2022. https://doi.org/10.14505/jemt.v13.3(59).09

[47] B. Khussain, A. Brodskiy, A. Sass, B. Teltayev and K. Rakhmetova, “Research of the thermal effect on the Fe-Cr-Al alloy foil in the initial state and with the deposited secondary support,” *Zeitschrift fur Naturforschung - Section A Journal of Physical Sciences*, vol. 78, no. 3, pp. 271-280, 2023. https://doi.org/10.1515/zna-2022-0272

[48] G. Albeaino, R. Eiris, M. Gheisari, and R. R. Issa, “DroneSim: A VR-based flight training simulator for drone-mediated building inspections,” *Construction Innovation*, vol. 22, no. 4, pp. 831-848, 2021. https://doi.org/10.1108/ci-03-2021-0049

[49] G. Palaigeorgiou, G. Malandrakis and C. Tsolopani, “Learning with drones: Flying windows for classroom virtual field trips,” in *2017 IEEE 17th International Conference on Advanced Learning Technologies (ICALT)*. New York: IEEE, pp. 338-342, 2017. https://doi.org/10.1109/ICALT.2017.116

[50] B. Orazbayev, E. Dyussembina, G. Uskenbayeva, A. Shukirova and K. Orazbayeva, “Methods for modeling and optimizing the delayed coking process in a fuzzy environment,” *Processes*, vol. 11, no. 2, p. 450, 2023. https://doi.org/10.3390/pr11020450

[51] L. Sandra, Y. Heryadi, Lukas, W. Suparta, A. Wibowo, “Deep Learning Based Facial Emotion Recognition using Multiple Layers Model,” in *2021 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation, ICAMIMIA 2021 – Proceeding*. Surabya: Institute of Electrical and Electronics Engineers, pp. 137-142, 2021. https://doi.org/10.1109/ICAMIMIA54022.2021.9809908

[52] V. Korzhyk, V. Khaskin, O. Voitenko, V. Sydorets and O. Dolianovskaia, “Welding technology in additive manufacturing processes of 3D objects,” *Materials Science Forum*, vol. 906, pp. 121-130, 2017.

[53] K. Magsamen-Conrad, C. C. Billotte Verhoff, and J. M. Dillon, “Technology acceptance models,” *The International Encyclopedia of Health Communication*, pp. 1-8, 2022. https://doi.org/10.1002/9781119678816.iehc0776

[54] L. Rubino and G. Rubino, “Electrical Power Center with energy management capability for aeronautical applications,” in *2016 International Symposium on Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM 2016*. Capri: Institute of Electrical and Electronics Engineers, pp. 940-945, 2016. https://doi.org/10.1109/SPEEDAM.2016.7525944

[55] K. Bolatbek, A. R. Brodskiy, S. I. Ivanov, M. G. Gordienko, N. V. Menshutina, “Modeling of substances adsorption process in aerogel pores,” *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, vol. 3, no. BOOK 6, pp. 83-90, 2016.

[56] N. Bence, A. Lengyel and Z. Tarics “A simple model for describing the minimum differential cross-section of elastic proton scattering on protons at high energies,” *Scientific Herald of Uzhhorod University. Series "Physics"*, no. 51, pp. 30-38, 2022. https://doi.org/10.54919/2415-8038.2022.51.30-38

[57] L. Sandra, A. Trisetyarso, A. Ramadhan, E. Abdurachnan, F. Lumbangaol and S. M. Isa, “Social Network Analysis Algorithms, Techniques and Methods,” in *2021 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation, ICAMIMIA 2021 – Proceeding*. Surabya: Institute of Electrical and Electronics Engineers, pp. 182-189, 2021. https://doi.org/10.1109/ICAMIMIA54022.2021.9807748

[58] A. M. Al-Ansi, M. Jaboob, A. Garad, and A. Al-Ansi, “Analyzing augmented reality (AR) and virtual reality (VR) recent development in Education,” *Social Sciences & Humanities Open*, vol. 8, no. 1, p. 100532, 2023. https://doi.org/10.1016/j.ssaho.2023.100532

[59] M. Klendii, I. Logusch, A. Dragan, I. Tsvartazkii and A. Grabar, "Justification and calculation of design and strength parameters of screw loaders," *Machinery & Energetics*, vol. 13, no. 4, pp. 48-59, 2022. https://doi.org/10.31548/machenergy.13(4).2022.48-59

[60] P. Marino, G. Rubino, L. Rubino, S. Boyer, H. Mercadal and G. Raimondo, "Universal circuit breaker for aeronautic testing application," in *2016 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles and International Transportation Electrification Conference, ESARS-ITEC 2016*. Toulouse: Institute of Electrical and Electronics Engineers, p. 7841362, 2017. https://doi.org/10.1109/ESARS-ITEC.2016.7841362

[61] O. Bai, H. Chu, H. Liu and G. Hui, "Drones in education: A critical review," *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, vol. 12, no. 11, pp. 1722-1727, 2021.

[62] F. Sattar, L. Tamatea and M. Nawaz, "Droning the pedagogy: Future prospect of teaching and learning," *International Journal of Educational and Pedagogical Sciences*, vol. 11, no. 6, pp. 1632-1637, 2017.

[63] M. A. Almaiah *et al.*, "Smart mobile learning success model for higher educational institutions in the context of the COVID-19 pandemic," *Electronics*, vol. 11, no. 8, p. 1278, 2022. https://doi.org/10.3390/electronics11081278

[64] M. Kutia, L. Li, A. Sarkissian and T. Pagella, "Land cover classification and urbanization monitoring using Landsat data: A case study in Changsha city, Hunan province, China," *Ukrainian Journal of Forest and Wood Science*, vol. 14, no. 1, pp. 72-91, 2023. https://doi.org/10.31548/forest/1.2023.72

[65] N. M. Fialko, V. G. Prokopov, N. O. Meranova, Yu. S. Borisov, V. N. Korzhik and G. P. Sherenkovskaya, "Heat transport processes in coating-substrate systems under gas-thermal deposition," *Fizika i Khimiya Obrabotki Materialov*, vol. 2, pp. 68-75, 1994.

[66] M. Ismayil-Zada, "The new economic theory is the main branch of the new physics," *Astra Salvensis*, vol. 2022, no. 1, pp. 13-36, 2022.

[67] V. Panov, "The scientific process of two interferometers (optical) development and the mitigation of external influence," *Scientific Herald of Uzhhorod University. Series "Physics"*, no. 53, pp. 19-30, 2023. https://doi.org/10.54919/physics/53.2023.19

[68] H. Chun, "A study on the utilization of drone education in the Fourth Industrial Revolution," *Journal of Physics: Conference Series*, vol. 1875, p. 012017, 2021. https://doi.org/10.1088/1742-6596/1875/1/012017

[69] H. Azzaoui and Yu. Dyba, "Modern trends in the design and construction of hotels in Morocco," *Architectural Studies*, vol. 8, no. 1, pp. 7-14, 2022. https://doi.org/10.56318/as2022.01.007

[70] I. Nakach, O. Mouhat, R. Shamass and F. El Mennaouy, "Review of strategies for sustainable energy in Morocco," *Polityka Energetyczna*, vol. 26, no. 2, pp. 65-104. https://doi.org/10.33223/epj/163373

[71] M. Figueiredo, R. Mafalda and A. Kamensky, "Virtual reality as an educational tool for elementary school," in *Proceedings of IDEAS 2019 "The Interdisciplinary Conference on Innovation, Design, Entrepreneurship, and Sustainable Systems"*. L. Pereira, J. R. Hughes Carvalho, P. Krus, M. Klofsten, V. J. De Negri, Eds. Cham: Springer, pp. 261-267, 2020. https://doi.org/10.1007/978-3-030-55374-6_26

[72] K. Bolatbek, I. A. Shlygina, A. R. Brodskiy, S. I. Ivanov and M. G. Gordienko, "Quantum-chemical research methods of geometrical and electronic structure of silicon dioxide aerogels," *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*, vol. 3, no. BOOK 6, pp. 135-142, 2016.

[73] N. Trusova, I. Demchenko, N. Kotvytska, A. Hevchuk, D. Yeremenko and Y. Prus, "Foreign-Economic Priorities of the Development of Investment Infrastructure of Agri-Food Production Entities," *Scientific Horizons*, vol. 24, no. 5, pp. 92-107, 2021. https://doi.org/10.48077/scihor.24(5).2021.92-107

[74] N. V. Trusova, T. A. Cherniavska, Y. Y. Kyrylov, V. H. Hranovska, S. V. Skrypnyk and L. V. Borovik, "Ensuring security the movement of foreign direct investment: Ukraine and the EU economic relations," *Periodicals of Engineering and Natural Sciences*, vol. 9, no. 3, pp. 901-920, 2021.

[75] N. S. Buktukov, B. Z. Buktukov and G. Z. Moldabayeva, "Sail-aerodynamic wind power station with automatically changing blade-swept area," *International Journal of Mechanical and Production Engineering Research and Development*, vol. 10, no. 3, pp. 911-920, 2020.

[76] M. M. Ibrahim, "Investigation of a grid-connected solar pv system for the electric-vehicle charging station of an office building using pvsol software," *Polityka Energetyczna*, vol. 25, no. 1, pp. 175-208, 2022. https://doi.org/10.33223/epj/147329

[77] A. Kussainova, M. Rakhimberdinova, O. Denissova, G. Taspenova and M. Konyrbekov, "Improvement of technological modernization using behavioral economics," *Journal of Environmental Management and Tourism*, vol. 9, no. 7, pp. 1470-1478, 2018. https://doi.org/10.14505/jemt.v9.7(31).11

[78] C. Gu *et al.*, "Examining the influence of using first-person view drones as auxiliary devices in matte painting courses on college students' continuous learning intention," *Journal of Intelligence*, vol. 10, no. 3, p. 40, 2022. https://doi.org/10.3390/jintelligence10030040

[79] T. Fedoniuk, R. Fedoniuk, T. Klymenko, O. Polishchuk and A. Pitsil, "Bioindication of Aerotechnogenic Pollution of Agricultural Landscapes Caused by the Activities of Industrial Hubs," *Ekologia Bratislava*, vol. 40, no. 2, pp. 115-123, 2021. https://doi.org/10.2478/eko-2021-0013

[80] T. P. Fedoniuk and O. V. Skydan, "Incorporating geographic information technologies into a framework for biological diversity conservation and preventing biological threats to landscapes," *Space Science and Technology*, vol. 29, no. 2, pp. 10-21, 2023. https://doi.org/10.15407/knit2023.02.010

[81] V. D. Danchuk, L. S. Kozak and M. V. Danchuk, "Stress testing of business activity using the synergetic method of risk assessment," *Actual Problems of Economics*, vol. 171, no. 9, pp. 189-198, 2015.

[82] V. Danchuk, H. Shlikhta, I. Usova, M. Batyrbekova and G. Kuatbayeva, "Integrated project management systems as a tool for implementing company strategies," *Periodicals of Engineering and Natural Sciences*, vol. 9, no. 4, pp. 259-276, 2021. https://doi.org/10.21533/pen.v9i4.2308

Appendix A

Questionnaire for the survey of teachers on the use of VR and drones in the educational process of students of various specialties (1 – strongly disagree, 5 – fully agree)

Subscales and questions	Answers 1	2	3	4	5
Overall perception					
Integrating drones and virtual reality enhances the overall educational experience					
The use of drones and VR has a positive impact on student engagement in the learning process					
Pedagogic influence					
The use of drones and VR contributes to more active learning for students who use it					
The use of drones and VR contributes to a better understanding of theoretical concepts and educational material in general					
Specifics of using drones and VR in the study of certain specialties					
The use of drones and VR in my field has a positive impact on student learning					
The use of drones and VR improves visuospatial learning and understanding, especially in subjects that require an understanding of certain phenomena					
Challenges and opportunities					
The use of drones and VR poses certain challenges in terms of technological infrastructure and resources					
Despite these challenges, the use of drones and VR still prevails over these difficulties					
Professional development					
I received sufficient training and professional development opportunities to effectively integrate drones and VR into my teaching methods					
I feel sufficiently prepared to use drones and VR in the classroom					
Professional development and training opportunities on the use of drones and VR in education fit with my teaching and learning schedule					
It is easier for me to teach a subject using drones and VR					
There is sufficient support for continuous improvement of knowledge on the use of roles and VR in the learning process					

Subscales and questions	Answers 1	2	3	4	5
Overall perception					
I like to share my experience of using drones and VR, and collaborative problem solving with colleagues					
Drone integration challenges in education					
The availability of technological infrastructure (drones and headsets for VR use) in our educational institution is sufficient					
Teachers have easy access to training programs to effectively incorporate drones and VR into their teaching methods					
The use of drones and VR encourages joint initiatives and interdisciplinary projects, cooperation among teachers					
The use of drones and VR has had a positive impact on students' adaptability to the use of technology in the primary process					
Engaging and interacting with students					
Students show greater enthusiasm and participation in classes that use virtual reality and drones					
The use of drones and virtual reality leads to a noticeable improvement in student retention					
Students are relatively better able to navigate the learning material when using VR and drones					
The use of VR and drones has a positive impact on students' critical thinking and problem-solving skills					
Specific considerations for the use of drones in the educational process of certain specialties					
In my subject area, the use of drones and VR aligns well with the curriculum and learning objectives					
Drones and VR have proven to be effective tools for practical application in your subject area					
Using drones and VR has a positive impact on understanding complex concepts in your subject area					
The use of drones and VR has a positive impact on the development of interdisciplinary knowledge among students					
Updating and improving the use of drone and virtual reality technologies in education					

Subscales and questions	Answers 1	2	3	4	5
Overall perception					
I am adequately trained to deal with the challenges of using drones and virtual reality in education					
Limitations in maintaining and updating technology hinder the effective use of drones and UAVs					
Limitations in maintaining and updating technology hinder the effective use of drones and virtual reality					
Overcoming the challenges of using drones and VR in education					
The university takes care of the ongoing professional development of teachers in the use of various technologies, including VR and drones					
The higher education institution supports funding for the use of drones and VR, including the cost of training for teachers					
Curricula for students are constantly updated to include additional technological tools, including drones and VR					