Catalogization and systematic analysis of immersive applications for general secondary education

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Abstract

Digital solutions are integrated into education at all levels, becoming integral. Among modern developments, a special place is occupied by immersive services, the implementation of which contributes to increasing student motivation and engagement, improving the assimilation of educational material, the formation of practical skills through simulations, etc. Since the market for immersive services has significantly enriched in recent years and continues to fill dynamically, it is often difficult, and sometimes impossible, for users, including teachers, to choose an appropriate service among hundreds of existing solutions. In this regard, the problem of developing a database of immersive services arises - cataloging services with a balanced filtering system that would consider the needs of teachers and facilitate their search for appropriate solutions. Recent systematic analyses indicate that immersive technologies in secondary education span diverse platforms including virtual reality (VR), augmented reality (AR), mixed reality (MR), and tele-immersive environments, each offering unique pedagogical affordances for spatial visualization, simulation, and collaborative learning. Meta-analyses demonstrate significant improvements in student engagement (effect size g=0.596-0.603) and learning outcomes, particularly in STEM subjects. The purpose of this article is to substantiate the structure of the catalog of immersive services with the aim of their pedagogically appropriate systematization for general secondary education. We analyzed various catalogs and aggregators of immersive services, comparing their features, filtering systems, advantages, and disadvantages. A survey of 16 experts with experience in scientific research and practical use of immersive services in education was conducted to determine filtering criteria. The developed "Catalog of Immersive Services" includes filtering by category (AR, VR, XR, 360-degree video, 3D-modelling), educational level (grades 1-4, 5-9, 10-11(12)), subject area, interface language, terms of use, and platform compatibility. The catalog serves as a practical resource for teachers to identify and implement appropriate immersive technologies in their educational practice.

Keywords

immersive services, VR, AR, catalog of immersive services, general secondary education, pedagogical effectiveness, teacher support frameworks, technological integration

1. Introduction

Modern education is undergoing significant transformations under the influence of digital technologies [1]. Modern solutions such as cloud services [2, 3, 4, 5, 6, 7], adaptive learning systems [8, 9], artificial intelligence [10, 11, 12, 13, 14, 15, 16, 17], immersive technologies [18, 19, 20, 21, 22, 23, 24, 25, 26, 27], and others are actively integrated into the educational process, becoming its integral organic element. Among modern developments, immersive services occupy a special place. Their integration into the educational process contributes to increasing student motivation and engagement [28, 29, 30], improving the assimilation of educational material, understanding of complex topics [29, 30, 31], forming practical skills through simulations, gamification, developing critical thinking and problem-solving skills [32, 33, 31, 34, 35, 36, 37, 38, 39, 40].

Recent research demonstrates exponential growth in immersive technology applications in education. Statistical analysis from the Web of Science database reveals that scientific publications on VR in

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education increased from 22,010 in 2013 to 82,087 in 2024, while AR publications grew from 3,243 to 25,933 in the same period [41, 42]. This surge reflects both technological maturation and growing recognition of pedagogical benefits, particularly in secondary education contexts where abstract concept visualization and practical skill acquisition are critical [43, 44].

Users of these new technologies (teachers, students, developers) face the problem of finding the necessary services for educational purposes. When choosing a service, it is necessary to take into account various aspects that significantly affect the effectiveness of its use. Therefore, the creation of specialized service catalogs is relevant and appropriate. Given the rapid development of these technologies, research into the scientific and methodological aspects of their implementation and use in general secondary education is relevant and timely.

Along with the undeniable advantages and great potential of immersive developments, there are related problems with their use and serious educational challenges. Thus, the rapid growth of VR/AR services has led to their rapid introduction into education at various levels, causing a certain dispersion and chaos in their use. The market for immersive services has significantly enriched in recent years and continues to fill dynamically. Users, including teachers, often find it difficult, and sometimes impossible, to choose an appropriate service among hundreds of existing solutions. There are compatibility problems, the lack of uniform standards for integrating VR/AR into the educational process, schools risk investing in outdated or unsupported technologies, and teachers find it challenging to choose the appropriate service.

Developing a database of immersive services – cataloging VR/AR services with a balanced filtering system that would consider the needs of teachers and facilitate their search for appropriate solutions – will help solve the outlined problems. The filtering system should consider pedagogical, technological, regulatory, and other aspects of using services.

2. Related work

Scientific interest in immersive technologies in various fields of education and science has almost doubled over the past three years, as confirmed by statistical data on publications indexed by the international database Web of Science (table 1, figure 1).

Table 1
Dynamics of scientific interest in immersive technologies in various fields of education and science.

Keywords	2013	2019	2023	2024
VR	22,010	39,064	68,221	82,087
AR	3,243	8,829	20,315	25,933
XR	2,323	5,007	9,928	12,333
360-degree video	408	783	1,886	2,190

The scientific understanding of the phenomenon of immersive technologies (derived from "to immerse") is substantiated in the works of many researchers. The essence of the concept of "immersive technologies" was considered by Simpkins et al. [45], Pavithra [46], Kirandeep [47], Mütterlein [48], Suh and Prophet [49], Ahmadi and Gilardi [50], Mystakidis and Lympouridis [51], Lytvynova and Soroko [52]. The advantages of using immersive technologies, VR, AR, XR in education were studied by Merchant et al. [53], Parong and Mayer [30], Fitrianto and Saif [54], Shi et al. [55], Alzahrani [32], Özeren and Top [29], Ibáñez and Delgado-Kloos [56], Ferrer-Torregrosa et al. [33], Lytvynova and Soroko [52], Parshukova and Parshukov [57], Palamar et al. [58].

Recent systematic reviews and meta-analyses provide robust evidence for the pedagogical effectiveness of immersive technologies. A comprehensive meta-analysis by Zhou [59] examining 46 studies with 5,415 students found that online argumentation activities using immersive platforms showed significant positive effects on both "Learn to Argue" (Hedges' $g = 0.603$) and "Argue to Learn" (Hedges' $g = 0.596$) abilities. Furthermore, research indicates that VR environments are particularly effective for

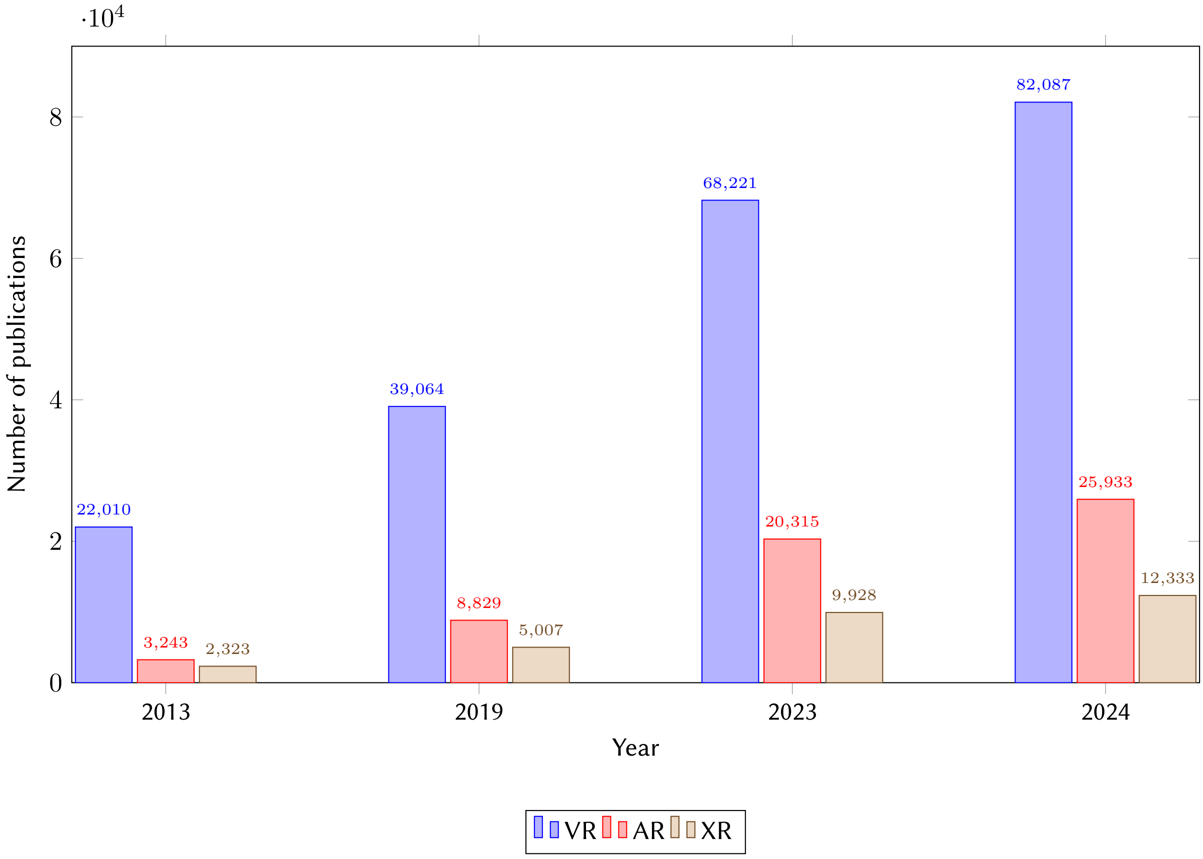

Figure 1: Growth of scientific publications on immersive technologies in education (2013-2024).

STEM education, with the greatest impact observed in natural science topics, while AR shows stronger adoption in K-12 contexts compared to higher education [41, 60].

In a number of publications, experts emphasize the feasibility and advantages of cataloging apps. Various aspects of cataloging software applications are presented by Shuqing et al. [61], who analyzes XRZoo, a large-scale and versatile dataset containing 12,528 free XR applications from nine app stores. The dataset covers all XR techniques (AR, MR, VR) and different usage areas, providing detailed meta-information about each application.

Kwid et al. [62] reviews AI tools and platforms for K-12 education and provides practical guidance for teachers on using these tools. AI tools are classified by purpose: educational, administrative, and analytical. The review conducted in the article aims to help teachers choose the appropriate AI tools for specific purposes.

Recent research identifies critical factors for effective immersive technology integration in secondary education (table 2). A study by Boel et al. [60] involving 2,640 secondary education students found that behavioral intention to use immersive VR was significantly influenced by performance expectancy, effort expectancy, and personal innovativeness, accounting for 50% of variance. Additionally, gender-specific design considerations are crucial, as research by Portuguez-Castro and Santos Garduño [63] demonstrated that female students showed superior engagement across all motivational dimensions (attention, relevance, satisfaction, confidence) when using VR applications.

3. Research methods

During the study, theoretical methods of scientific knowledge were applied: analysis, synthesis, generalization of national (Ukrainian) and foreign scientific sources on the research problem; analysis of various catalogs and aggregators of immersive services; comparison of their features, filtering systems,

Table 2
Comparative analysis of immersive technology types in secondary education.

Type	Key features	Pedagogical uses	Challenges
VR	3D simulation, full immersion	STEM labs, spatial visualization	Cost, motion sickness, training
AR	Overlay, real-world context	Field trips, language, textbooks	Usability, content creation
MR	Hybrid, remote collaboration	Interactive, collaborative tasks	Technical complexity, cost
Tele-immersive	Real-time remote presence	Distributed learning, teamwork	Infrastructure, integration
AI-integrated	Adaptive, personalized	All subjects, inclusive learning	Ethics, teacher support
Metaverse	Social, collaborative	Teamwork, situated learning	Technical, pedagogical alignment

advantages, and disadvantages.

To determine the feasibility of filtering options in the "Catalog of Immersive Services", a practical method was used – a survey of experts (16 people with experience in scientific research and practical use of immersive services in education, of which 12.5% are doctors of sciences, 50% are PhD, 37.5% are researchers without a scientific degree).

4. Results

Currently, some resources in the web space aggregate immersive services according to specific parameters. For example:

- *Vrara.com* – a selection of VR/AR solutions from the VR/AR Association (VRARA);
- *Commonsense.org* – contains various resources (reviews, analytics, services, lessons, etc.), the ability to filter (by age (grade), resource type, subject, language (English, Spain), etc.);
- *EdTechIndex.org* – a selection of services of various types, over 1800 units. A filtering system has been developed based on various categories – age, subject area, target audience, resource type, purpose, etc. However, the set of immersive services is quite limited: the catalog contains only 21 VR services, 5 AR services, and 3 XR services;
- *Classvr.com* – a platform for schools with ready-made VR lessons. Offers high-quality immersive learning solutions, which, however, are paid and mainly in English;
- *MelScience.com* – contains a list of specialized services – for studying STEM, mathematics, physics, chemistry, and medicine. In total – about 45 services;
- *Sketchfab.com* – contains an extensive library of 3D models for AR/VR. These are not ready-made solutions, but can be used in the development of such solutions.

Some of the existing resources offer the ability to filter by technology (VR, AR, XR, etc.), by subject area (STEM, mathematics, biology, history, etc.), by age group (preschool education, elementary school, middle/high school, higher education, adult education, etc.), by price (free, paid, demo versions), by supported platforms (iOS, Android, Web, etc.), by interface language (monolingual (mostly English), multilingual), etc. When describing a service, such aspects as its name, link to the official page or website, an overview of functionality, equipment requirements, and screenshots/videos are mainly considered.

However, the resources that currently exist have some shortcomings that reduce their usefulness for implementation in the educational process, in particular in Ukraine:

- existing aggregators usually offer a regular list of services in a list limited to the name and their description, sometimes a link. At the same time, the possibility of filtering is either completely absent or contains only a few options;
- a small selection of immersive services - the vast majority of existing databases and catalogs aggregate services of various types, excluding AR/VR altogether or including only a small number of them (small selection);
- a language barrier - existing developments do not have a Ukrainian-language interface; they are mainly English-language;
- some aggregators work only on a paid subscription (e.g., Labster), which imposes an additional financial burden on schools;
- some platforms (e.g., Meta/Oculus) collect user data, which may contradict Ukrainian laws on protecting personal data about children.

In this regard, there was a need to create a catalog of immersive services that could be used to support the educational process in general secondary education institutions in Ukraine.

4.1. Choosing an appropriate immersive technology or service

There are three key components required for any immersive technology to function:

1) hardware (equipment) – high-quality hardware is of paramount importance to ensure a realistic and practical immersion effect: headsets, sensors, controllers, and haptic devices that provide physical feedback (Oculus Quest, HTC VIVE Focus, etc.); smartphones equipped with a camera and sensors, etc.;
2) software – the software component creates the digital environment where users interact. Various programming languages, libraries, and software development kits are used to create immersive environments, ranging from realistic simulations to fantasy worlds. Good software provides good integration between the hardware and the user interface.
3) user interface (UI) – an essential component of immersive technology, referring to how users interact with the digital environment. An intuitive and natural user interface contributes significantly to an immersive experience. Factors to consider include:
   - User comfort and ease of use – users should be able to interact with the digital environment without stress or discomfort, which can be achieved by providing an intuitive interface.
   - Integration: the user interface should be well integrated with the hardware component, supporting the user's convenience and ease of interaction.

Considering these aspects will help ensure a positive user experience and broader adoption of the technology, which is especially important when using it for educational purposes.

In addition, it is essential to enable the selection of services taking into account the following aspects:

- purpose of use – think about the subject area for which the service is planned, what goals we are trying to achieve by implementing a new technology, and determine the specific tasks that need to be performed. Understanding the needs of use allows you to decide which functions are most important;
- user experience – determine the target group of users and assess their overall understanding of using immersive technology (is prior training, instruction, training required?);
- technical requirements – check whether the selected technology is compatible with the devices, software, and networks used by the team you are using;
- scalability – consider the possible allowable number of users, whether the technology provides the desired level of collaboration and interaction, whether it will allow you to reach the required number of users;

- cost – assess the cost of the technology, including any hardware, software, or licensing fees, and determine whether this fits within the available budget;
- localization – determine which languages are available in the settings and whether there is a language barrier;
- security – assess the security features of the technology, including data protection, encryption, and access control to ensure that confidential information is protected;
- support – determine the level of support available from the technology provider, including technical assistance, training, and user forums.

Thus, when creating a "Catalog of Immersive Services", it is essential to provide such a filtering option so that the teacher can choose the most appropriate service, taking into account their own experience, material, and technical capabilities.

4.2. Selecting options for filtering in the "Catalog of Immersive Services"

To determine the appropriateness of the selected filtering options in the "Catalog of Immersive Services", we surveyed experts – 16 people with experience in scientific research and practical use of immersive services in education (12.5% – doctors of science, 50% – PhD, 37.5% – researchers without a scientific degree).

The researchers were offered a list of criteria for selecting immersive services (what should the user (teacher) be guided by when choosing a service?), the importance of which had to be assessed on a Likert scale from 1 to 10, where "1" is entirely insignificant, "10" is very important.

The experts selected the following criteria for choosing immersive services as the most important:

- subject-oriented nature of the service (e.g., for physics simulations, for anatomy visualizations, etc.);
- "complexity" or "simplicity" of the service (need for prior preparation to work with the service);
- availability of ready-made visualizations/simulations;
- the possibility of creating your visualizations/simulations;
- compatibility of the service with existing technical means (ability to reproduce on the existing operating system, ability to use on existing gadgets, with available disk space, etc.);
- scalability (does the service allow to reach the required number of users);
- cost (is the service free? If not, is the price affordable?);
- localization (does the service support the Ukrainian language?);
- security (security features of the service, including data protection, encryption, and access control to ensure the protection of confidential information, etc.);
- support (high-quality and prompt technical support from the provider).

Table 3 presents the ordered results of the experts' responses.

The evaluation of the proposed criteria is summarized as follows:

- 8-10 points – critical (in the table marked as "+");
- 5-7 – possible (in the table marked as "+/–");
- 1-4 – not important (in the table marked as "–").

From the data presented in table 3, we can draw the following conclusions:

- all the proposed criteria are appropriate to be used when selecting immersive services since each criterion received expert ratings in the range of 5-10 on a 10-point Likert scale (which we summarized as "very important" and "possible");
- the experts excluded none of the proposed criteria (none received low scores in the range of 1-4, which would characterize it as "not important");
- the proposed criteria can be used when developing a filtering system in the "Catalog of Immersive Services" to simplify the search for appropriate services by secondary school teachers.

Table 3
Results of experts' responses on the selection of the most significant criteria for the selection of immersive services.

Criteria	10	9	8	7	6	5	4	3	2	1
Subject orientation	8	5	3							
Ease of mastering	3	8	5							
Ready-made simulations	10	3	1		2					
Create own simulations	8	4	1	2	1					
Technical compatibility	10	4	2							
Scalability	6	7	2	1						
Price	6	7	1	2						
Localization	1	7	4	1	1	2				
Security	6	6	2	1		1				
Technical support	6	3	5	1	1					

4.3. Technical aspects of creating the "Catalog of Immersive Services"

Before creating the "Catalog of Immersive Services", the task was set to obtain the following results:

- a convenient filtering system that takes into account the needs of the target group;
- an attractive and convenient presentation of data at the stage of use;
- the catalog should provide convenient filling and editing for its editors.

The catalog was designed using a no-code approach, without the need to pay for services or infrastructure during its use.

Given the task set, Softr (https://softr.io/) was chosen to create the catalog – a service for creating websites and web applications without code.

In the free tariff plan, Softr allows you to:

- create an interface to data that will be stored in Airtable, Google Sheets, or Notion;
- use the main types of blocks when creating, such as list, grid, table, form, object detail, and others;
- have up to 10 users who can log in using a password or Google account (in our case, these are moderators who add new services to the catalog or check services added by unregistered visitors before publication);
- serve an unlimited number of users;
- connect your domain (in our case, we used our domain in the pp.ua zone – the only zone in the Ukrainian segment that provides the opportunity to register a domain for free);
- set up integration with Google Analytics and/or Google Tag Manager.

We also analyzed certain limitations inherent in Softr and also identified ways to solve potential related problems:

- in the free tariff plan, the service allows the created web application to work with a maximum of 1000 records (immersive services). Achieving the threshold value by the catalog would mean its demand and usefulness for users. In this case, the task of expansion will arise, which can be achieved by moving away from the no-code approach, rewriting the interface part of the catalog using, for example, the Astro framework (https://astro.build/) and Cloudflare Pages hosting (https://pages.cloudflare.com/). At the same time, the possibility of unrestricted use of the catalog will continue to be preserved;
- when creating the catalog, Softr allowed you to choose the sorting of elements only when creating a web application and not during use. We bypassed the restriction on sorting selection by creating an additional page on which you can view the catalog elements in the reverse order of the time they were added to the catalog.

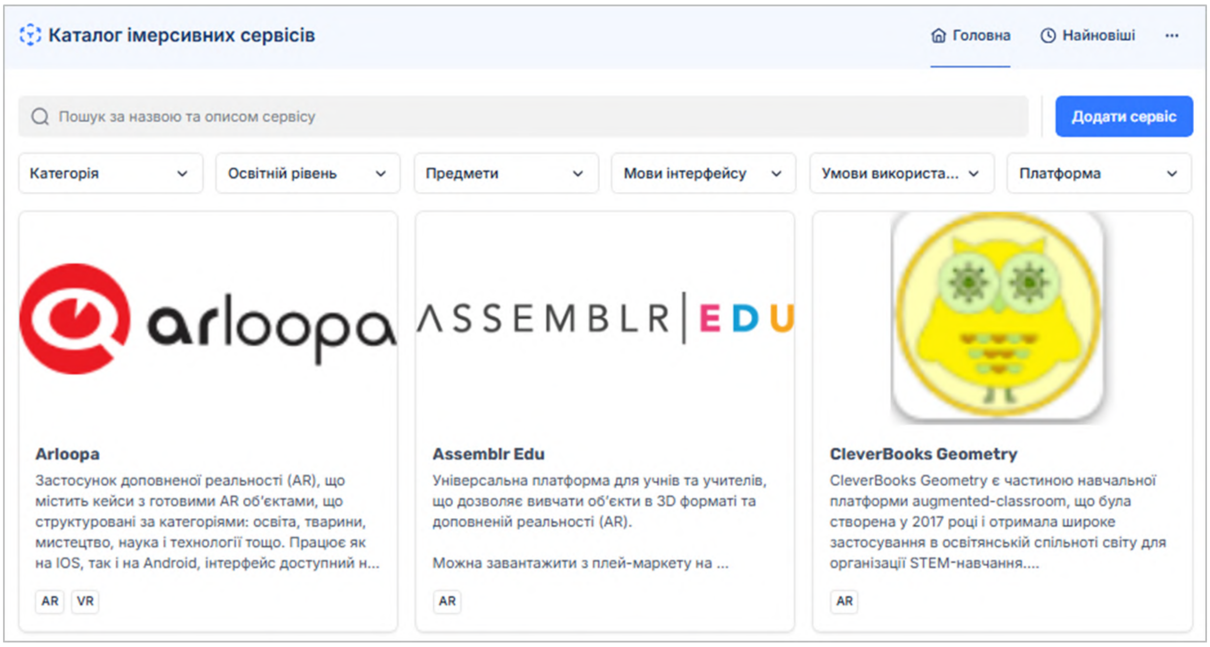

Figure 2: The homepage of the "Catalog of Immersive Services".

Figure 2 shows the start page of the "Catalog of Immersive Services".

Figure 3 shows the filtering system for users' convenience in choosing the appropriate service. When developing the filtering options, the results of the expert group survey, presented in the previous section, were taken into account. In particular, this is the ability to select services by their category (AR, VR, XR, 360-degree video, 3D-modelling), educational level (grades 1-4, 5-9, 10-11(12)) and subject (astronomy, biology and ecology, computer science, foreign language, history, etc.) for which the service is planned to be used, interface language, terms of use (free and under specific tariff plans), platform (operating system).

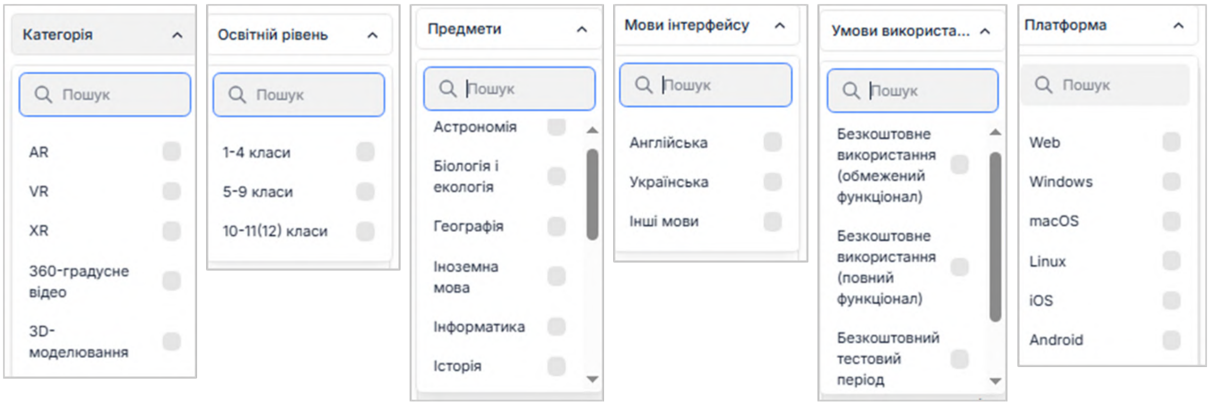

Figure 3: Filtering system in the "Catalog of Immersive Services".

Figure 4 shows a description of one of the services as it is displayed in the catalog. In addition to the functionality and possibilities of use, the description also contains a link to this service and screenshots. This also helps in deciding on the appropriateness of a particular service for educational purposes.

5. Framework for teacher support and professional development

Research consistently demonstrates that teacher training and support are critical factors for successful immersive technology integration. A longitudinal study by Mills et al. [64] found that while teachers'

Figure 4: Example of a description of a separate service in the "Catalog of Immersive Services".

beliefs about inquiry-based learning improved after VR implementation, their actual classroom practices remained unchanged without continuous professional development. This highlights the need for comprehensive support frameworks that bridge the gap between technological potential and pedagogical practice (table 4).

In the future, it is planned to create a separate function in the catalog, "Compatibility Calculator", with which the user can set their preferences (in the form of corresponding coefficients), and the system will calculate an integral indicator for each service. This will allow you to optimize the choice of the necessary service further.

6. Conclusions and prospects for further research

In the current digital transformation of education, immersive technologies occupy a special place. Their implementation is less intensive in general secondary education than in higher and vocational education. Still, it has significant prospects in increasing student motivation and engagement, improving the assimilation of educational material, developing critical thinking and problem-solving skills, and forming practical skills through simulations, gamification, etc.

Along with the undeniable advantages and great potential of immersive developments, there is a

Table 4
Essential components of teacher support frameworks for immersive technology integration.

Framework component	Description	Implementation strategy
Technical training	Hardware setup, software navigation, troubleshooting	Hands-on workshops, video tutorials
Pedagogical integration	Curriculum alignment, lesson design, assessment methods	Collaborative planning sessions, exemplar lessons
Content creation	Developing custom VR/AR materials	Template libraries, authoring tools training
Continuous support	Ongoing assistance, community building	Online forums, peer mentoring, regular check-ins
Evaluation methods	Measuring impact on learning outcomes	Pre/post assessments, student feedback tools

problem with their organization and cataloging to ensure a convenient search for appropriate services for use by teachers in the educational process. A review of the literature and some existing online resources showed that existing catalogs and service aggregators have shortcomings and do not fully provide the functionality necessary for educators. Typically, such catalogs are not specialized and do not allow you to search for the required services by specialized attributes.

Our analysis, informed by comprehensive research spanning 2018-2024, reveals that effective catalogization must address multiple dimensions: technological diversity (VR, AR, MR, tele-immersive platforms), pedagogical alignment, teacher support mechanisms, and context-specific implementation challenges. The integration of systematic filtering criteria based on expert consensus and empirical evidence ensures that the catalog serves as both a practical tool and a framework for informed decision-making in educational technology adoption.

In this regard, there was a need to create a "Catalog of Immersive Services", which satisfies the key search needs of teachers, who can choose the optimal VR/AR services and take advantage of their advantages in teaching various subjects (figure 5). The catalog contains a convenient filtering system, which took into account the results of a survey by a group of experts. In particular, the catalog allows you to select services by category, educational level, subject for which the service will be used, interface language, and payment terms.

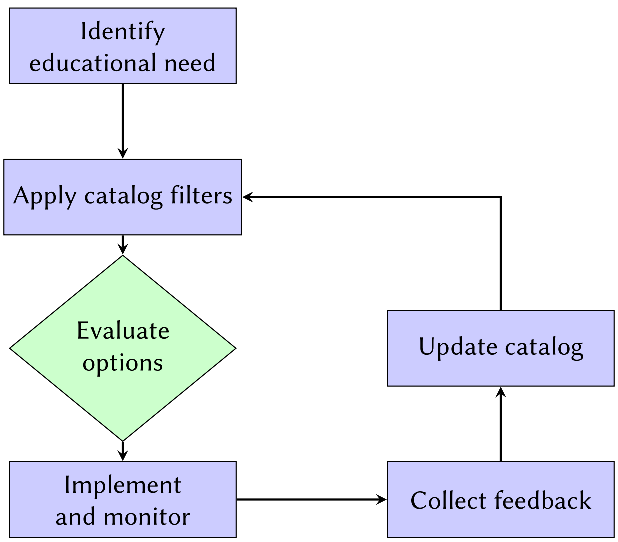

Figure 5: Iterative process for immersive technology selection and catalog improvement.

We consider it appropriate to recommend the "Catalog of Immersive Services" to teachers for use in the educational process.

Based on our findings and the comprehensive analysis of current research trends, we propose the following directions for future development:

1. Conduct extended research (minimum 6-12 months) to assess the sustained impact of immersive technologies on learning outcomes, particularly in Ukrainian secondary schools.
2. Create culturally relevant, Ukrainian-language immersive content aligned with national curriculum standards, addressing the current dominance of English-language resources.
3. Develop and evaluate low-cost immersive solutions suitable for resource-limited schools, particularly in rural areas where infrastructure challenges persist.
4. Establish comprehensive training programs that combine technical skills with pedagogical strategies, incorporating the TPaCK (Technological Pedagogical Content Knowledge) framework.
5. Develop new assessment tools specifically designed for evaluating learning in immersive environments, moving beyond traditional testing methods.
6. Establish clear protocols for data privacy, student safety, and ethical use of immersive technologies in educational settings, particularly concerning minors.

Further research should be directed to studying the effect of the widespread implementation of the catalog of immersive services, reflections of users of this catalog, substantiation of the methodological foundations of its use, in particular for various subject areas.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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