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Virtual Pedagogy: Scenarios for Future Learning with VR and AR Technologies

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Abstract: Modern education and science are at the stage of active practical implementation of digital technologies aimed at improving the efficiency of the educational process. The fourth wave of industrial development offers digital and technological solutions that enhance the practical learning experience through the use of immersive technologies such as augmented and virtual reality. The purpose of this study is to assess the possibilities of using currently available Virtual Reality /

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Augmented Reality (VR/AR) technologies and to develop specific recommendations for improving the quality of the educational process, as well as to explore promising areas for the development of immersive education. The study used methods of criterion-based selection of the optimal tool for creating educational virtual content. This selection was made among the research nomenclature of currently available relevant digital platforms based on the calculation of specialised metrics for assessing the focal technical and technological capabilities of the studied cloud resources. Based on the results of this study, the optimal and currently available means of creating educational content has been identified, which provides users with the opportunity to use VR/AR technologies without acquiring special skills and abilities. Pedagogical scenarios that have already been immersed and can be adapted to different sectors of education are proposed. Probable vectors for the further development of educational VR/AR technologies are considered, and a hypothesis is formed about the need to use real experience in implementing immersive and virtualised educational processes to adjust and moderate the future development of global education in the context of the and Education 4.0 paradigms. The results of this study indicate the dynamic development of the field of immersive and virtualised educational space, formulate practical recommendations for using currently available tools for creating virtual educational content, and also point to the problem of low scientific support for the development of the studied field, which requires a systematic approach and a generally accepted strategy in the transformational processes of civilisational evolution. According to the results of the study, it is recommended to actively introduce available cloud-based platforms for creating virtual educational content into educational processes, as well as to use a nomenclature of pedagogical scenarios that have already been adapted and transformed to the use of VR/AR technologies in educational processes. It is necessary to constantly monitor and moderate the processes of involving immersive and virtualisation tools in the educational space.

Keywords: virtualisation, virtual educational content, immersive educational space, immersion, interactivity, scientific support, pedagogical scenario, transformation, cloud solutions, digital platforms

Introduction

Modern education, like modern science, is at the stage of intensive practical testing, which leads to the search for transformational tools to increase the practical component in the educational process. Digital and technological solutions of the fourth industrial age provide an opportunity to increase the practical experience of the educational process by using immersive technologies such as augmented and virtual reality (AR and VR). The majority of students (about 97%) want to start their education using VR/AR technologies (ZipDo, 2023; Raturi, 2023). On average, 68% to 72% of teachers want to incorporate virtual immersive tools into their courses, and about 54% already use virtualisation tools in education (VictoryXR, n. d.; ZipDo, 2023). Students who have studied in immersive learning environments demonstrate greater motivation to learn and a significant increase in academic performance compared to similar results in typical educational processes (Clegg, 2023; ZipDo, 2023).

The immersive nature of the educational space has been the subject of numerous research papers and publications (Al-Ansi et al., 2023; Gómez-Rios et al., 2023; Rojas-Sánchez et al., 2023). A large number of review publications on the implementation of VR/AR technologies in the field of education, its possible applications and further development vectors only show the problems that are typical for this dynamic environment, namely the low number of relevant scientific papers on the practical application of the technology under study at the present time (Pathania et al., 2023; Fitria, 2023; Yenioglu et al., 2023).

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Immersive experience in the educational process means the use of virtual and augmented reality technologies to create a favourable environment where students can immerse themselves in the learning material and actively interact with its elements. This increases the level of student engagement and interest, helps them to understand complex concepts, and provides an opportunity to apply the knowledge they have gained in practice. This approach can be used in a variety of disciplines, such as history, art, science and technology, languages, and others (Lion-Bailey et al., 2023; Lock & MacDowell, 2023; Dengel et al., 2023).

One of the key aspects of VR and AR's impact on education is the ability to make complex concepts more accessible and understandable to students. The immersive nature of these technologies allows for the visualisation of abstract concepts, which contributes to their better absorption. For example, in science and mathematics, VR can help solve complex problems and understand difficult mathematical concepts (Fakih, 2023; Sun et al., 2023; van Dinther et al., 2023).

VR and AR create immersive learning environments that capture students' attention and increase engagement. The interactive capabilities of these technologies allow students to learn the material not as passive observers, but to actively interact with it, which contributes to better learning and understanding of the educational material (Fernandes et al., 2023; Jia & Qi, 2023; Aguayo & Eames, 2023).

In addition, VR and AR allow for individualised learning, in particular by creating individual tasks and content for each student. This helps to take into account differences in students' knowledge levels and interests, improving the quality of learning. It is also worth noting that VR and AR allow for interactive simulations and virtual tours, which facilitates the teaching of practical skills and allows students to explore places and events that would otherwise be inaccessible due to physical limitations (Hwang, 2023; Almurbati, 2021; Garcia et al., 2023).

Thus, the use of VR and AR in education helps to improve the understanding of complex concepts, increases student engagement, individualises learning, facilitates the learning of practical skills, and expands access to quality education. These technologies are becoming an important tool for improving the quality of the educational process.

Research Problem

Despite the numerous scientific papers and relevant publications on the educational context of VR/AR technologies, the studied array is still a review and does not allow to reliably determine the vectors of future development of immersive educational processes. Moreover, a large number of review publications only form the phenomenon of “white noise” around the studied issues, and practical recommendations for the implementation of currently available means of creating virtual educational content contain only a small number of relevant scientific papers. Nevertheless, the experience of integrating VR/AR technologies into the educational environment is crucial in shaping trends and vectors of future development, as it forms the basic factual background on which experts adapt immersive technologies to educational purposes.

Research Focus

The identified problems of research and scientometric support of the process of integrating immersive tools into the educational sector direct the focus of the current study to identify models, methods, and recommendations for the practical application of VR/AR technologies in the formation of the educational process at the already achieved level of technical and technological development of

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virtual learning environment tools. This focus of the study allows us to include this publication in the scientific works that form the basis for the balanced development and deep implementation of VR/AR technologies in the educational space, forming the necessary practical experience in testing and verifying theoretical developments and assumptions.

Research Aim and Research Questions

The purpose of the study is to develop practical recommendations for the use of currently available VR/AR technologies in order to improve the quality of the educational process and identify promising areas for further development of the immersive education.

Objectives of the study:

1. Establish the nomenclature of currently available tools for creating virtual educational content.
2. Identify tools that can be used to test virtual educational content creation tools.
3. To develop a system of criteria for choosing the optimal means of creating virtual educational content.
4. Conduct testing and determine the appropriate means of creating educational content using elements of VR/AR technologies.

Research Methodology

The general research procedure involves several iterations to determine the optimal solution for the immediate integration of VR/AR technologies into educational processes (Figure 1).

Figure 1

General Research Procedure

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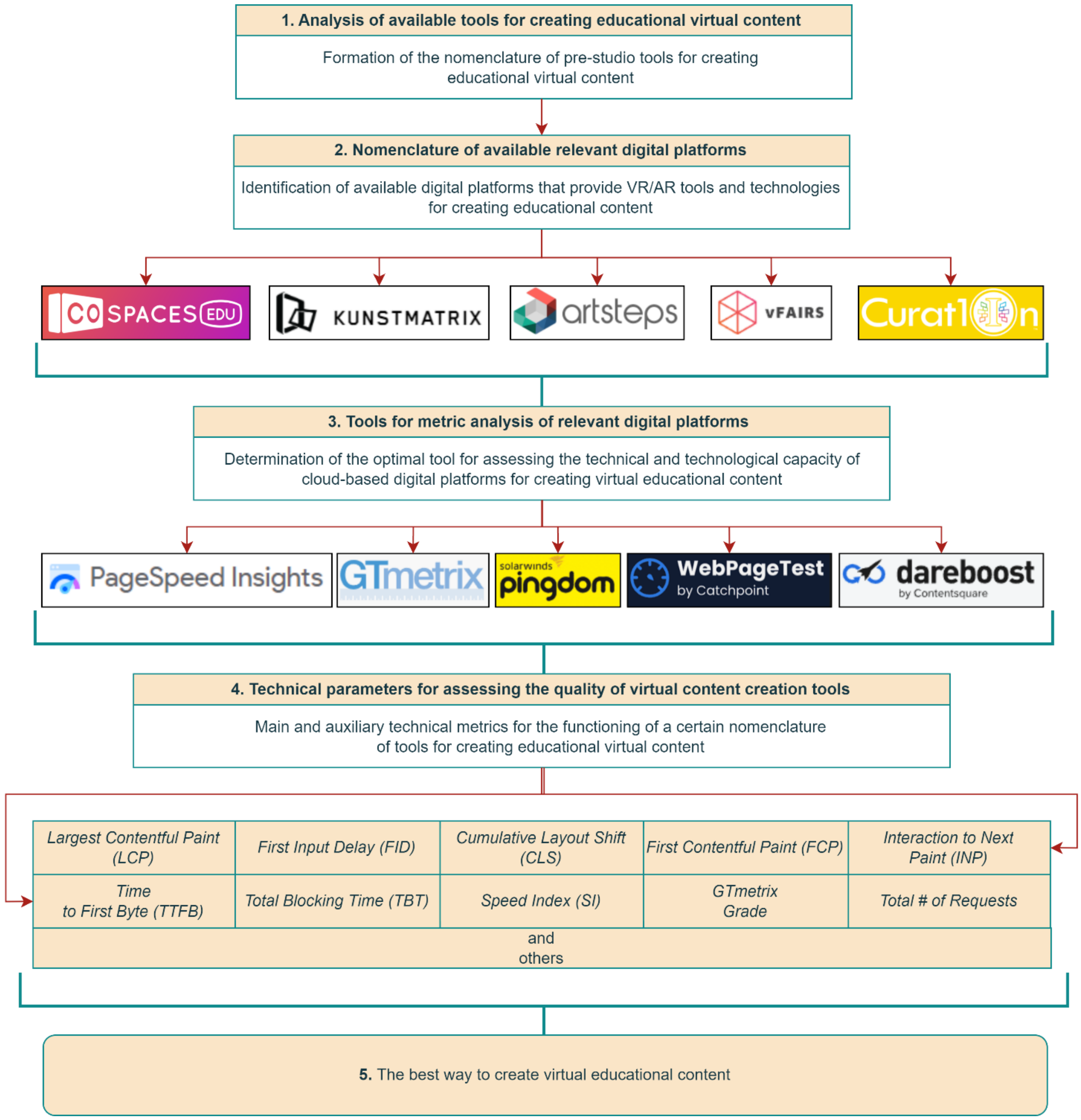

Source: author own development.

The appropriate tool for analysing the technical and technological capability of available digital platforms for developing virtual educational content is determined on the basis of the indicator of applicability, as evidenced by the relevant trend parameter over the past five years, which is determined using the *Google Trends* tool (https://trends.google.com/trends/).

Since the focus of the study is to determine the optimal educational platform currently available, which will allow for the effective development of relevant educational content without the need for the teacher to acquire special skills, the relevant VR/AR technology tools should meet the general "Ready to use" paradigm. In the process of searching for the described tools for creating virtual educational content, the following digital platforms were considered. The concept of "Ready to use" is based on the formation of such functionality on platforms for the creation of virtual educational material, which does not require special skills or knowledge in the field of programming and site creation (Table 1).

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Table 1

Research Nomenclature of Digital Platforms for Creating Virtual Educational Content

Name of the digital platform	Brief description and links
CoSpaces Edu	*CoSpaces Edu is a* web-based platform for creating interactive virtual environments with augmented reality elements, which is intended for use in education. The resource allows users to create virtual exhibitions that can be interacted with using virtual and augmented reality (https://www.cospaces.io/).
Kunstmatrix	*Kunstmatrix is an* online platform for creating virtual galleries and art exhibitions. With *Kunstmatrix, you* can create and publish virtual exhibitions that can include augmented reality elements. In addition, the platform allows users to create interactive exhibition tours and use audio and video materials to enhance the visitor experience (https://www.kunstmatrix.com/en).
Artsteps	*Artsteps is a* platform for creating virtual exhibitions and galleries using augmented reality. Users can create their own exhibitions, add paintings, photos, videos, and other objects, and place them in a virtual space. In addition, the platform allows users to add sound effects, animation,s and other elements to make the exhibition more interactive and engaging for viewers. *Artsteps* also has the ability to add augmented reality to enhance the experience of exhibition visitors (https://www.artsteps.com/).
vFairs	*vFairs is a* platform for creating virtual exhibitions and events. It provides the ability to create virtual exhibitions using augmented reality, which allows you to create a more immersive experience for visitors. In addition, the platform provides ample opportunities for interactivity and communication with event participants (https://www.vfairs.com/event-management-platform/virtual-exhibition/).
Curat10n	*Curat10n is a* platform for creating virtual exhibitions with augmented and virtual reality elements. With this tool, users can create their own exhibitions, add audio and video materials, text descriptions and 3D models that allow visitors to experience the virtual exhibition in the most immersive and convenient way. The platform also offers the possibility of using video conferencing to organise online tours and interact with visitors (https://curat10n.com/).

Source: author's own development.

Given that the above digital platforms are cloud solutions, it is advisable to use the following cloud metrics analysers as tools for analysing the technical and technological capability of these resources (Table 2).

Table 2

Research Nomenclature of Tools for Analysing Digital Platforms for Creating Virtual Educational Content

Tools for analysing digital platforms	Brief description and links
PageSpeed Insights	*PageSpeed Insights is a* free online tool from Google that analyses the speed and performance of web pages on mobile and desktop devices. It helps you understand how a page loads and what components affect its speed. It provides recommendations on how to optimise web pages and information on speed metrics that affect the user experience and search engine rankings. *PageSpeed Insights* analyses page load speed based on several metrics,

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Tools for analysing digital platforms	Brief description and links
	including *Largest Contentful Paint*, *First Contentful Paint*, *Time to First Byte*, and others (https://pagespeed.web.dev/).
GTmetrix	*GTmetrix is a* free web service that allows you to measure the speed of website pages and analyse their performance. The service offers a detailed analysis of web page performance using a variety of metrics such as load time, page size, image optimisation, caching, and others. In addition, *GTmetrix* provides recommendations on how to improve page performance to help reduce page load times and improve performance (https://gtmetrix.com/).
Pingdom Website Speed Test	*Pingdom Website Speed Test is an* online tool for measuring the loading speed of a web page and getting detailed information about its performance. The tool is used to determine the time it takes to send a request to the server and the time it takes for the server to respond, calculate the time it takes for a web page to load, and analyse the speed of loading individual resources (images, CSS styles, scripts). *Pingdom* also provides detailed reports on web page load speed, including recommendations for improving performance and reducing load times (https://tools.pingdom.com/).
WebPageTest	*WebPageTest is a* free tool for testing web page loading speed. This resource allows you to determine the page load time, number of requests, page size, as well as other performance indicators such as *Time to First Byte* (*TTFB)*, *Speed Index,* and *Time to Interactive* (*TTI)*. With *WebPageTest, you* can test from different locations around the world using different browsers and devices. In addition, the resource has the ability to visualise page load, which helps to find and fix problems that affect the performance of web pages (https://www.webpagetest.org/).
DareBoost	*DareBoost is an* online service for analysing web page loading speed and performance. This resource offers a wide range of tools that allow you to identify problem areas on your website and make recommendations on how to solve them. The service analyses a variety of parameters, including page load time, image size, and other resources, and offers various approaches to optimise them. *DareBoost* can be used to improve website performance and ensure a high quality user experience (https://www.dareboost.com/en).

Source: author's own development.

Given that the digital platforms that can be used to create virtual educational content are cloud technologies (Table 1), the most appropriate means for the purpose is determined by comparing the relevant technical parameters, the most important of which are shown in Table 3.

Table 3

Characteristics of Analytical Metrics for Determining the Technical and Technological Capacity of Digital Platforms for Creating Virtual Educational Content

Parameter.	Brief description
Largest Contentful Paint (*LCP*)	*Largest Contentful Paint* (*LCP) is a* web performance metric that measures the time it takes for a browser to load and display the largest content on a page, such as an image, video, or block of text. *LCP* helps determine how quickly users can view important content on a page and whether it is being pushed to the far side of the screen or delayed until later. The less time it takes to load *LCP,* the better the user experience and the more likely they are to stay on the site.
First Input Delay (*FID*)	*First Input Delay* (*FID) is a* web performance metric that measures how quickly users can interact with a web page. It is determined by the time that

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Parameter.	Brief description
	elapses between the first user interaction with the page, such as clicking on a link or button, and the moment when the response from the server is returned with sufficient speed for the user to perceive the response. This allows you to understand how quickly a page responds to user actions and can help reduce wait times on pages with a lot of interactivity. The lower the FID value, the better, as it means that the page responds to user actions quickly and efficiently.
Cumulative Layout Shift (*CLS*)	*Cumulative Layout Shift* (*CLS) is a* metric that reflects the degree of stability of a page's visual layout as it loads. It measures the total change in the layout of a page from the moment it starts to load to the moment it is fully loaded. This parameter is important for users because a large change in layout during page loading can lead to users not being able to find the information they need or perform the desired actions. The ideal *CLS value* should be less than 0.1. The lower the *CLS value,* the more stable the visual layout of the page.
First Contentful Paint (*FCP*)	*First Contentful Paint* (*FCP) is a* web performance metric that measures the time it takes for a browser to render the first content on a page. The content can be text, an image, or another element. *FCP is reflected* in the *Core Web Vitals* metric, which is important for assessing the user experience of a website. Quickly displaying the first content can have a positive impact on website visitors, reduce bounce rates, and increase engagement.
Interaction to Next Paint (*INP*)	*Interaction to Next Paint* (*INP) is a* metric that measures how quickly a user can interact with the content of a page after it loads. This is measured by the response time to the first active element (such as a button or link) after the page loads. This parameter allows you to evaluate the speed of the page's response to user interaction and determine how quickly a user can start interacting with the page after it loads. The ideal *INP* speed is considered to be less than 100 ms. The shorter the response time, the better the page meets the needs of users and the higher its ranking in search results.
Time to First Byte (*TTFB*)	*The Time to First Byte* (*TTFB)* parameter indicates the time it takes for the server to respond to a browser request for the first time. This parameter is measured from the moment the request is sent until the first part of the response is received from the server. The lower the TTFB, the faster the browser receives a response from the server. A slow server response can lead to delays in page loading and a poor user experience.
Total Blocking Time (*TBT*)	*TBT* (*Total Blocking Time*) is a website performance metric that measures the time a web page is blocked from responding to user actions. This means that users may be forced to wait for a page to load, which can affect their satisfaction with the site. The lower the *TBT* value, the less likely it is that users will experience unfair delays and blockages when interacting with the website.
Speed Index (*SI*)	*Speed Index* (*SI) is a* parameter that measures the speed of page loading. It shows how quickly users receive visual content on a page. The lower the value of the parameter, the faster the page will be displayed. Page load speed can affect users, which can affect their interaction with the site, as well as search engine rankings.
GTmetrix Grade	*GTmetrix Grade is a* performance metric that evaluates the performance of a web page based on testing its loading speed and resource optimisation. The grading is based on a scale of A-F, where A stands for the best performance and F for the worst. The score takes into account various factors such as loading speed, image and script optimisation, caching, code minification, page size, and much more. The higher the *GTmetrix Grade score,* the faster the page loads and the more efficiently it uses server resources.

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Parameter.	Brief description
Total # of Requests	*The Total # of Requests* parameter indicates the total number of requests that were made during the loading of a website page. These can be requests for resources such as images, *CSS* styles, JavaScript scripts, fonts, and others. A higher number of requests can lead to a longer page load time, so it is an important factor in measuring website load speed. When measuring website page load speed, the optimal number of requests depends on the type of website and its functionality.

Source: author's own development.

The given metrics make it possible to determine the performance of cloud-based solutions for setting up platforms for creating virtual educational content. Platforms with higher performance will have correspondingly better metrics, indicating the ability to identify the optimal digital medium for creating immersive learning materials from a selected nomenclature of relevant cloud solutions.

The above nomenclature of metrics (Table 3) is not exhaustive; other parameters are also used to determine the technical characteristics of cloud resources, which make it possible to determine the optimal digital platform for creating virtual educational content.

The optimal tool from the nomenclature of available digital platforms, selected on the principle of "Ready to use", has been identified, which will allow teachers to create educational content with elements of VR/AR technologies without additional special training. This has far-reaching results in terms of a well-grounded (based on real-world implementation experience) definition of the future of pedagogy in the general concept of Education 4.0.

The developed methodology is limited by time frames, because over time both the nomenclature of relevant educational cloud platforms and the nomenclature of tools for testing these platforms may change, forming other optimal solutions in the future.

The results of this study allow educators to obtain information about the optimal cloud solution for the development and implementation of the principles of virtual education in educational processes at the time of writing. And the methodology will allow a similar study to be conducted for another set of relevant platforms and testing tools that have the potential to emerge in the future.

Research Results

In accordance with the proposed methodology, we define a tool for assessing the technical and technological capabilities of available digital platforms for creating educational content with elements of VR/AR technologies (Table 1), which is adequate to the purpose of the study, and which can be installed among the possible services for material analysis of cloud solutions (Table 2). *Google Trends* (https://trends.google.com/trends/) was identified as an arbitration tool, the trendiness parameter of which indicates the frequency of use, and, accordingly, the suitability for use of certain metric monitors (Figure 2).

The use of Google Trends for the selection of tools for testing platforms for the creation of virtual educational content is appropriate in connection with the use of current, broad and relevant databases by the specified resource, regarding the applicability of each of the comprehensive solutions selected in the experimental nomenclature. Applicability is determined by tendency, that is, a more adaptive and stable digital solution is used more actively by the global community. And that's why Google Trends can point to such a tool.

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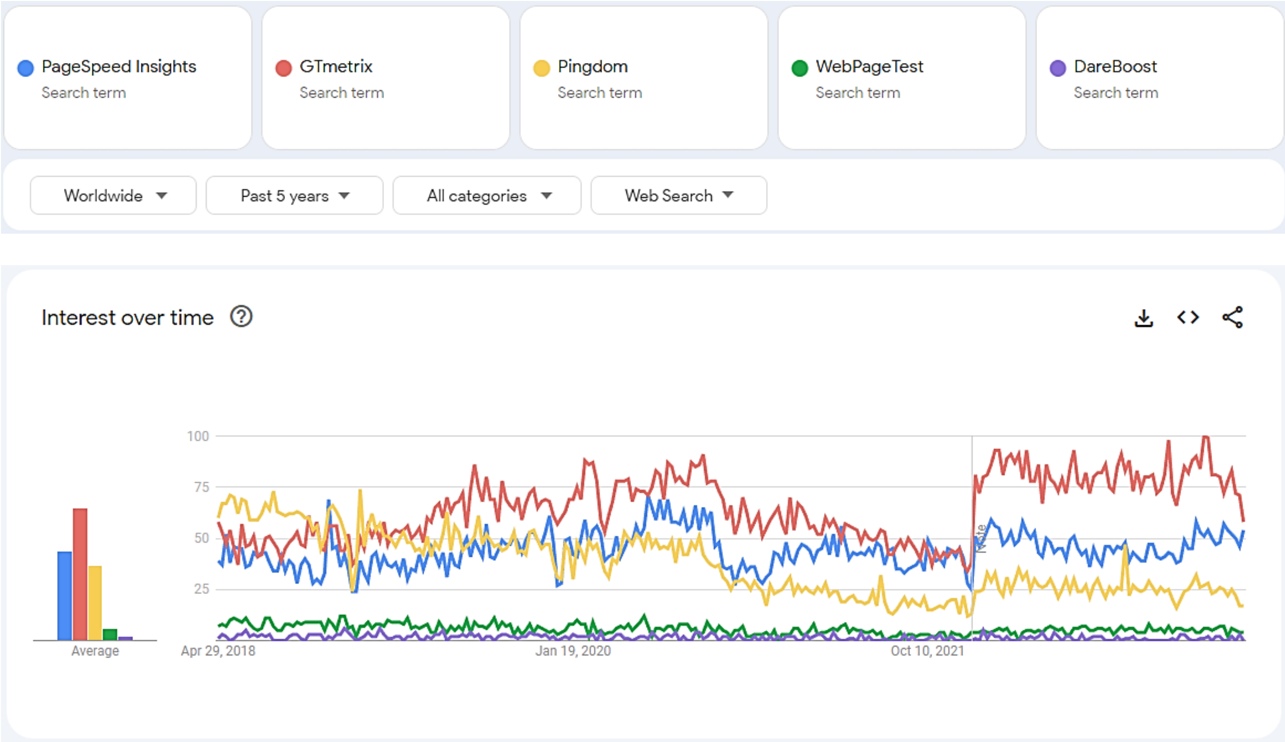
The use of Google Trends to select tools for testing platforms for creating virtual educational content has its limitations. Google Trends provides only general information about the popularity of queries in the Google search engine, and this information may be limited by regional specificities and Google users. It is important to consider that Google Trends does not provide detailed data on specific testing tools and their capabilities. Additionally, the popularity of tools may change over time, and the analysis results may only be relevant for a specific moment. Therefore, for a comprehensive and objective selection of testing tools for platforms for creating virtual educational content, it is necessary to combine data from Google Trends with other sources of information and research.

Figure 2

Identification of an Appropriate Tool for Analysing the Technical and Technological Capabilities of Available Digital Platforms for Creating Virtual Educational Content



Source: created by the author on *Google Trends* (https://trends.google.com/trends/).

According to the results of the analysis of the applicability parameter (Figure 2) (based on the trendiness of queries in *Google Trends), it was* found that the leading tools for metric analysis of cloud solutions are Pingdom Website Speed Test, PageSpeed Insights, and GTmetrix. However, the *GTmetrix* monitoring service is the most trendy, so we accept it as the main tool for metric analysis of the range of available digital platforms with the ability to use VR/AR technologies to create educational materials and immersive environments (Table 1).

Parameters such as Largest Contentful Paint (LCP), First Input Delay (FID), Cumulative Layout Shift (CLS), First Contentful Paint (FCP), Interaction to Next Paint (INP), Time to First Byte (TTFB), Total Blocking Time (TBT), Speed Index (SI), GTmetrix Grade, and Total # of Requests (Table 3) play an important role in determining the performance of cloud-based digital platforms for creating virtual educational content. Each of these parameters affects the quality and performance of a digital platform that delivers virtual educational experiences. Largest Contentful Paint (LCP) determines the load time of the largest content on a page. This parameter is important for virtual educational content because it

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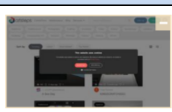
affects the loading speed and accessibility of the main material. The lower the LCP, the faster the user gets access to important educational content. First Input Delay (FID) measures the delay between the first interaction on a page and the platform's response to that interaction. It is important for users interacting with virtual learning materials, as a short delay helps to improve engagement and usability. Cumulative Layout Shift (CLS) determines the stability of the page layout during loading. It's important for virtual learning platforms because it ensures that content doesn't move around during the learning experience, which can be annoying for users. First Contentful Paint (FCP) indicates the time when the first content becomes visible on the page. This is important for virtual education content because a fast FCP can improve the user experience and reduce wait times. Interaction to Next Paint (INP) shows the delay between user interaction and the next page refresh. This is important for virtual learning materials because a short delay helps to create a comfortable and continuous learning experience. Time to First Byte (TTFB) measures the time it takes for the server to respond to a user request. It is important for the speed of downloading virtual materials. Total Blocking Time (TBT) indicates the time when a user cannot interact with content due to blocking resources. This is important for ensuring continuous learning. Speed Index (SI) measures how quickly a page becomes visible to the user. This is important for improving usability and engagement. GTmetrix Grade and Total # of Requests are also important for the overall performance of a digital platform for creating virtual educational content, as they indicate overall performance and download speed.

Thus, each of these key metrics affects the effectiveness of a cloud-based digital platform for creating virtual educational content, improving the quality and productivity of learning. Therefore, optimising these parameters is an important task for creating a high-quality virtual educational experience.

Using the most trendy tool for analysing the technical and technological capabilities of available digital platforms for creating virtual educational content - *GTmetrix* (Figure 2), we obtained not only the above-described performance metrics of cloud solutions but also additional parameters that allowed us to determine the optimal available means of immersing educational processes - Table 4.

Table 4

Calculation of Metrics of Available Digital Platforms for Immersive Educational Processes

Parameter.	**Results of calculating metrics for available cloud solutions**				
					
	CoSpaces Edu	*Kunstmatrix*	*Artsteps*	*vFairs*	*Curat10n*
Key metrics					
GTmetrix Grade	A (96%)	B (87%)	D (65%)	D (69%)	E (58%)
Performance Score	100%	92%$_{-8\%}$	57%$_{-43\%}$	68%$_{-32\%}$	49%$_{-51\%}$
Structure Score	85%	74%$_{-11\%}$	85%	70%$_{-15\%}$	78%$_{-7\%}$
Largest Contentful Paint	559ms	1.4s$_{-887ms}$	3.5s$_{+2.9s}$	2.2s$_{-1.6s}$	3.2s$_{+2.7s}$
Total Blocking Time	78ms	0ms$_{-78ms}$	162ms$_{+83ms}$	178ms$_{+99ms}$	26ms$_{-52ms}$
Cumulative Layout Shift	0	0.05$_{-005}$	0.07$_{-0.07}$	0.08$_{+0.08}$	0.46$_{+0.46}$
Total Page Size	5.82MB	2.75MB$_{-308MB}$	2.81MB$_{-3.02MB}$	4.65MB$_{-1.17MB}$	3.88MB$_{-1.94MB}$
Total # of Requests	100	69$_{-31}$	57$_{-43}$	165$_{+65}$	102$_{+2}$
Auxiliary metrics of content engagement					

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Parameter.	**Results of calculating metrics for available cloud solutions**				
					
	CoSpaces Edu	*Kunstmatrix*	*Artsteps*	*vFairs*	*Curat10n*
Cumulative Layout Shift	0.01	0.05	0.24	0.06	0.4
First Contentful Paint	410ms	1.2s	2.7s	1.5s	1.2s
Largest Contentful Paint	628ms	1.6s	3.5s	1.7s	1.5s
Speed Index	1.1s	1.6s	4.1s	2.7s	2.9s
Time to Interactive	595ms	1.6s	3.6s	3.2s	1.5s
Total Blocking Time	0ms	0ms	111ms	131ms	22ms
Redirect Duration	N/A	N/A	N/A	N/A	N/A
Connect Duration	170ms	459ms	327ms	56ms	478ms
Backend Duration	43ms	293ms	160ms	742ms	158ms
Time to First Byte	213ms	752ms	487ms	798ms	636ms
First Paint	410ms	1.2s	1.7s	1.5s	1.2s
DOM Loaded	596ms	1.6s	2.7s	1.8s	1.5s
DOM Interactive	554ms	1.6s	2.7s	1.7s	1.5s
Onload Time	1.0s	3.2s	3.9s	3.2s	1.5s
Fully Loaded Time	3.0s	4.0s	5.1s	13.9s	5.3s
Auxiliary metrics of structure performance					
Allow back/forward cache restoration	(100)	(100)	(100)	(93)	(100)
Avoid an excessive DOM size	(100)	(97)	(89)	(63)	(96)
Avoid chaining critical requests	(100)	(99)	(98)	(99)	(97)
Avoid CSS @import	(100)	(100)	(100)	(100)	(100)
Avoid document.write()	(100)	(100)	(100)	(100)	(100)
Avoid enormous network payloads	(40)	(90)	(91)	(82)	(60)
Avoid large layout shifts	N/A	(100)	(82)	(99)	(72)
Avoid long main-thread tasks	(100)	(100)	(94)	(92)	(100)
Avoid multiple-page redirects	(100)	(100)	(100)	(100)	(100)
Avoid non-composed animations	(100)	(100)	(100)	(100)	(100)
Combine images using CSS sprites	(100)	(100)	(100)	(100)	(100)
Defer offscreen images	(100)	(100)	(100)	(100)	(100)
Don't lazily load Largest Contentful Paint image	(100)	(70)	(100)	(100)	(100)
Efficiently encode images	(100)	(100)	(100)	(100)	(76)

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Parameter.	Results of calculating metrics for available cloud solutions				
					
	CoSpaces Edu	*Kunstmatrix*	*Artsteps*	*vFairs*	*Curat10n*
Eliminate render-blocking resources	N/A	(97)	(67)	(99)	(93)
Enable Keep-Alive	(100)	(100)	(100)	(100)	(100)
Enable text compression	(100)	(84)	(100)	(100)	(100)
Ensure text remains visible during webfont loading	(100)	(98)	(100)	(99)	(100)
Lazy load of third-party resources with facades	(100)	(100)	(100)	(100)	(85)
Minify CSS	(100)	(100)	(100)	(100)	(100)
Minify JavaScript	(100)	(100)	(100)	(100)	(100)
Preconnect to required origins	(100)	(100)	(92)	(100)	(100)
Preload key requests	(100)	(100)	(100)	(100)	(100)
Preload Largest Contentful Paint image	(100)	(100)	(100)	(100)	(100)
Properly size images	(100)	(100)	(100)	(100)	(100)
Reduce initial server response time	N/A	(100)	(100)	(30)	(100)
Reduce JavaScript execution time	(100)	N/A	(94)	(90)	(100)
Reduce unused CSS	(100)	(97)	(99)	(100)	(97)
Reduce unused JavaScript	(100)	(97)	(97)	(99)	(97)
Remove duplicate modules in JavaScript bundles	(100)	(100)	(100)	(100)	(100)
Serve images in next-gen formats	(100)	(100)	(100)	(100)	(96)
Serve static assets with an efficient cache policy	(72)	(77)	(72)	(74)	(94)
Use a <meta name=”viewport” > tag with width or initial-scale	(100)	(100)	(100)	(100)	(100)
Use a Content Delivery Network (CDN)	(100)	(75)	(94)	(95)	(76)
Use explicit width and height on image elements	(70)	(70)	(70)	(70)	(100)

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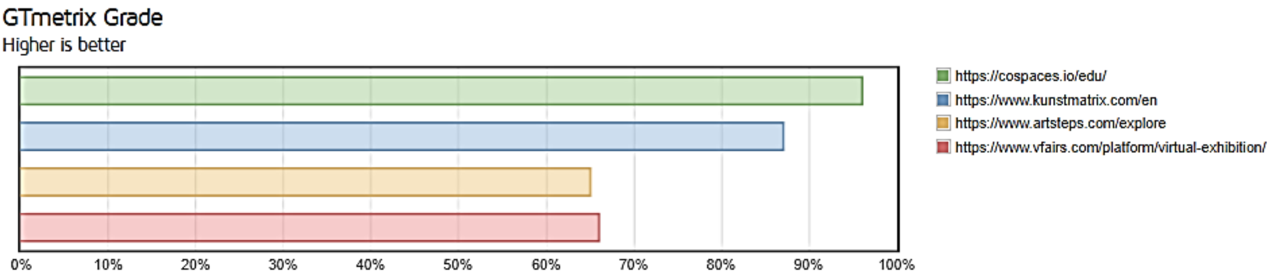
Parameter.	Results of calculating metrics for available cloud solutions				
					
	CoSpaces Edu	*Kunstmatrix*	*Artsteps*	*vFairs*	*Curat10n*
Use HTTP/2 for all resources	(100)	(100)	(100)	(100)	(100)
Use passive listeners to improve scrolling performance	(93)	(100)	(100)	(100)	(100)
Use video formats for animated content	(100)	(100)	(100)	(100)	(100)

Source: created by the authors on the *GTmetrix* resource (https://gtmetrix.com/).

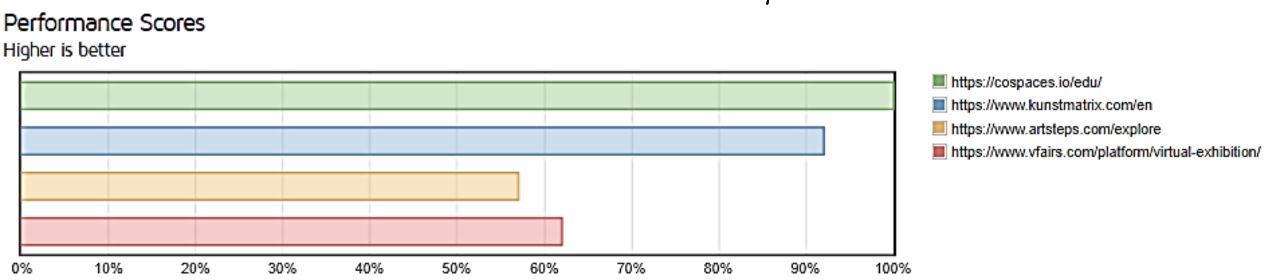
GTmetrix's internal tools allow for a comparative and correlative analysis of the results (Table 4) according to the main metrics for assessing the effectiveness of available digital platforms for creating educational content with elements of virtual and augmented reality (Figure 3).

Figure 3

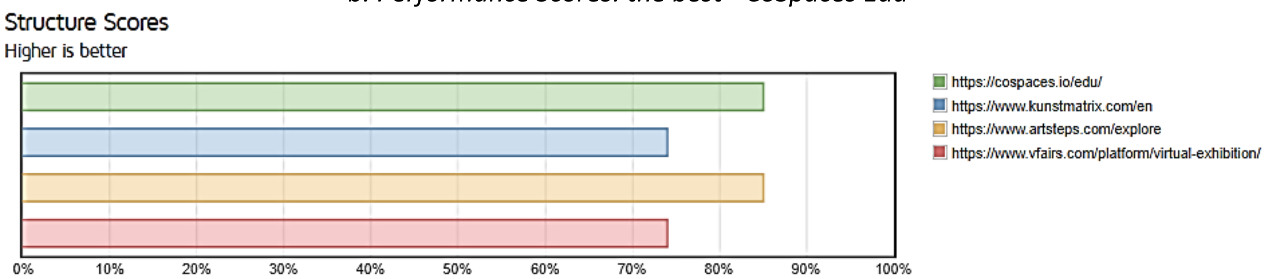
Determining an Appropriate Tool for Analysing the Technical and Technological Capabilities of Available Digital Platforms for Creating Virtual Educational Content



a. GTmetrix Grade: the best - CoSpaces Edu



b. Performance Scores: the best - CoSpaces Edu



c. Structure Scores: the best - CoSpaces Edu

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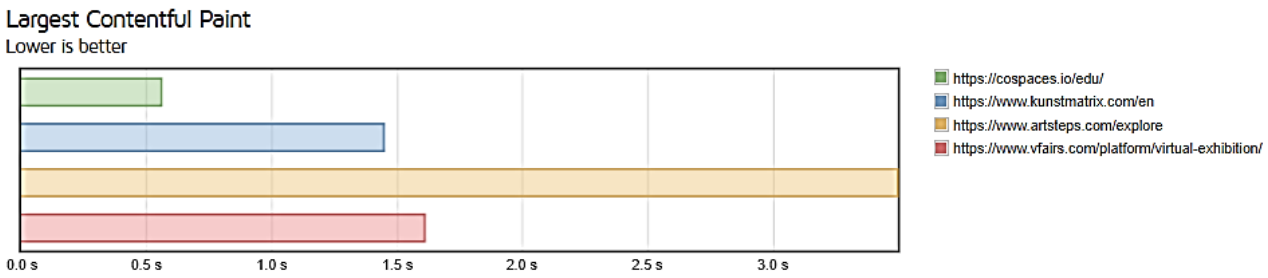
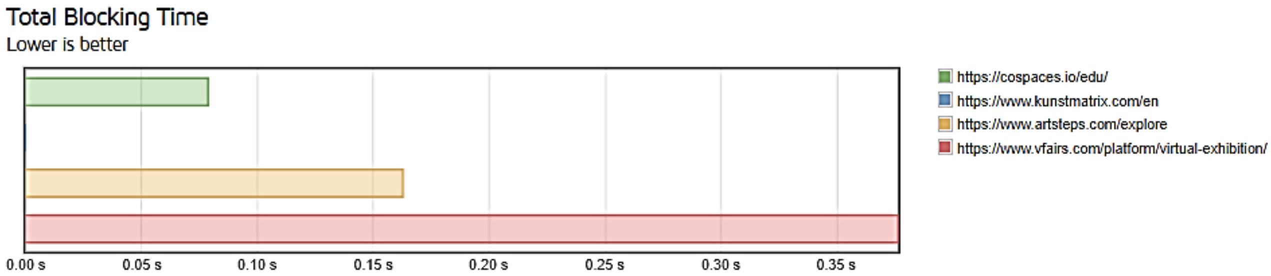
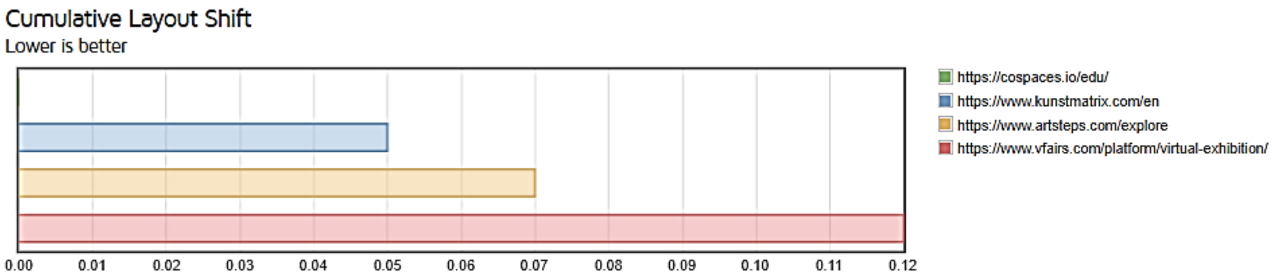


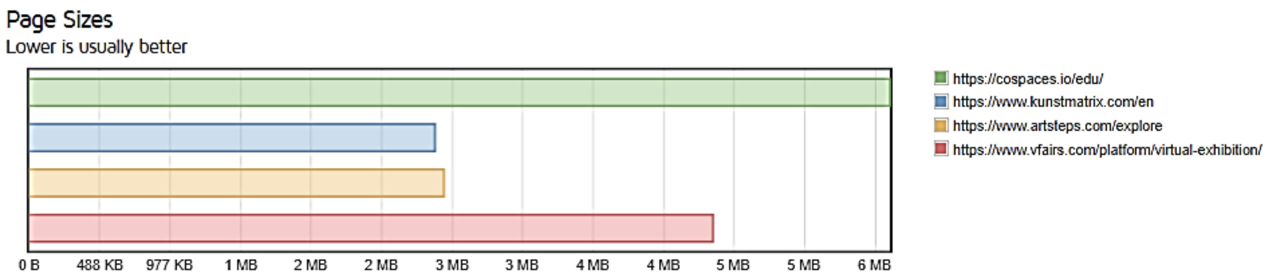
d. Largest Contentful Paint: the best - CoSpaces Edu



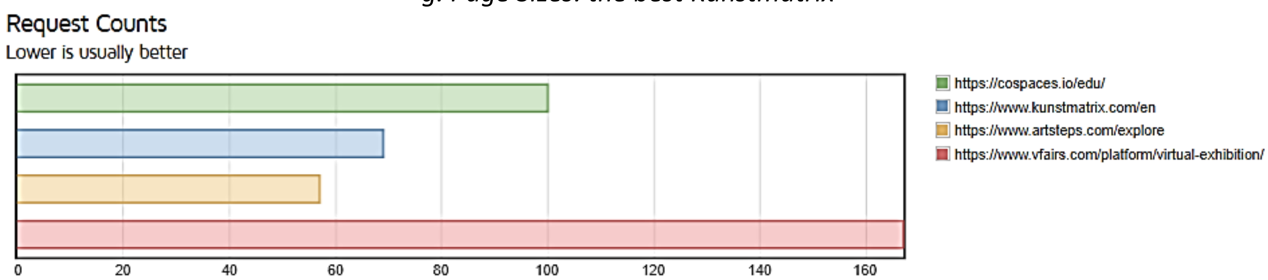
e. Total Blocking Time: the best - CoSpaces Edu



f. Cumulative Layout Shift: the best - CoSpaces Edu



g. Page Sizes: the best Kunstmatrix



h. Request Counts: the best Artsteps

Source: created by the authors on the *GTmetrix* resource (https://gtmetrix.com/).

According to the results of the general metric analysis by *GTmetrix* (Table 4) and comparative and correlative evaluation (Figure 3), the digital platform *CoSpaces Edu* prevails in most of the parameters of cloud solutions' efficiency (inferior to others only in *Page Sizes* and *Request Counts*), which received a *GTmetrix Grade of* A. Other resources that can be used as immersive learning environments include *Kunstmatrix (*which is optimal in terms of *Page Sizes)* and *Artsteps* (which is optimal in terms of *Request Counts)*.

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The contextual analysis also points to the advantage of *CoSpaces Edu,* as this resource contains a wide range of tools and instruments for creating VR/AR educational content. The introduction of virtual reality and augmented reality into the educational process significantly transforms traditional educational approaches. VR allows creating immersive learning environments where students can interact with virtual objects and scenarios. AR complements the real world with digital elements, providing an opportunity for extended interaction with physical objects. Let's consider the possibilities of immersing the modern educational space that have already been achieved and are available to a wide range of teachers, in particular on the currently optimal CoSpaces Edu resource (Table 5).

Table 5

Pedagogical Characteristics of Educational Processes, Methods and Tools Transformed by Immersive and Virtualisation Technologies

Educational process, method and tool	Brief pedagogical description
Virtual exhibitions	Virtual exhibitions allow students to explore art and cultural heritage in immersive virtual galleries and museums. They can interact with art, look at details and explore art history in realistic environments.
Virtual tours	VR allows you to create virtual journeys to historical and geographical locations that may be out of reach for students. This expands the possibilities of geographical learning and allows you to study historical events at their places of origin.
Guided tours with augmented reality elements	AR adds interactivity to physical tours by expanding students' knowledge through information layers overlaid on the real world during tours.
Dialogues with reconstructed personalities	With VR, students can interact with virtual reconstructions of historical or scientific figures, learning from them about their achievements and contributions to their fields.
Interactive immersive environments	Creating virtual interactive worlds for learning and research. This allows students to explore scientific concepts, historical events, or solve problems in immersive scenarios.
Interactive laboratories and simulations of various professional areas	Virtual laboratories allow students to conduct virtual experiments and research in various fields of science, including physics, chemistry, biology, and others.
Interactive conceptual visualisations of abstract mathematical and natural concepts	VR/AR makes it possible to visualise complex mathematical and scientific concepts, helping students to understand abstract ideas.
Interactive historical and cultural exhibitions	VR allows you to create virtual exhibitions where students can learn about history and cultural heritage through interactive scenarios.
Interactive biological and therapeutic expositions	Virtual expositions in biology and medicine allow students to acquire practical skills, learn about biological processes and treatment methods.

Source: author's own development.

The use of VR/AR technologies expands learning opportunities, making it more interactive, immersive, and interesting for students in various fields of education. The use of the listed and described pedagogical processes, methods, and tools (Table 4) already allows teachers to transform their approach to teaching and improve the quality of education.

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The contextual analysis allows us to determine the likely nature of the future development of educational VR/AR technologies, which include a number of promising areas. First of all, it is expected that these technologies will be integrated into the general educational system at the level of educational institutions, which will ensure their accessibility to a wide range of students and facilitate further development. The development of content and curricula involves the creation of new pedagogical methods and virtual learning materials aimed at supporting learning in various fields of knowledge, including STEM. The main trend is the individualisation of learning, which allows for the creation of personalised learning paths for students, taking into account their needs, level of knowledge, and individual learning style.

It also envisages the development of communities and collaboration through the creation of virtual learning environments that allow students and teachers to interact and share learning experiences. The development of applications and platforms for learning in VR/AR environments is an important component of future development, with the aim of facilitating learning and expanding educational opportunities in various fields. The assessment and measurement of student performance in virtual learning environments will evolve in parallel with the development of technologies that take into account the specifics of learning in these environments.

The use of VR/AR technologies is not limited to education and can be used in other fields such as medicine, business, engineering, art, and many others, which will help expand opportunities for education and training in these areas. The increasing availability and decreasing cost of VR/AR equipment is also an important trend that will provide greater access to these technologies for different social groups and reduce barriers to their use in education.

Thus, it has been found that currently available digital platforms and tools (in particular, the optimal *CoSpaces Edu* resource identified in this study) already allow teachers and other stakeholders to transform the content of educational processes, increasing the immersiveness and interactivity of the educational space, which contributes to increasing student interest and improving the quality of learning. The experience of introducing VR/AR technologies into the processes of education and professional training of students will allow us to form a convincing array of data that will determine the fundamental vectors of the future development of pedagogy and global education.

Discussion

Based on the results of this study, the following aspects have been identified for discussion:

- The author notes that the current scientific support for the immersive nature of educational processes contains a small number of practical recommendations for the transformation of learning and pedagogy using VR/AR technologies;
- the hypothesis is formed that the currently available digital platforms for the development of virtual educational content provide an opportunity to transform the approach, tools, and methods to the processes of education and professional training of students;
- the nomenclature of relevant and accessible digital platforms that already allow integrating elements of virtualisation and immersive learning into the educational space is formed and reviewed;
- A system of criteria for assessing the technical and technological capabilities of digital platforms for creating virtual educational content was developed;
- an appropriate metric monitor has been identified, based on the results of a criterion-based assessment, which identifies the optimal digital platform that can already be used by teachers to immerse and improve the quality of education;

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- pedagogical scenarios that have undergone a transformation process involving VR/AR technologies and that can already be used by teachers and other stakeholders are considered and characterised, which confirms the hypothesis of the current study;
- based on the results of the contextual analysis, the article reveals probable vectors for the future development of educational VR/AR technologies, and forms a hypothesis for further research based on the use of a reliable data set of experience in implementing immersive and virtualisation tools to adjust and moderate the further development of global education in the general Education 4.0 paradigm.

Alam and Mohanty (2023) emphasise the importance of virtual online laboratory learning in computer science and engineering, especially during the COVID-19 pandemic. The results showed that the Software Engineering Virtual Lab (SE VLab) is more effective than traditional laboratories, which is manifested by an increase in student achievement. Virtual online laboratory learning allows for increased student engagement and facilitates objective assessment of performance, emphasising its significant advantages in software engineering education. The results of Alam and Mohanty (2023) confirm the hypothesis of this study regarding the potential of existing digital platforms for the development of virtual educational content to transform the context of educational processes, but the authors use a limited data set (based on the analysis of one resource), which makes the current study more objective.

The team of authors de Moraes Rossetto et al. (2023) developed their own tool for immersive educational processes, which includes a virtual and augmented reality module. The authors also conducted an empirical test of the effectiveness of the developed pedagogical tool, according to which a significant improvement in academic performance among students was found. The results of the study by de Moraes Rossetto et al. (2023) confirm the findings of the current study but create the false impression that teachers need to have special skills to modernise educational processes using VR/AR technologies. At the same time, this study proves that the use of immersive and virtualisation tools is already available to every teacher without any special skills.

AlGerafi et al. (2023) identify the potential of augmented reality (AR) and virtual reality (VR) in education, focusing on their impact on student motivation, learning outcomes, and the overall learning experience. The authors carefully consider how AR and VR can enhance learning, knowledge retention, and skill development, especially in the context of distance education. AlGerafi et al. (2023) also explores the role of software tools and relevant digital platforms in creating immersive and interactive learning environments, promoting active learning and critical thinking through simulations and interactive experiences. Although the results of the described publication correlate with the findings of the current study, AlGerafi et al. (2023) did not conduct empirical research, and practical recommendations are limited due to the lack of specificity of the studied tools for virtualisation and immersive education.

Ivanova et al. (2023) confirm that the use of virtual and augmented reality technologies in the mechanical engineering education process facilitates and increases the effectiveness of learning by increasing student engagement. The applications reviewed by Ivanova et al. (2023) for learning in 3D environments create interactive opportunities for mastering skills related to the operation of grinding devices for sharpening cutting tools. The authors also confirm that learning in virtual and augmented reality environments is as effective as learning in a real laboratory and contributes to improving the learning experience of students. The results of this publication fully confirm the conclusions and hypotheses of the current study, but are limited to only one educational sector and need to be extended to other educational spaces.

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Raja and Priya (2023) confirm that the use of augmented reality (AR) and virtual reality (VR) in the educational process encourages students to actively learn and seek knowledge. The authors note that the introduction of these technologies (in the form of digital platforms and applications) is an effective tool for improving the educational process by creating immersive learning environments with various sensory elements. However, the researchers also point out the existing limitations and challenges of implementing AR and VR in the education sector. Unlike the current study, the described publication is a review and does not contain an empirical component. And although the findings of Raja and Priya (2023) confirm the results of this study, the application of the recommendations formulated by these researchers is limited.

Thus, the analysis of the data set of scientific support for the immersive transformation of global education from the above and similar publications indicates a number of limitations, including a large number of review papers that make a limited contribution to the research vector, narrowly focused conclusions that require scaling and wider verification, and other obstacles. These limitations create obstacles to the perception of relevant scientific information and create an urgent need to develop a general research strategy and practical recommendations that will be available to a wide range of teachers and stakeholders. However, this situation only points to the fact that the field of virtualisation and immersive learning is in a dynamic stage of development and requires further validation of research results, in particular through empirical verification in a real learning environment.

The study has several potential limitations, including selection bias in the choice of digital platforms and potential publication bias if only positive findings were included. The rapidly evolving nature of VR/AR technologies may affect the relevance of the recommendations over time, and resource constraints and pedagogical challenges in adopting these technologies might not be fully addressed. Access and equity issues, privacy concerns, and long-term effects on education are essential considerations. The study might not delve deeply into the user experience, usability, and interdisciplinary collaboration required for successful implementation. Acknowledging these limitations is crucial for a more comprehensive understanding of VR/AR integration in education and the practicality of the provided recommendations.

Conclusions and Implications

The analysis of the results of this study has revealed the following practical aspects. Firstly, it has been determined that there are not enough practical recommendations on the use of VR/AR technologies in the educational process, which creates a lack of information for educators and pedagogical staff. The second important aspect is the confirmation of the hypothesis that modern digital platforms for creating virtual educational content open up opportunities for rethinking learning and pedagogical methods in the educational process. This hypothesis becomes the basis for further research. The third important aspect is the analysis of available digital platforms that allow the integration of immersive elements into the educational environment. This analysis provides information about the potential opportunities and limitations of such platforms.

The study developed a system of criteria for assessing the technical and technological efficiency of digital platforms for creating virtual educational content. This system of criteria can serve as a guideline for choosing the optimal means of creating virtual educational content based on the use of cloud services and resources. An important step is to define a metric monitor that helps determine the optimal digital platform for use in the educational process.

According to the results of testing based on a defined set of metrics and contextual analysis, it was established that currently the optimal cloud solution for the development of virtual educational content is *CoSpaces Edu.*

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The study also includes an analysis of pedagogical scenarios that have already been transformed using VR/AR technologies and can be used by teachers and other participants in the educational process. The final stage is to identify possible areas for further development of educational VR/AR technologies based on contextual analysis and experience in implementing these technologies.

The practical significance of this study is that it identified key aspects of the use of VR/AR technologies in the educational process and provided practical recommendations for educators and teachers. The scientific novelty of the study is that it examines the relevant aspects of using digital platforms to create virtual educational content and provides a systematic approach to evaluating their effectiveness.

The results of this study should be implemented by teachers and stakeholders, as the availability of immersive and virtualisation technologies for educational processes has been proven. At the same time, the experience of implementing VR/AR technologies and modernising educational processes is the basis for moderating and adjusting the future development of pedagogy and global education.

Suggestions for Future Research

For future studies, it is important to consider the main prospects for further research on the research problem. First of all, it is recommended to develop and improve pedagogical strategies for the use of VR/AR technologies in the educational process in order to achieve specific educational goals. Researchers can study effective methods and approaches that will help improve learning outcomes and student motivation. The second area for future research is to assess in more detail the impact of VR/AR technologies on students' academic achievements, motivation, and perception of educational material. This will allow for a better understanding of how these technologies can improve the learning process and the learning experience. For the third area of research, it is important to work on creating more accessible tools for creating virtual educational content. This will help teachers and educational institutions to integrate VR/AR technologies into curricula more easily and quickly and make them more accessible to all stakeholders.

Another area for future research involves studying the impact of VR/AR technologies on distance education and online learning. Particular attention should be paid to how these technologies can improve the quality of distance learning. The next area involves researching innovative solutions and opportunities that VR/AR can open up in education, including interactive games, virtual laboratories, and other forms of immersive learning. Another interesting area for future research is to analyse the costs of introducing VR/AR technologies into education and facilitating access to these technologies for various educational institutions. Equally important is the area of studying the psychological impact of VR/AR technologies on student learning, in particular on motivation, interest, and perception of the learning process. The direction of further research is also worthy of attention, which will include studying the impact of VR/AR technologies on the development of students' interpersonal skills, such as cooperation, communication, and teamwork.

Similar studies should be conducted for other aspects of the introduction of VR/AR technologies in educational processes. In particular, a forward-looking area of research is the development of standards and guidelines for the use of VR/AR technologies in education, which will contribute to greater standardisation and quality of education. Another area of research that could be worth exploring is the analysis of the effectiveness of curricula that use VR/AR technologies compared to traditional teaching methods. Another area could include exploring the possibilities of using VR/AR technologies in specialised educational fields, such as medicine, engineering, or the arts. Equally important is the area

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that involves exploring opportunities for cooperation between educational institutions and technology companies to further develop and integrate VR/AR technologies into the educational process.

The impact of virtualisation and immersion of the educational space on the psycho-emotional state of students should also be studied in detail. In particular, a basic research area that may include the study of ethical issues related to the use of VR/AR technologies in education, including student privacy and security. Another important area is the study of the possibilities of integrating VR/AR technologies with other innovative pedagogical approaches, such as gamification or artificial intelligence. The emphasis is on the area of research on the impact of VR/AR technologies on the development of critical thinking and problem-solving. The research area that may include an analysis of the impact of VR/AR technologies on the psychomotor development of students and their skills in solving practical problems is extremely important.

Future research in these areas will contribute to the further development of VR/AR technologies in education and help create more innovative and effective learning environments. In general, future research in the field of VR/AR technologies in education is important for the further development of modern education and the improvement of students' learning opportunities. Future research in the field of VR/AR technologies in education should be aimed at a deeper and more comprehensive understanding of the impact of these technologies on student learning and development, as well as the development of effective pedagogical approaches for their implementation in the educational process.

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