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The Role of Virtual Platforms in Modern Astronomy Education: Analysis of Innovative Approaches

Oleksii Khorolskyi

Candidate of Science in Physics and Mathematics, Associate Professor, Department of General Physics and Mathematics, Faculty of Computer Sciences, Mathematics, Physics and Economics, Poltava V. G. Korolenko National Pedagogical University, Poltava, Ukraine, https://orcid.org/0000-0001-9272-0395

***Corresponding author**: *khorolskiy.alexey@gmail.com.*

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Abstract: The purpose of the article was to study the role of virtual platforms in modern astronomy teaching by identifying and using innovative approaches as well as conducting an empirical study on this topic. To achieve this goal, the scientific methods of descriptive statistics and comparative analysis were used. Subsequently, qualitative interviews were transcribed, and the thematic analysis was used in order to identify recurring themes and patterns in the data. At the same time, a content analysis of the professional literature (41 items) on the integration of virtual platforms into the educational process (including the use of its achievements for teaching astronomy) was carried out. The results showed that the use of virtual platforms in the process of teaching astronomy is one of the promising innovative technological trends that requires further study. The study found that almost all the surveyed specialists used digital tools in their teaching and learning process at least once a week, which is in line with international standards. The interest in the latest technologies, such as artificial intelligence, indicates the relevance of global trends in education in Ukraine, especially in the context of astronomy. In this regard, it is important considering the issues of corporate ethics, the introduction of new approaches to the organisation of the educational process, structural and managerial changes, and pedagogical strategies aimed at adapting to new realities. The scientific novelty of the paper is the use of empirical data to determine the role of virtual platforms in teaching astronomy in Ukraine. The

conclusions indicated that these innovative approaches contribute to the improvement of the level of astronomy understanding and to the increase of students' interest in learning about the universe. They allow creating more dynamic and interactive lessons for the learning process.

Keywords: astronomy, virtual platforms, application, education, programme, digitalisation.

Introduction

Today's world is characterised by the development of information environments and the rapid evolution of digital means of information transmission. Thus, learning is acquiring new technological features that distinguish it from similar processes of relatively recent times. This revolution in education is changing the way we think about learning and transforming traditional methods into dynamic and interactive processes where virtual platforms play a key role (Osores, 2020). These platforms become essential tools for modern education, transform the way of learning and expanding learning opportunities at all levels of the education system. Virtual platforms provide access to a vast amount of knowledge and resources that were previously unavailable. Their impact spans all areas of learning, from early childhood education to higher education. They allow teachers and students effectively communicating, working together on projects, and developing creative and analytical skills.

Qualitative transformations in the education system are impossible without digital changes in the educational process, which aims to maximise the potential of digital technologies. For this reason, digital platforms for online classes and supplementary learning allow all participants in educational interactions facilitating the access to the learning management, online courses, etc. These resources become increasingly important due to several factors such as the total integration of digital technologies into all spheres of public life, large-scale educational changes caused by quarantine restrictions, and the global COVID-19 pandemic (Abumalloh et al., 2021). For Ukrainian realities, the intensification of online learning technologies was caused by the Russian military invasion, as a result of which a return to traditional forms of education was absolutely impossible for a long time due to the threat to the physical life as well as teachers and students health.

Research Problem

These changes are undoubtedly also relevant for astronomical science, which plays an important role in the study of the universe, solar systems, constellations, etc. Given the current proficiencies of digital technologies and the success of modelling, the use of digital platforms for educational purposes is an integral part of modernity. The peculiarities of such use are an innovative phenomenon that will require additional reflection, given the constant evolution of digital educational environments and the Internet in general. As educational environments change, the teaching and learning astronomy aspects are also transforming. This issue was partially studied by Cui et al. (2017), who in their conclusions emphasised the use of certain important programmes. Similarly, Chaiyarak et al. (2021) identified the relevance of digital technologies, including for teaching astronomy. The importance of virtual reality and other digital opportunities for teaching astronomy has also been repeatedly emphasised (de Moraes Rossetto et al., 2023; Haleem et al., 2022), as well as national experience in distance learning (Gargano et al., 2018). However, some issues of improving astronomy teaching (given the continuous development of learning platforms) require some improvement and further development.

Research Focus

In this article the role of virtual platforms in modern astronomy education by examining their advantages and challenges was discussed. The extent to which these platforms can change and improve

approaches to education at different levels was explored, as well as their contribution to the development of skills and knowledge in astronomy were demonstrated. Using specific examples and statistics, it was expected to illustrate the impact of virtual platforms on modern education and to discuss the prospects for their future development.

Research Aim and Research Questions

The purpose of the article was to analyse the role of virtual platforms in modern astronomy teaching by identifying and using innovative approaches. The realisation of this goal involved the examination of the following tasks:

1. The consideration of modern virtual platforms in teaching astronomy importance.
2. The significance and results of the empirical study explanation.
3. The main shortcomings and difficulties in further developing the use of digital tools and virtual platforms identification.

Research Methodology

General background

The research process began with the selection of participants in the experiment. All participants – were teachers of Ukrainian educational institutions of different levels that used modern interactive platforms for studying astronomy for 3 months. The main emphasis was placed on using such tools as Stellarium, SkySafari, NASA's Eyes on the Solar System, WorldWide Telescope, etc. Subsequently, the respondents had to identify the specifics of using these platforms. Based on the obtained data, the role of using these platforms in teaching astronomy was characterised. The obtained information was compared with the results of other scientists, and a general conclusion about the importance of innovative platforms in the educational process was made.

Sampling Procedure

First, the target group was identified: teachers involved in teaching astronomy at different levels (e.g., primary, secondary, college, or university). The sampling method was a stratified random sample, which helped ensuring the representation from different educational levels (e.g., primary, secondary, high school, college) and geographical regions. The sample size was 65 teachers.

Participants

The study involved 65 teachers with different experience in teaching the discipline “Astronomy” and different experience in using innovative methods and forms of teaching.

Criteria for inclusion in the study:

1. Teachers who teach astronomy.
2. Teachers with different levels of experience.
3. Teachers of different types of educational institutions (public schools, private schools, colleges, etc.).
4. Teachers who wish to participate voluntarily.

Participants were recruit through an email invitation to participate in the experiment. This letter

provided clear information about the objectives and procedures of the study. After that, consent was obtained from each participant.

Research Design

Mixed methods research was used in this study, combining both quantitative and qualitative research methods. A sequential research design was used, starting with the collection and analysis of quantitative data, followed by the collection and in-depth analysis of qualitative data.

Instruments and Data Collections

At the first stage of the study, a structured online questionnaire was developed in order to collect quantitative data on the experience and perception of virtual platforms in the process of teaching astronomy. The online questionnaire was created based on Google Forms and distributed through social media. Thus, the empirical materials were collected in stages from 15.02.2023 to 27.05.2023, i.e., throughout the second semester of the academic year. In general, a questionnaire was developed, which consisted of some open and closed questions.

The first level. Open questions.

1. How often have you used innovative technologies in your teaching of astronomy? (Please select one answer)

a) Constantly

b) Once a week

c) Several times a month

d) Not often

e) I do not use it at all

2. Has the use of interactive platforms influenced students' attitudes towards learning? (Select one answer)

a) Yes

b) No

3. In your opinion, what is missing for the effective use of digital learning platforms in the educational process? (Please select one or more answers)

a) High level of digital literacy

b) Suitable material and technical conditions

c) Motivation for use

d) Satisfaction with everything

The second level. Closed questions.

1. Do you use innovative approaches to teaching astronomy through virtual platforms? If so, please provide examples of innovative methods or projects you are implementing.

2. Which approach have you used most often in your professional activities?

3. How do you assess the effectiveness of using virtual platforms in teaching astronomy?

4. Please briefly describe the features of using interactive platforms in your astronomy teaching. How do they help you and your students to understand the subject better?

5. What are the benefits of using learning platforms in teaching astronomy?

6. What challenges have you faced in using certain platforms?

7. How do you assess the overall value of using interactive platforms in teaching astronomy?

8. What improvements or recommendations would you suggest for the use of interactive platforms in astronomy education?

Subsequently, semi-structured interviews were also conducted with some teachers to gain an in-depth understanding of their experiences.

Data analysis

To analyse the quantitative data, descriptive statistics were used to summarise the data. A comparative analysis was also used to compare and evaluate the responses of the participants. Subsequently, qualitative interviews were transcribed, and an analysis was used to identify recurring themes and patterns in the data. After that, the results were integrated: the results of the quantitative and qualitative analyses were combined to draw comprehensive conclusions.

Research Results

Modern Virtual Platforms in Teaching Astronomy: The Essential and the Unessential

According to researchers, the main directions of digitalisation of astronomy education may be the use of augmented, virtual, and mixed realities, cloud computing technologies, special online learning platforms, mobile applications, and other digital technologies (Potkonjak et al., 2016). At the same time, the possibilities of distance and blended learning should not be dismissed, as they will require appropriate digitalisation of library collections in educational institutions (Chaiyarak et al., 2021; Kamińska et al., 2019). According to researchers, the most popular virtual platforms with educational content within Europe are Coursera (37 million users), Edx (18 million users), XuetangX (14 million users), Udacity (10 million users), FutureLearn (8.7 million users) (Anthony Jnr & Noel, 2021). Popular platforms in the Ukrainian context are Prometheus, MIT Open Course Ware, Moodle, Classroom, MixSumDu (Malchenko et al., 2021). All of these platforms have their own potential for learning and teaching astronomy.

Special virtual platforms are important for learning astronomy (Hasan & Hasan, 2019; Sarkar et al., 2021). Particularly, a free software product is Stellarium, which allows users observing stars, planets, and other astronomical objects in real-time. Here, you can choose the date and place of observation to study astronomical phenomena (Taghizadeh-Popp et al., 2020). Another important application is SkySafari. It allows users exploring the sky by using smartphones or tablets (Mickaelian & Mikayelyan, 2019) and contains useful features for amateur astronomers. Celestia is a free computer application that allows users exploring the space by moving from planet to planet, star to star (Zhang & Zhao, 2015). NASA's Eyes on the Solar System virtual platform provides an opportunity to explore the solar system and other astronomical phenomena using 3D models and visualisations (Kersting et al., 2023). At the same time, WorldWide Telescope is a special application created by Microsoft that allows users

exploring the universe by viewing a large amount of astronomical data and visualisations. On the other hand, an important resource for learning astronomy is Slooh. It is an online service for observing the sky in real-time using webcams and telescopes located in different parts of the world (Sit, 2022). It provides an opportunity to join online events and the community of astronomers. Table 1 provides basic information about the above programmes and describes their functional mechanisms.

Key information	Functions
Stellarium	
Stellarium is a freely available computer application that allows users tracking astronomical objects in real-time.	Stellarium allows setting the time and place of observation, observing planets, stars, galaxies, and other astronomical objects. The application allows quickly moving to the celestial sphere and observe moving objects.
SkySafari	
SkySafari is a mobile application for smartphones and tablets available on iOS and Android platforms.	SkySafari provides many different features for exploring the sky (including interactive sky maps, detailed descriptions of astronomical objects) the ability to track satellites and other objects, and information about planets and their satellites.
Celestia	
Celestia is a computer application that allows users traveling through the space and explore the universe.	It has a large number of astronomical objects, and it is possible to choose any of them for a closer look. The application allows moving from planet to planet, observing the movement of stars and galaxies.
NASA's Eyes on the Solar System	
This virtual platform from NASA provides an opportunity to explore the solar system through interactive visualisations.	This application allows visualising planets, their satellites, asteroids, and comets in detail, observing NASA missions, and much more.
WorldWide Telescope	
The platform allows users exploring the universe with a large amount of astronomical data and visualisations.	WorldWide Telescope allows exploring galaxies, stars, planets, and other astronomical objects (Nakata et al., 2014). The app allows creating the own tours and exploring the space from different angles.
Slooh	
Slooh is an online service for observing the sky in real-time.	Slooh provides an opportunity to join online observations of astronomical phenomena that are carried out on various telescopes around the world. Users can take part in joint observations and communicate with astronomers.

Source: author's development.

In the context of the analysed problem regarding the peculiarities of teaching astronomy in the modern era, hypotheses about the gradual transition from the quantitative accumulation of technological means to a smooth change of goals and priorities, the manifestation of corporate ethics, new principles of training, appropriate structural and managerial changes and pedagogical techniques focused on the new reality are relevant (Haleem et al., 2022). Educational institutions are faced with a number of challenging tasks (Kruss et al., 2015). These include improving the information and technological infrastructure for providing educational space, productive use of up-to-date digital tools in teaching astronomy, the importance of training, retraining, and upgrading of teaching staff in the context of the growing influence of digital technologies on the new quality and efficiency of learning;

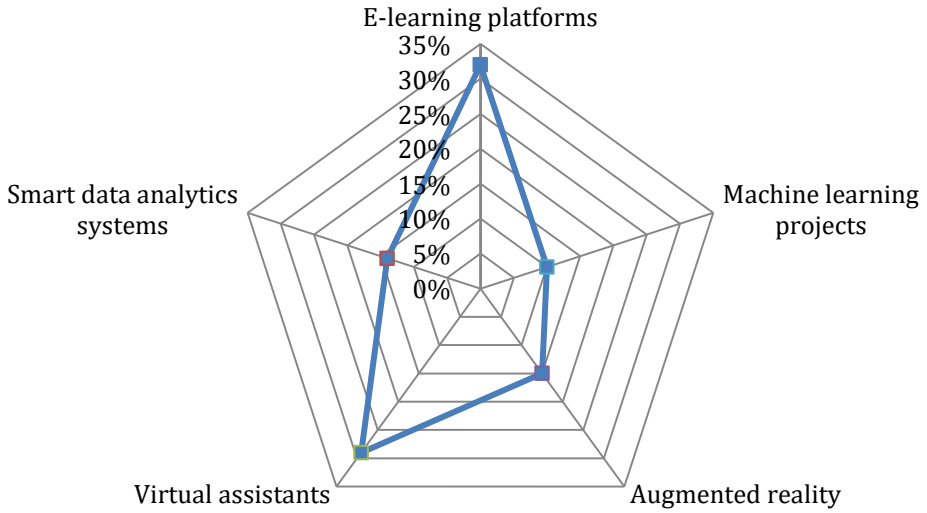
creating a new look for educational content in astronomy.

Virtual Platforms for Teaching Astronomy in Ukraine: An Empirical Aspect

Innovative educational platforms are actively used in modern Ukrainian education. As evidenced, particularly, 70% of respondents use modern educational technologies in the implementation of the astronomy learning process (See Figure 1).

Figure 1

Diagram of the use of Modern Educational Technologies in the Process of Studying Astronomy



Source: author's development.

When reviewing and analysing the survey results, some peculiarities of using virtual learning platforms in education were identified. The results are presented in the form of tables (See Tables 2-4). Innovative educational technologies are actively used in the process of studying astronomy. As evidenced, 41% of respondents used modern learning platforms in the process of teaching astronomy regularly. 45 percent of respondents said they used them once a week (See Table 2).

Table 2

Frequency of Use of Innovative Educational Technologies

How often have you used innovative technologies during your studies? (Please select one answer)		
Answer	Quantity	Percentage
Constantly	26	41 %
Once a week	30	45 %
Several times a month	5	7 %
Not often	4	6%
I do not use it at all	1	1%

Source: author's development.

Nevertheless, the use of special platforms for studying astronomy affects the transformation of students' attitudes to learning. This is confirmed by the answers of the respondents (See Table 3).

Table 3

Transformation of Students' Attitude to Learning as a Result of Using Virtual Platforms in the Process of Studying Astronomy

Has the use of artificial intelligence influenced students' attitudes to learning? (Please select one answer)		
Answer	Quantity	Percentage
Yes, motivation has improved	42	65 %
Nothing has changed	13	20 %
On the contrary, the results have deteriorated	6	9%
No answer	4	6%

Source: author's development.

At the same time, the respondents' opinions were divided when asked "What is missing for the effective use of virtual platforms in teaching astronomy." 45% of respondents said it was important to have a high level of digital literacy. Others noted that Ukrainian institutions lack the appropriate material and technical conditions to actively use virtual platforms (25%). Another 15% said they lacked motivation. At the same time, 15% of respondents emphasised that their institutions have all the conditions for the introduction and use of learning platforms and are therefore satisfied with everything (See Table 4).

Table 4

Notes on the Use of Virtual Platforms

What do you think is lacking for the effective use of artificial intelligence in the educational process? (Choose one answer)

Answer	Quantity	Percentage
High level of digital literacy	30	44 %
Suitable material and technical conditions	13	25 %
Motivation to use	10	14 %
Everything suits me	10	14 %

No answer	2	3

Source: author's development.

At the same time, the respondents' opinions were also divided when determining the benefits of using virtual learning platforms in the study of astronomy. The majority of them noted the possibilities of individualised learning - artificial intelligence is able to adapt to the needs of students, and therefore develop an individual approach to learning (40% of respondents). Slightly fewer pointed out the importance of monitoring the progress of students (26%), while others focused on the availability of online platforms (18%). It should be noted that the survey results generally correlate with the opinions of researchers, although, for example, respondents did not mention the importance of the ability of digital learning platforms to help people with special needs. At the same time, the majority of respondents clearly emphasise the positive impact of learning platforms on the quality of the educational process (68% of respondents).

When using virtual platforms in modern astronomy teaching, teachers had ample opportunities to implement modern innovative approaches (Mokhun et al., 2022). It was particularly important to use virtual 3-D tours or other digital tools (in particular, based on the use of WorldWide Telescope, Slooh, Celestia and other programmes) (54% of respondents). Another important approach was the use of game-based learning methods and simulations. This approach contributed to the individualisation of learning and improved motivation of students (Malchenko et al., 2020). When using virtual platforms, the use of cooperative projects was also implemented (cooperative learning - indicated by 42%), etc. However, such an approach as involving students in astrophotography was not widely popular among the spitters. Only 5% of respondents mentioned it (See Table 5)

Table 5

Characteristics of Innovative Approaches

Approach	Features of use
Active learning through simulations and virtual labs	Use of interactive simulations and virtual laboratories to explore astronomical phenomena (Gargano et al., 2018; Impey, 2019). Students can independently experiment and observe the consequences, which contributes to a deeper understanding of the material.
Using virtual tours	Organising virtual journeys to space objects, galaxies, planets, and other astronomical objects using virtual reality applications or interactive platforms (Atta et al., 2022). This allows students exploring the space from different perspectives.

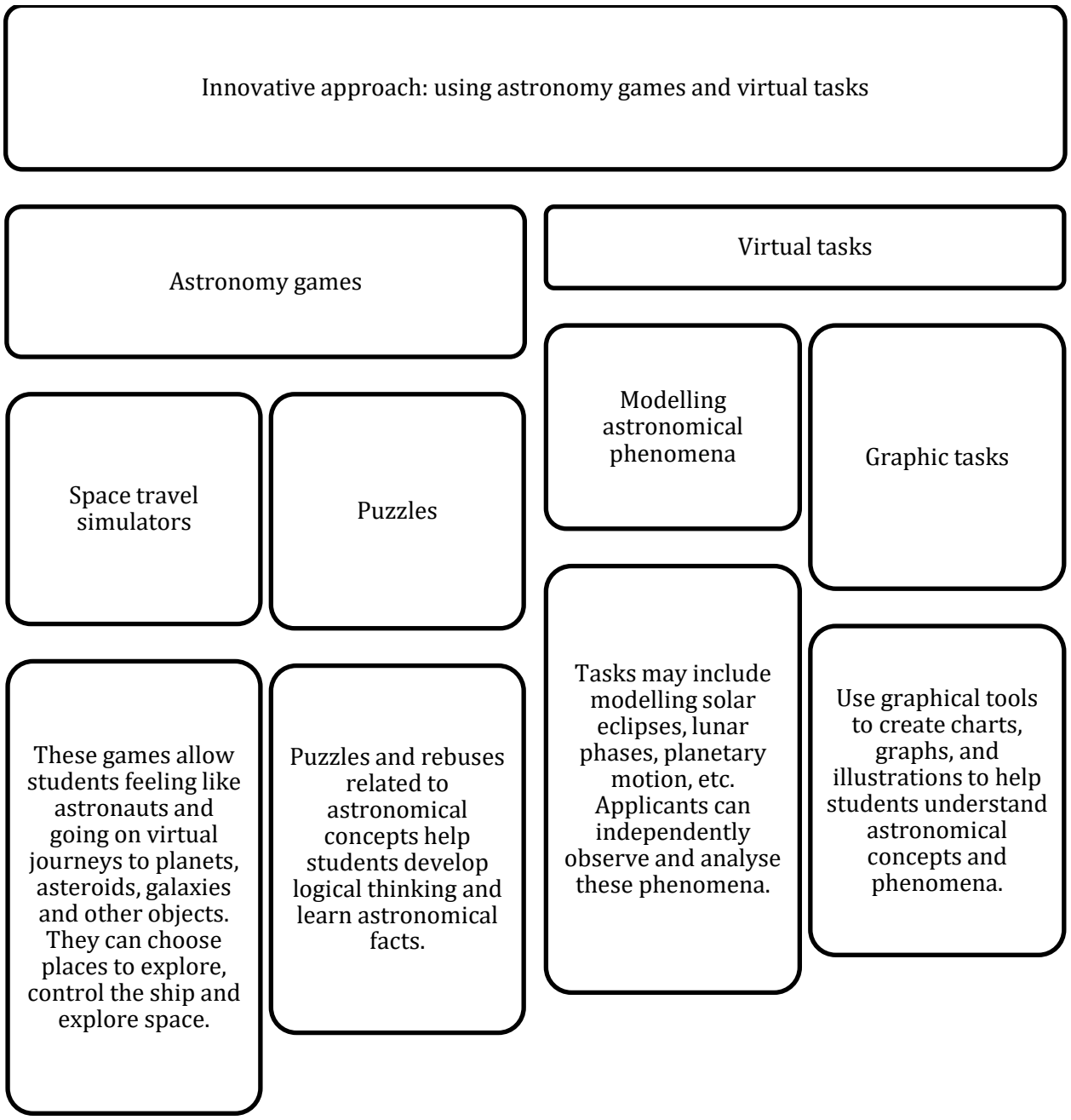
Cooperative learning	The use of virtual platforms for students to work together on astronomy projects or tasks (Abichandani et al., 2019). Students can communicate, share opinions, and research, even if they are at a great distance from each other.
Astronomy games and virtual tasks	Developing game environments or virtual tasks (Bedregal-Alpaca et al., 2020) that allow students learning astronomy by solving puzzles, problems, and simulations.
Astrophotography Astronomical observation networks:	Involving students in astrophotography, where they can take pictures of astronomical objects using virtual platforms and special photo-processing software (Cui et al., 2017). Separately, astronomical observations contribute to the involvement of students in global observing networks, where they can join joint projects and exchange observations with other students around the world.

Source: author's development.

Respondents stated that the use of games that can be used by students outside of class time plays an important role in the system of additional learning (about 62% of respondents emphasised this). Thus, in the system of innovative approaches, it is important to use astronomy games, which can be divided into space travel stimulators, puzzles, or star study games (see Figure 2).

Figure 2

Scheme of Using Astronomical Games and Virtual Tasks in the Process of Studying Astronomy



There are several ways to use this approach:

1. In-class activities. It means that games and virtual tasks can be included in the curriculum and used as additional materials for studying astronomy in class.

2. Distance learning. Students can complete assignments and play astronomy games at home if they are studying remotely.

3. Extracurricular work. Teachers can provide game assignments or virtual research for additional study of astronomy outside of class.

Discussion

The development of modern educational systems is influenced by the general impact of digitalisation and, in general, leads to an important challenge (Reynosa Navarro et al., 2022; Zhang et al., 2020).

First of all, on the one hand, it is already extremely important to ensure that astronomy specialists are trained with appropriate digital competences (Cortiz & Silva, 2017). At the same time, on the other hand, the educational system is faced with the urgent task of adapting its internal organisational and institutional logic to improve its competitiveness in the current market conditions (Domingo & Bradley, 2017). Therefore, the expansion of the use of information technologies and virtual platforms in the near future will lead to fundamental changes in the processes of supply and demand formation in the labour markets, which in turn will adjust the requirements for the need to learn and teach astronomy as an important worldview discipline.

Under current conditions, learning takes place with the active use of digital channels (Ergüzen et al., 2021; Plass et al., 2022). We are talking about cloud services, digital platforms, and tools. Distance and blended learning, which are popular due to quarantine restrictions, use the potential of online platforms, because it is impossible to function otherwise while providing quality educational services without modern technologies (Schneps et al., 2014). Researchers have drawn attention to the fact that the quality of education in general (a broad understanding of this process) is presented as a certain balanced ratio of knowledge (both results and the learning process itself, which is the basis of this system (Cejas Martínez et al., 2021)) with different needs, searches, goals, rules, principles (standards) (Smith et al., 2022; Volioti et al., 2022). At the same time, it is a systemic set of hierarchical and organised in a certain sequence of socially significant important properties (features and attributes of parameters) of education. In practice, this does not mean that traditional forms of education will completely disappear (as well as educational institutions in general). However, much more can be achieved with the use of virtual platforms and new learning technologies - the use of ordinary gadgets (everyday smartphones and other Internet-connected devices) can significantly facilitate the process of learning and gaining knowledge from anywhere and at any time.

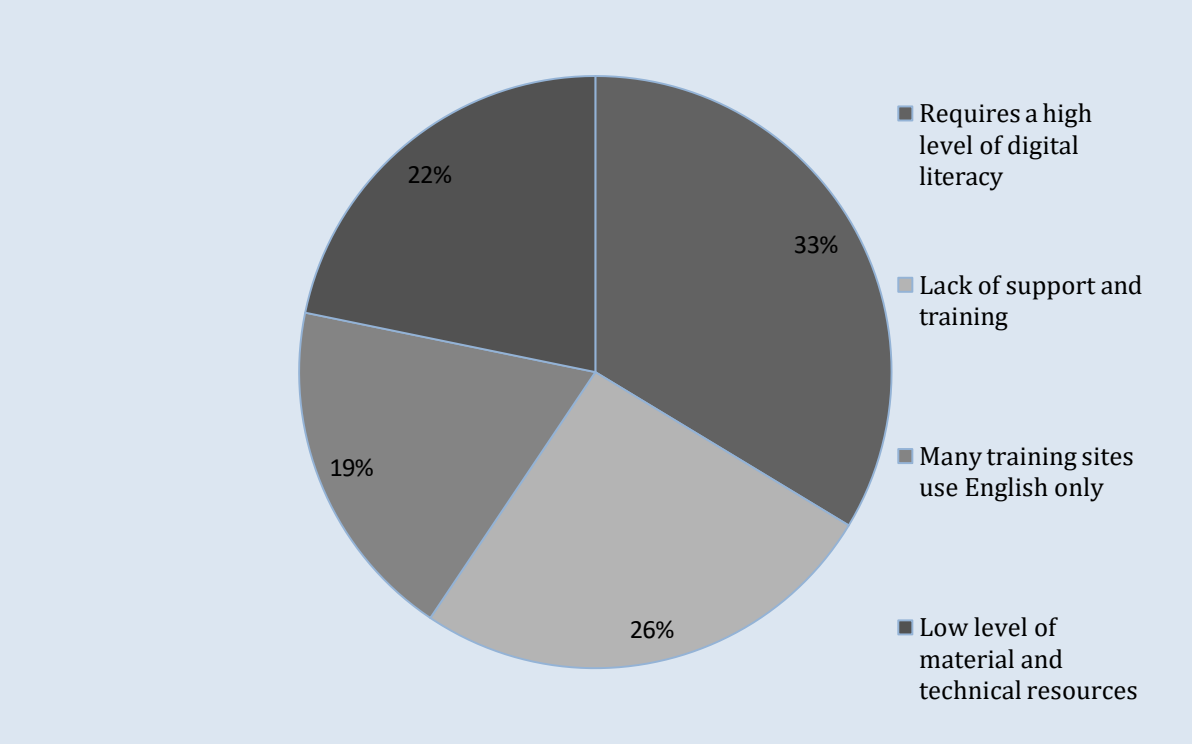
The findings are in line with the trends noted by scholars. Particularly, the vast majority of respondents (86% in total) use innovative technologies in teaching astronomy at least once a week. These figures correlate with those of other researchers (Bedregal-Alpaca et al., 2020; Herwig et al., 2018). In general, it can be argued that the interest in using virtual platforms as innovative teaching tools will be further developed and obviously continued after the COVID-19 pandemic. One of the manifestations of this process is the interest in the use of artificial intelligence, which, according to the study, has found a response in the Ukrainian environment of education seekers (almost 90%). This trend reflects the general direction of the development of astronomy teaching.

However, the implementation of these innovative approaches in the study of astronomy may face some difficulties for teachers (Cole et al., 2018; de Moraes Rossetto et al., 2023). Respondents emphasised that their effective use requires a high level of digital literacy (34%). For this reason, a major challenge for today teachers is to close the gap they may have in digital literacy (Cheng et al., 2021). For teachers who have no previous experience of using interactive learning approaches, it can be difficult to understand how these technologies work and how to apply them in the educational process.

Accordingly, time and effort must be invested in familiarising themselves with the basics of using innovation platforms and their capabilities. Another difficulty in using them is the lack of support and training (22% of respondents). Consequently, a modern educational institution should have adequate training resources so that teachers can understand and effectively use interactive tools in their work. An important disadvantage of using modern innovative platforms in the process of studying astronomy is that almost all available sites are in English (19%), because the level of understanding English is low. Despite this, an important challenge is the inadequate material and technical base. This was emphasised by many respondents (22%) (See Figure 3).

Figure 3

Diagram of the Main Disadvantages and Difficulties of Using Interactive Approaches (Based on the Use of Virtual Platforms) in the Process of Teaching Astronomy



Source: author's development.

Thus, the use of innovative approaches based on the use of virtual learning platforms in the process of teaching astronomy has several advantages and several disadvantages because of the widespread use of modern innovative educational technologies, the above problems should be solved.

Conclusions and Implications

The use of virtual platforms in teaching astronomy is one of the promising innovative technological areas that will require further consideration. Based on the study, it was found that the vast majority of respondents used digital tools in teaching and learning at least once a week, which is in line with European and global indicators. The interest in new technologies, such as Artificial Intelligence, indicates the relevance of other global trends in the Ukrainian educational space (for example, astronomy). In the context of the problem under consideration, which concerns the peculiarities of teaching astronomy in the modern era, hypotheses about a gradual transition from the simple accumulation of technological resources to a smooth change in targets and priorities are relevant. In this context, it is especially important considering the corporate ethics, new approaches to the organisation of the educational process, structural and managerial transformations, and pedagogical strategies aimed at considering new realities. In general, these innovative approaches encourage independent research. The use of virtual tours, virtual laboratories, and games encourage students to explore astronomy on their own and gain a deeper understanding of space phenomena. The above-mentioned innovative approaches lead to more dynamic and interactive lessons resulting in better understanding of astronomy for students and increased interest.

Suggestions for Future Research

Promising areas for further research include the improvement of the tools for acquiring the

necessary digital competencies in the future, as virtual platforms will continue to evolve. These changes will require technological upgrades and the work of both teachers and students. Thus, it is believed that the research on the role of different virtual platforms in modern astronomy education is a dynamic field with ample opportunities for future research. For example, it is necessary to conduct studies to assess the effectiveness of virtual astronomy labs in comparison to traditional hands-on labs. Investigate whether virtual labs provide the same level of learning outcomes and whether they can replace or complement physical labs. Therefore, it is worth conducting an empirical study that will determine the effectiveness of virtual online platforms in comparison with the traditional education system. Research should be conducted in special focus groups and based on the results, describe ways to improve the system of astronomy teaching in modern educational institutions. At the same time, a separate direction for further research is the analysis of interactive modelling. It is worth investigating the impact of interactive simulations and simulation tools on students' understanding of complex astronomical phenomena. An important aspect of this research is to analyse how these tools can improve conceptual understanding and problem-solving skills. Therefore, one believes that by addressing these research areas, scholars can contribute to the ongoing advancement of virtual astronomy education, providing insights and evidence-based practices to enhance the learning experiences of students interested in astronomy.

References

Abichandani, P., Mcintyre, W., Fligor, W., & Lobo, D. (2019). Solar energy education through a cloud-based desktop virtual reality system. *IEEE Access*, *7*, 147081–147093. https://doi.org/10.1109/access.2019.2945700

Abumalloh, R. A., Asadi, S., Nilashi, M., Minaei-Bidgoli, B., Nayer, F. K., Samad, S. … Ibrahim, O. (2021). The impact of coronavirus pandemic (COVID-19) on education: The role of virtual and remote laboratories in education. *Technology in Society*, *67*, Article 101728. https://doi.org/10.1016/j.techsoc.2021.101728

Anthony Jnr, B., & Noel, S. (2021). Examining the adoption of emergency remote teaching and virtual learning during and after the COVID-19 pandemic. *International Journal of Educational Management*, *ahead-of-print, 35*(6), 1136–1150. https://doi.org/10.1108/ijem-08-2020-0370

Atta, G., Abdelsattar, A., Elfiky, D., Zahran, M., Farag, M., & Slim, S. O. (2022). Virtual reality in space technology education. *Education Sciences*, *12*(12), Article 890. https://doi.org/10.3390/educsci12120890

Bedregal-Alpaca, N., Sharhorodska, O., Jiménez-Gonzáles, L., & Arce-Apaza, R. (2020). A gamification experience and virtual reality in teaching astronomy in basic education. *International Journal of Advanced Computer Science and Applications*, *11*(5). https://doi.org/10.14569/ijacsa.2020.0110566

Cejas Martínez, M. F., Navarro Cejas, M., Venegas Alvarez, G. S., Proaño Rodríguez, C. E., & Mendoza Velazco, D. J. (2021). Student perceptions of ecuadorian virtual platforms during the Covid-19 pandemic. *Problems of Education in the 21st Century, 79*(2), 241–254. https://doi.org/10.33225/pec/21.79.241

Chaiyarak, S., Nilsook, P., & Wannapiroon, P. (2021). An empirical study of intelligent virtual universal learning platforms. In *2021 research, invention, and innovation congress: Innovation electricals and electronics (RI2C)*. IEEE. https://doi.org/10.1109/ri2c51727.2021.9559785

Cheng, L., Niu, W.-C., Zhao, X.-G., Xu, C.-L., & Hou, Z.-Y. (2021). Design and implementation of college

physics teaching platform based on virtual experiment scene. *The International Journal of Electrical Engineering & Education*. https://doi.org/10.1177/0020720920984688

Cole, M., Cohen, C., Wilhelm, J., & Lindell, R. (2018). Spatial thinking in astronomy education research. *Physical Review Physics Education Research*, *14*(1), Article 010139. https://doi.org/10.1103/physrevphyseducres.14.010139

Cortiz, D., & Silva, J. O. (2017). Web and virtual reality as platforms to improve online education experiences. In *2017 10th international conference on human system interactions (HSI)* (pp. 83–87). IEEE. https://doi.org/10.1109/hsi.2017.8005003

Cui, C.-Z., He, B.-L., Li, C.-H., Fan, D.-W., Li, S.-S., Mi, L.-Y. … Han, X. (2017). AstroCloud: A distributed cloud computing and application platform for astronomy. In J. Wang, H. Wang, B. Cheng, & T. Chen (Eds.), *3rd international conference on wireless communication and sensor networks (WCSN 2016)*. Atlantis Press. https://doi.org/10.2991/icwcsn-16.2017.108

de Moraes Rossetto, A. G., Martins, T. C., Silva, L. A., Leithardt, D. R. F., Bermejo-Gil, B. M., & Leithardt, V. R. Q. (2023). An analysis of the use of augmented reality and virtual reality as educational resources. *Computer Applications in Engineering Education*. https://doi.org/10.1002/cae.22671

Domingo, J. R., & Bradley, E. G. (2017). Education student perceptions of virtual reality as a learning tool. *Journal of Educational Technology Systems*, *46*(3), 329–342. https://doi.org/10.1177/0047239517736873

Ergüzen, A., Erdal, E., Ünver, M., & Özcan, A. (2021). Improving technological infrastructure of distance education through trustworthy platform-independent virtual software application pools. *Applied Sciences*, *11*(3), 1214. https://doi.org/10.3390/app11031214

Gargano, M., Gasperini, A., Schiavone, L., & Brunetti, F. (2018). Polvere di stelle The Italian platform for data-sharing and data-preserving of modern and ancient astronomical resources. *EPJ Web of Conferences*, *186*, Article 07002. https://doi.org/10.1051/epjconf/201818607002

Haleem, P. A., Javaid, D. M., Qadri, P. M. A., & Suman, D. R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275–285. https://doi.org/10.1016/j.susoc.2022.05.004

Hasan, P., & Hasan, S. N. (2019). Astronomy data, virtual observatory and education. *Proceedings of the International Astronomical Union*, *15*(S367), 151–154. https://doi.org/10.1017/s174392132100034x

Herwig, F., Andrassy, R., Annau, N., Clarkson, O., Côté, B., D'Sa, A. … Woodward, P. (2018). Cyberhubs: Virtual research environments for astronomy. *The Astrophysical Journal Supplement Series*, *236*(2). https://doi.org/10.3847/1538-4365/aab777

Impey, C. (2019). Online resources for astronomy education and outreach. *Proceedings of the International Astronomical Union*, *15*(S367), 105–115. https://doi.org/10.1017/s1743921321000399

Kamińska, D., Sapiński, T., Wiak, S., Tikk, T., Haamer, R., Avots, E. … Anbarjafari, G. (2019). Virtual reality and its applications in education: Survey. *Information, 10*(10), Article 318. https://doi.org/10.3390/info10100318

Kersting, M., Bondell, J., Steier, R., & Myers, M. (2023). Virtual reality in astronomy education: Reflecting

on design principles through a dialogue between researchers and practitioners. *International Journal of Science Education, Part B*. https://doi.org/10.1080/21548455.2023.2238871

Kruss, G., McGrath, S., Petersen, I.-h., & Gastrow, M. (2015). Higher education and economic development: The importance of building technological capabilities. *International Journal of Educational Development*, *43*, 22–31. https://doi.org/10.1016/j.ijedudev.2015.04.011

Malchenko, S. L., Mykoliuk, D. V., & Kiv, A. E. (2020). Using interactive technologies to study the evolution of stars in astronomy classes. In A. E. Kiv & M. P. Shyshkina (Eds.), *Proceedings of the 2nd International Workshop "Augmented reality in education" (AREdu 2019)* (pp. 145–155). https://doi.org/10.31812/123456789/3752

Malchenko, S. L., Tsarynnyk, M. S., Poliarenko, V. S., Berezovska-Savchuk, N. A., & Liu, S. (2021). Mobile technologies providing educational activity during classes. *Journal of Physics: Conference Series*, *1946*(1), Article 012010. https://doi.org/10.1088/1742-6596/1946/1/012010

Mickaelian, A. M., & Mikayelyan, G. A. (2019). The role of Big Data in astronomy education. *Proceedings of the International Astronomical Union*, *15*(S367), 214–217. https://doi.org/10.1017/s1743921321000570

Mokhun, S., Fedchyshyn, O., Kasianchuk, M., Chopyk, P., Basistyi, P., & Matsyuk, V. (2022).Stellarium software as a means of development of students' research competence while studying physics and astronomy. In *2022 12th international conference on advanced computer information technologies (ACIT)*. IEEE. https://doi.org/10.1109/acit54803.2022.9913116

Nakata, M., Hamacher, D., Warren, J., Byrne, A., Pagnucco, M., Harley, R. … Bolt, R. (2014). Using modern technologies to capture and share indigenous astronomical knowledge. Australian *Academic & Research Libraries, 45*(2), 101–110. https://doi.org/10.1080/00048623.2014.917786

Osores, J. J. V. (2020). Virtual university education in the context of the health emergency due to COVID-19: Challenges in the evaluation processes. *International Journal of Early Childhood Special Education*, *12*(1), 467–477. https://doi.org/10.9756/int-jecse/v12i1.201027

Plass, J. L., Hovey, C., Maso, A. S., Fröhlich, F., Ghosh, S., Olsen, A., & Perlin, K. (2022). Designing effective immersive VR learning experiences. *Immersive Learning Research – Practitioner, 1*(1), 32–37. https://doi.org/10.56198/A6PFY1CBT

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, *95*, 309–327. https://doi.org/10.1016/j.compedu.2016.02.002

Reynosa Navarro, E., Montero, J. M. C., Meléndez, L. V., & Navarro, E. R. (2022). Development of social skills of high school students on virtual platforms, 2021. *World Journal on Educational Technology: Current Issues*, *14*(1), 231–242. https://doi.org/10.18844/wjet.v14i1.6720

Sarkar, B., Saha, D., & Das, A. (2021). Voice of the future classroom: Virtual and augmented reality. In S. Pal, T. Quang Cuong, & R. S. S. Nehru (Eds.), *Digital education for the 21st century* (pp. 181–206). Apple Academic Press. https://doi.org/10.1201/9781003180517-8

Schneps, M. H., Ruel, J., Sonnert, G., Dussault, M., Griffin, M., & Sadler, P. M. (2014). Conceptualizing astronomical scale: Virtual simulations on handheld tablet computers reverse misconceptions. *Computers & Education*, *70*, 269–280. https://doi.org/10.1016/j.compedu.2013.09.001

Sit, E. C. L. (2022). Astronomy for special education needs. *Revista Mexicana de Astronomía y Astrofísica Serie de Conferencias*, *54*, 104–106. https://doi.org/10.22201/ia.14052059p.2022.54.23

Smith, J. R., Snapp, B., Madar, S., Brown, J. R., Fowler, J., Andersen, M. … Orban, C. (2022). A smartphone-based virtual reality plotting system for STEM education. *Primus, 33*(1), 1–15. https://doi.org/10.1080/10511970.2021.2006378

Taghizadeh-Popp, M., Kim, J. W., Lemson, G., Medvedev, D., Raddick, M. J., Szalay, A. S. … Rippin, M. (2020). SciServer: A science platform for astronomy and beyond. *Astronomy and Computing*, *33*, Article 100412. https://doi.org/10.1016/j.ascom.2020.100412

Volioti, C., Keramopoulos, E., Sapounidis, T., Melisidis, K., Zafeiropoulou, M., Sotiriou, C., & Spiridis, V. (2022). Using augmented reality in K-12 education: An indicative platform for teaching physics. *Information*, *13*(7), Article 336. https://doi.org/10.3390/info13070336

Zhang, Q., Wang, K., & Zhou, S. (2020). Application and practice of VR virtual education platform in improving the quality and ability of college students. *IEEE Access*, *8*, 162830–162837. https://doi.org/10.1109/access.2020.3019262

Zhang, Y., & Zhao, Y.(2015). Astronomy in the Big Data era. *Data Science Journal*, *14*(11), 1–9. https://doi.org/10.5334/dsj-2015-011