

Article

Hybrid Educational Ecosystem of a Metauniversity: Integrating a Web Platform and an Immersive Digital Twin in Engineering Education

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Abstract

The timely integration of technology in education is a key factor in developing competitive specialists. Given this, the development of a digital educational platform for training engineering specialists is of strategic importance. The paper presents the development of a proprietary digital educational platform using immersive technologies for training engineering specialists while providing educators with easier access to their educational progress and ability to spend less time processing it. The results are considered data from an initial test, aimed primarily at assessing user perception, usability, and the potential of the immersive environment. The platform's effectiveness stems from its ability to simulate complex processes and allow students to independently control the experiment.

Keywords: digital platform; higher education; engineering training; immersive technologies; metauniversity; digital twins; hybrid architecture

1. Introduction

In today's environment, the evolution of educational technologies necessitates the creation of hybrid ecosystems that integrate infrastructure data and educational processes [1,2]. Traditional educational web platforms (Web 2.0) provide effective tools for accessing theoretical content and administering the educational process. However, they are limited by a traditional 2D interface, which reduces student engagement and limits the number of skills developed [3,4]. Therefore, the transition to the next stage of digitalization is the creation of digital copies (twins) of universities using virtual reality (VR) technology, where students retain the advantages of a digital tool while maintaining a level of presence close to reality [5,6].

The global surge in distance learning during the COVID-19 pandemic has led to a sharp increase in the adoption of modern educational technologies. Various digital educational platforms [7–9], interactive mobile systems [10,11], virtual labs [12–16], and online courses [17,18] have been developed. These technologies have significantly expanded the capabilities of the educational process; however, the academic community



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is currently recognizing the need to transition from content management systems to the metauniversity concept.

Digital educational platforms (DEPs) are a modern learning tool that provides flexible access to materials [19,20]. They facilitate the individualization of the educational track [21], but the traditional communication format within them is often limited to the “person-to-screen” paradigm. Studies [22,23] note that the next stage of platform evolution should be aimed at strengthening cognitive competencies through the creation of a unified immersive space where students can “express themselves” through non-verbal cues.

Research [24,25] emphasizes that virtual learning tools have the potential to replace expensive equipment in engineering disciplines. In the context of metauniversity, these tools are transformed into full-fledged social laboratories (digital twins), where interaction with devices and classmates occurs in the most natural way possible.

Today, there are a significant number of digital platforms (Moodle, Open edX, Microsoft Teams, etc.) actively used in higher education [26–29]. However, a comparative analysis of platforms in engineering science teaching [30–32] shows that the technical capabilities of text and video formats are not the only criteria for success. A study [33] conducted at a major technical university in the United States identified systemic problems with online education: lack of practice, low engagement, and “digital fatigue.” The solution to these problems lies in a transition to a hybrid format, where natural interaction in a digital twin eliminates communication barriers.

Examples of the use of AR/VR technologies (the ScoolAR [34] and i-DERASSA [35] platforms) demonstrate significant improvements in the learning process thanks to real-time 3D visualization [36–38]. Therefore, the web platform should act as a data repository, and the digital twin as an immersive space. In this case, complex material is more easily absorbed, and interactive tasks are transformed into collaborative practical experiences.

During the pandemic, universities in Kazakhstan actively integrated MS Teams, Zoom, and Google Meet. However, these platforms have disadvantages for engineering education: interface complexity, time constraints, and a lack of immersive interaction tools. Video conferencing does not provide the “social presence” necessary for meaningful learning.

In response to these challenges, many universities in Kazakhstan have developed their own adapted web platforms:

- L.N. Gumilyov Eurasian National University uses Platonus, Moodle, and its own MOOC platform [39,40].
- S. Seifullin Kazakh Agro Technical University has implemented a MOOC platform and the Unihub.kz system [41,42].
- Al-Farabi Kazakh National University is developing the OpenEdx platform [43] and the UNI-VER system [44].
- Satbayev University has implemented PolytechOnline with an AI proctoring system [43].
- Turan University uses the Canvas LMS and its own automated control system [45].

Despite the successful adoption of these, they are still missing some features, especially in terms of interaction and practical knowledge.

In this paper we propose hybrid educational system (web platform + digital twin) marking a transition to a qualitatively new, interactive, and accessible education. The web platform serves as the foundational layer (data management, theory, scheduling), while digital copy of the university’s campus provides an immersive interface for practicing not only skills but also communication.

The combination of the web platform and the digital twin transforms an isolated educational resource into a full-fledged metauniversity.

The key advantage of a digital twin over traditional systems is the creation of a “co-presence” effect. In a Web 2.0 environment, interaction is often limited to text or video,

which creates a sense of distance and leads to rapid fatigue. On the contrary, in a digital twin, communication becomes natural through spatial sound positioning and the use of avatars.

Immersivity allows students to move from studying flat diagrams on a web platform to directly interacting with 3D models of devices in a virtual digital twin laboratory. This ensures a high level of visualization of physical processes and the ability to conduct experiments without the risk of causing injury or damaging real, expensive equipment. The digital environment becomes a safe testing ground for developing practical competencies [46,47].

Students can navigate virtual labs, communicating as intuitively as on a physical campus. The use of simplified avatars instead of hyper-realistic models is a conscious decision: it ensures social safety, minimizes bias based on external features, and ensures high technical scalability of the system [48,49].

Thus, the development of an integrated educational environment (web platform + digital twin) marks a transition to a qualitatively new, interactive, and accessible education. In this study, a digital twin is defined as an immersive 3D environment that reproduces the structure of classrooms, the logic of interaction with laboratory equipment, and individual elements of the educational process at the International Information Technology University (IITU, Almaty, Kazakhstan). The proposed approach differs from an industrial digital twin in that its primary goal is not continuous synchronization with a physical object, but rather to support educational interaction, visualize engineering processes, and record student learning activities.

Therefore, the experience of IITU deserves special attention. As an ASIIN-certified university [50] and a Coursera partner [51], IITU is implementing a strategy for transitioning to the metauniversity. The development of an integrated system allows for a shift away from passive content consumption. This allows for the establishment of new quality standards in the Web 3.0 era.

2. Methodology

The main research question of this work is following “Is it possible to create a system combining practical skills development tool together with a data collection to ease educational process?”. As the system proposed suggests combination of the information system in the form of a website and VR environment, that allows us to get educational and educational experience. While the data exchange among these provides possibility to analyze students’ behavior and educational progress within with no additional effort. The research methodology for the creation of a hybrid educational environment consists of several stages as follows: an analysis of the platforms of leading technical universities in Kazakhstan focusing on communication and interactivity limitations that hinder the emergence of an immersive experience. The second stage is the development of two-tier hybrid architecture. The first tier consists of a classic web platform (developed using Python v3.11/FastAPI v0.115.12), responsible for administration, data storage, and integration with university systems. The second tier consists of a digital twin of the university (developed in C# in the Unity 3D environment with 3D models from Blender), providing an immersive environment providing practical skills training.

To evaluate the functional prototype, a descriptive, cross-sectional empirical design was employed. As the current iteration of the system is in the pilot phase, the primary objective was to assess user satisfaction, system usability, and technical feasibility rather than longitudinal pedagogical effectiveness. A convenience sampling method was utilized to recruit participants from the student body of the IITU. The final sample consisted of 38 undergraduate students enrolled in Information Technology study program.

The study was conducted in accordance with the university's internal research ethics guidelines. All participants were provided with a comprehensive briefing regarding the study's objectives and the nature of their involvement. Written informed consent was obtained from each participant, ensuring complete data anonymity and the right to withdraw from the evaluation at any time. During the empirical phase, participants interacted with the immersive environment using Meta Quest 3 for 15 min, executing a predefined practical scenario at Physics class.

3. System Implementation

The educational ecosystem being developed is a multifunctional platform that combines web infrastructure and VR environment.

The diagram in Figure 1 represents the architecture of the metauniversity system. The architecture is clearly divided into the server infrastructure (web and data tiers) and the client-side immersive component (digital twin). The approach to the use of both tools is aimed at differentiating interaction during learning. Thus, the platform mostly operates as a traditional instrument, providing access to general information about the courses and eases work with routine and administrative tasks, but still having an option to work with VR practice, with no 3rd party tools as VR headsets. At the same time, metauniversity is created for another level of interaction within the virtual reality environment, focusing on execution and interaction.

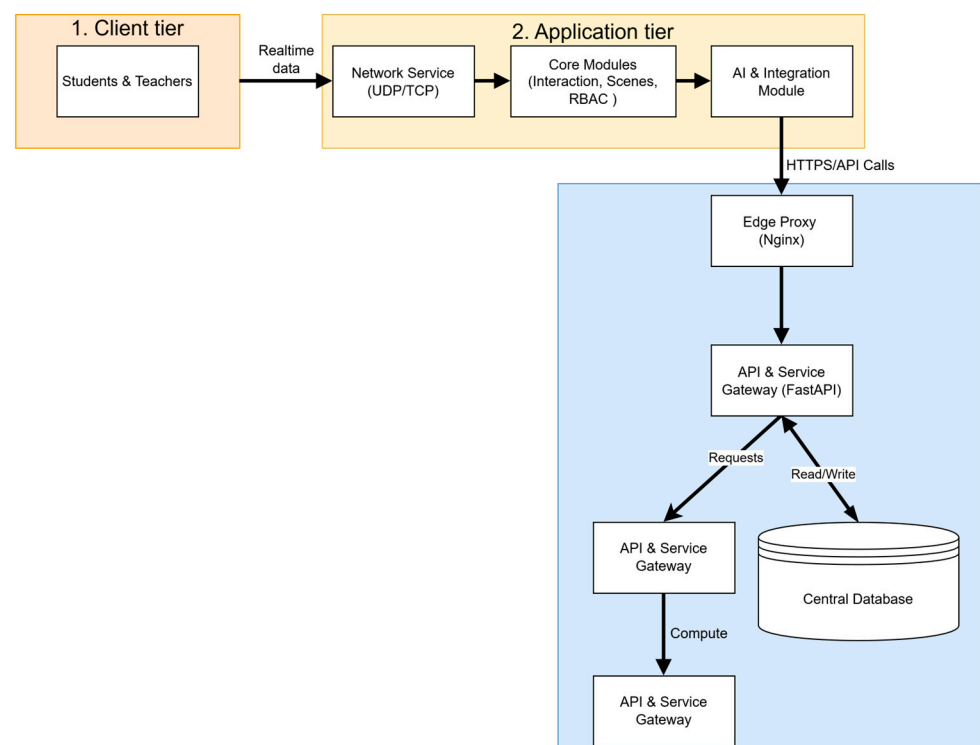


Figure 1. Scheme of the Metuniversity's architecture.

This combination ensures integration of physical, web-based and immersive learning environments, having a persistent data layer and user identity. The platform operates as a middleware stage, as existing LMS and educational VR applications are not connected to each other. Thus, our approach creates a scalable foundation for such systems.

The server infrastructure is hosted on Cloud VPS. Incoming API requests are routed through Nginx reverse proxy. The REST API is implemented using FastAPI v0.115.12 (Python v3.11) and interacts with a PostgreSQL 16 relational database. This module serves as a multifunctional educational platform: it stores user profiles, course materials, grades,

attendance data, and the schedule. AI services are also integrated into this layer: Ollama (LLM inference for intelligent query processing), Whisper (Speech-to-Text), and Edge-TTS (speech generation), as well as tools for generating 3D content. At this stage, the AI modules are considered part of the platform's extensible architecture. Their purpose is to support intelligent student guidance, process voice requests, and generate voice responses in an immersive environment. However, a comprehensive pedagogical evaluation of the AI tutor's effectiveness requires a separate experimental study, including an analysis of response quality, speech recognition stability, the impact of the voice interface on student engagement, and the security of user data processing.

The client component is a digital twin built on the Unity engine. Students and teachers use Meta Quest 3 devices to access the 3D campus. Synchronization of actions is ensured by a hybrid PurrNet network layer (UDP/TCP), supporting the transmission of object changes and remote calls (RPC). The immersive portion of the system is implemented as an interactive VR environment in which the user can navigate the virtual learning space, interact with laboratory setup objects, perform measurements, and repeat experimental actions. Interaction with objects is carried out through VR headset controllers, allowing for the simulation of practical actions similar to working with physical laboratory equipment. Unlike a traditional LMS, where students primarily access text and multimedia materials, the VR environment provides activity-based learning through direct interaction with spatial objects and observing the results of their own actions.

The following modules operate within the digital twin:

- VR Interaction: responsible for movement and physical interaction with virtual objects;
- Collaboration: enables collaboration, spatial voice chat, and hand tracking;
- AI System & English Module: integration of language analysis and contextual AI guides;
- Classroom Scenes: precise 3D replicas of laboratories and lecture halls on the actual IITU campus.
- Data Layer & RBAC: modules for seamlessly synchronizing avatar actions with the web platform database (e.g., automatically transferring grades for a virtual experiment to the student's digital journal).

The unique feature of the VR component is that the student not only studies theoretical material but also performs a sequence of practical actions in an immersive environment. Within the laboratory scenario, the user can grasp and move objects, launch an experiment, use virtual measuring instruments, record results, and repeat attempts with altered initial conditions. This format allows distance learning to be more closely aligned with real laboratory practice and fosters more active student participation in the learning process.

3.1. Data Security

Creating a scalable digital educational environment requires a comprehensive approach to protecting user data.

The primary goal of digital security is to create a reliable, scalable, and user-friendly digital educational environment capable of ensuring both high user engagement and the protection of their data. Therefore, special attention is paid to information security and compliance with privacy requirements, the proposed architecture is shown in the Figure 2.

Key security requirements include:

- Protection of grades and user profiles, implemented through a reliable data storage system and a strict RBAC model that prevents unauthorized changes to information;
- Secure communication, including filtering of inappropriate content, a mechanism for monitoring private messages, and the ability to manage interactions between users;

- Confidentiality of correspondence, achieved with cryptographic methods to encrypt message history with the ability to control access for investigations in the event of an incident.

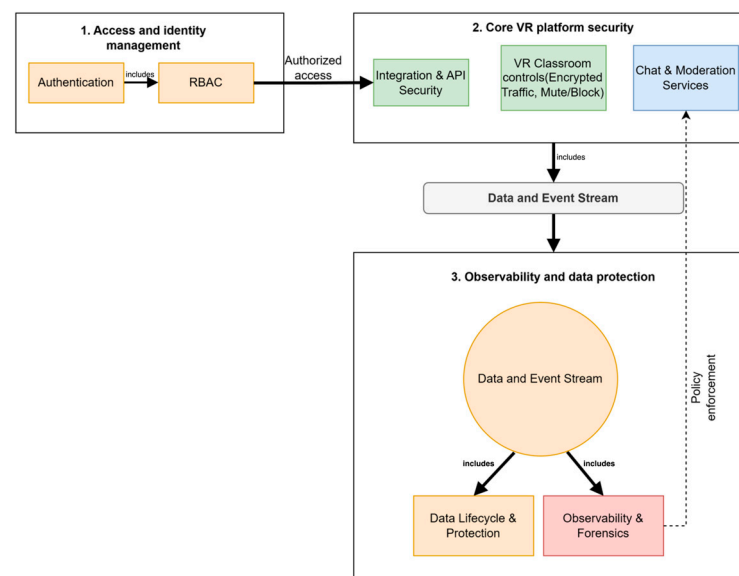


Figure 2. Diagram of data security architecture.

Modern educational systems require a comprehensive approach to ensuring data and infrastructure security. First and foremost, it is necessary to consider international and local security standards, such as the General Data Protection Regulation (GDPR), FERPA (Family Educational Rights and Privacy Act), as well as SOC 2 and ISO 27001 [52] information security standards. Data is protected using encryption at all levels: the AES-256 algorithm for data storage and TLS 1.2/1.3 protocols for data transmission.

To comply with privacy regulations, the platform's data lifecycle is strictly defined. The system collects academic records and VR telemetry, with telemetry automatically deleted at the end of each semester. Crucially, voice data is processed in real-time and never permanently recorded. Access to raw logs is restricted to system administrators, while instructors view only aggregated academic reports. Finally, students retain the right to review their data and request the deletion of their personal telemetry records.

3.2. Integration with the Web Platform

The key advantage of the hybrid ecosystem being developed is the implementation of end-to-end data exchange between the immersive layer (digital twin) and the administrative layer (web platform). Unlike disparate educational tools, this architecture enables the creation of a unified monitoring cycle.

The synchronization process is based on an event-driven interaction model and operates along two parallel vectors:

1. **Attendance Tracking:** When a student logs into the digital twin via a VR headset, the system automatically records the start of the learning session. A software module based on Unity 3D continuously monitors telemetry from the headset and controllers, recording the user's active time in the virtual lab. This eliminates simulated presence (equipment inactivity) and creates an objective digital trace. Data on active participation in the VR session is transmitted to a secure local gateway, after which the web platform automatically marks the attendance in the electronic course log.
2. **Recording Academic Achievements (Grade Synchronization):** The system simultaneously evaluates performance based on time. When a student completes a given

educational task within the digital twin (for example, successfully assembles a radio circuit, takes measurements, or passes an integrated test), an encrypted data packet is generated with the achieved result.

3. Processing and Updating Platform Data: A local API gateway receives incoming packets from multiple simultaneously connected avatars, validates them, and transmits them to the web platform database. As a result, the electronic journal is updated in real time: the system automatically records both the student's presence in the virtual lesson and the final grade for the completed lab.

The mechanism for synchronizing educational activity should be considered an important element of the system's further development. In a working scenario, this could include the following events: student authorization in the VR environment, recording the start of a study session, recording active time spent interacting with objects, completing a lab assignment, generating a result, transferring data via an API, and subsequently updating the electronic journal. To ensure the reliability of this approach, it is necessary to provide the ability for the instructor to verify data, manually adjust results, and handle situations related to network connection loss or misinterpretation of user actions.

Such integration potentially reduces the amount of routine work for the instructor related to attendance management and checking standard lab assignments. Automatic recording of student actions can reduce the likelihood of manual data entry errors, but the system must also provide the ability for pedagogical review, manual adjustment, and cancellation of automatically generated results. This is especially important in cases of technical failures, network connection loss, or misinterpretation of user actions in the VR environment. Thus, the digital twin can be viewed not as an isolated 3D simulator, but as a promising module of a hybrid educational ecosystem, linked to the overall learning management system.

3.3. Avatars

The approach to developing avatars for metauniversity is based on the use of simple geometric shapes instead of detailed realistic models (Figure 3).

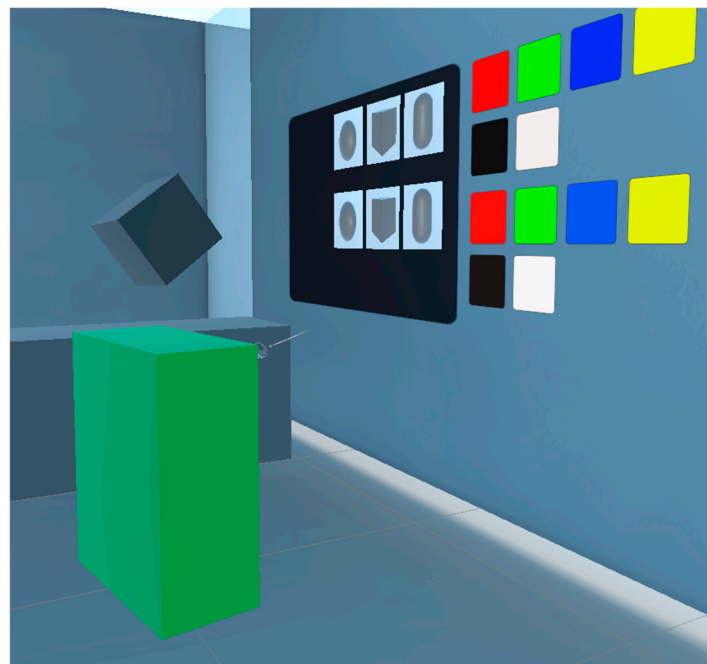


Figure 3. Avatar composing.

This decision was made to create a safe and effective educational environment. This way, the student's focus will be on learning and communication, not the avatar's appearance. Furthermore, the use of simple avatars helps avoid bias against students based on their appearance, age, or nationality. In such a space, participants' attention is focused solely on a person's knowledge and activity, not their appearance. The absence of realistic details also reduces the risk of cyberbullying and conflicts, as users have no reason to discriminate based on appearance.

Despite the apparent simplicity, communication in such an environment remains natural: the system accurately reproduces hand and head movements, allowing for the understanding of the interlocutor's intentions. From a technical standpoint, simplified avatars operate significantly faster and more reliably, precisely due to their simplified form. This allows many students to share a virtual classroom without loss of connection quality or system freezes. Users can distinguish each other by changing colors or shapes, ensuring recognizability without revealing personal information. This approach will further link the avatar's image to the student's academic achievements: their appearance will reflect acquired skills and achievements, rather than physical characteristics.

Thus, the approach to developing user avatars based on the metauniversity has the following parameters: anonymity of identity, the possibility of non-verbal communication, basic customization (choice of shape, colors and accessories), effective scalability (Figure 4).

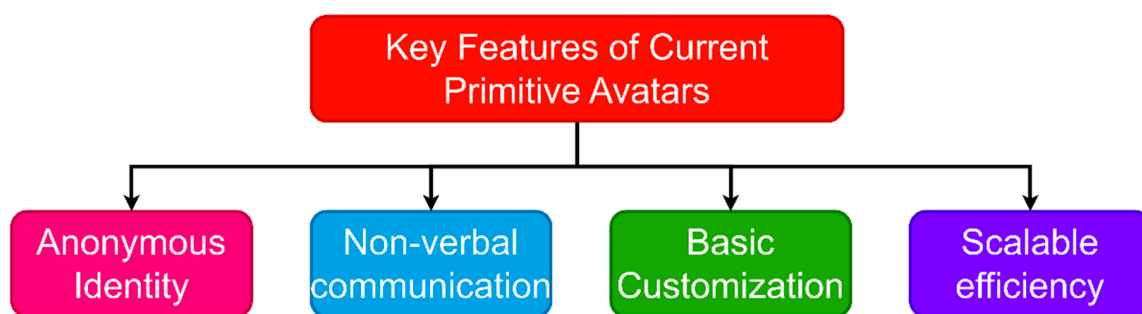


Figure 4. Key features of the avatars in metauniversity.

4. Results

To comprehensively test the effectiveness of the developed metauniversity hybrid architecture, the pedagogical experiment and feedback collection were divided into two stages, corresponding to two levels of the system: an evaluation of the basic web platform and an evaluation of the immersive level (digital twin). Undergraduate students from the IITU participated in the study.

4.1. Evaluation of the Basic Level (Web Platform)

The first stage assessed student satisfaction with the classic web interface, which functions as an LMS (access to theory, schedule, and instructions). The assessment was conducted using a questionnaire in which 38 participants (students) rated various platform experience factors on a Likert scale from 1 ("Strongly disagree") to 7 ("Strongly agree"). A custom-built questionnaire was developed based on the Technology Acceptance Model (TAM) and consisted of 29 questions. Those were grouped into four major dimensions: Interface Design, Functionality, Accessibility, and Error Recovery. For each category, composite scores were calculated by averaging participant responses across the items belonging to that dimension. Reliability was assessed using Cronbach's alpha, and user satisfaction was further quantified using Top-2 Box (T2B) analysis (ratings 6–7).

The first category on Interface Design contained 7 questions and focused on user interface clarity, navigation logic, menu structure, and command labeling. This category

included statements evaluating whether the platform provides a user-friendly interface, whether interface elements are visually distinguishable, and whether menu options and commands are logically organized and easy to understand.

The Functionality dimension included also 7 questions and focused on the system's usefulness, availability of required features, compliance with user expectations, and overall performance effectiveness. This category statements evaluated whether the platform provides access to educational materials, meets functional requirements, supports necessary learning activities, and operates in accordance with user needs.

The Accessibility dimension was evaluated through a ten-item subscale addressing ease of use, flexibility, learnability, and user independence. The Error Recovery category with 5 questions assessed system consistency, availability of help information, and the clarity and usefulness of error messages.

The survey results are presented in Table 1.

Table 1. Questionnaire's results.

Dimension	Mean (M)	Std. Deviation (SD)	Top-2 Box (%)	Cronbach's α
Interface Design	6.22	1.11	77.07%	0.914
Functionality	6.16	1.18	77.82%	0.927
Accessibility	6.43	1.01	84.21%	0.923
Error Recovery	6.21	1.20	75.00%	0.816

The empirical results demonstrate a high level of user satisfaction across all evaluated categories of the web platform.

The reliability analysis yielded Cronbach's Alpha values ranging from 0.816 to 0.927. These figures significantly exceed the widely accepted threshold of 0.70, confirming that the survey instrument possesses high internal consistency. The Functionality dimension showed the highest reliability (0.927), suggesting that the questions in this category were exceptionally cohesive in measuring user requirements.

The Accessibility dimension emerged as the top-performing category, achieving the highest mean score ($M = 6.43$) and the most impressive Top-2 Box score (84.21%). This indicates that most users found the platform intuitive and easy to navigate without external guidance. The relatively low standard deviation ($SD = 1.01$) further suggests a strong consensus among respondents regarding the platform's user-friendly nature.

Interface Design ($M = 6.22$) and Functionality ($M = 6.16$) both performed strongly. The T2B scores indicate that over three-quarters of the participants are highly satisfied with the visual clarity and the feature set provided. While the SD for Functionality is slightly higher (1.18), reflecting minor variations in how different users perceive the "completeness" of the functions, the overall trend remains overwhelmingly positive.

Error Recovery received a Mean of 6.21. While the T2B score of 75.00% is the lowest among the four categories, it still represents a solid majority of satisfied users. The higher standard deviation ($SD = 1.20$) in this section highlights that error handling is the most sensitive area of the user experience; users have slightly more diverse experiences when encountering and resolving system issues.

Overall, the platform demonstrates excellence in Accessibility, which serves as its primary competitive advantage. The high alignment between Interface Design and Functionality ensures a coherent user experience. To further enhance the platform, future development should focus on standardizing Error Recovery protocols to reduce the variance in user experience and push the T2B score toward the levels seen in the Accessibility dimension.

The presented approach to survey data analysis is an important tool for understanding student satisfaction with the digital educational platform. Analyzing the distribution of responses to various platform elements allows us to identify which elements already achieve high levels of satisfaction and where improvements are needed.

Furthermore, continuous monitoring of student satisfaction allows us to identify trends and changes in student ratings over time. This enables us to quickly respond to student needs and implement improvements to the platform, ensuring an optimal educational environment for learning and development.

However, it should be noted that the data obtained primarily reflects student satisfaction with the interface and usability of the web platform. Currently, these results are not interpreted as evidence of improved learning quality. To assess educational effectiveness, further analysis of the results of learning tasks, knowledge dynamics before and after using the platform, and comparison with groups that studied without the immersive environment are necessary.

4.2. Immersive Experience Assessment (Digital Twin and VR Lab)

The second stage of the experiment focused on exploring the educational potential of a digital twin for studying rotational dynamics in the Physics discipline. The study followed the logic of pilot evaluation pedagogical design, integrating the virtual environment into the existing curriculum.

For the experiment, a virtual laboratory task was developed to determine the moment of inertia of a sphere. The environment was created in Unity 6 using the XR Interaction Toolkit library, which enables precise user interaction with objects via the Meta Quest 3 headset controllers.

Attention was paid to the realism of the environment: the virtual classroom was modeled as an exact 3D replica of an actual IITU educational laboratory. Reproducing the familiar geometry of the room, the arrangement of tables, and equipment facilitated students' cognitive adaptation to the VR space, making the immersion process more natural. The central element of the digital twin was an interactive experimental setup. It included a laboratory stand, an arc-shaped chute, a ball, measuring instruments, and a horizontal surface for recording the impact point. The pedagogical experiment included the following steps:

1. Diagnostic Stage (Pre-test): Establishing a basic understanding of the concepts of rotational dynamics, the physical meaning of the moment of inertia, and the dependence of the moment of inertia on mass distribution.
2. Instruction and Adaptation: A brief introduction to the mechanics of using Meta Quest 3 avatars and controllers.
3. Immersive Practice (Activity-Based Learning): Students interacted with the setup, intuitively launching a ball down a chute. The experiment demonstrated the conversion of potential energy into kinetic energy of translational and rotational motion. By measuring the flight range using a virtual ruler, the students calculated the ball's velocity and its moment of inertia.
4. Analysis and Reflection: Processing experimental data and comparing them with theoretical calculations previously studied on the web platform.

The use of a digital twin provided students with a number of undeniable advantages. First, the immersive environment allowed them to visualize hidden physical processes—the ball's trajectory and energy distribution. Second, the ability to repeat the experiment multiple times with varying initial parameters (without risking equipment damage) can facilitate the development of a research approach and a better understanding of the relationship between mathematical formulas and the observed experimental dynamics. However,

further quantitative data, including a comparison of learning outcomes before and after using the VR lab, is needed to confirm this effect.

The final survey following the VR experience confirmed a high level of student engagement, which was also supported by respondents' responses to the question about their willingness to perform other VR labs (Figure 5). Subjective perceptions showed that the integration of immersive technologies in the metauniversity format makes a complex physics experiment more visual, interactive, and cognitively accessible.

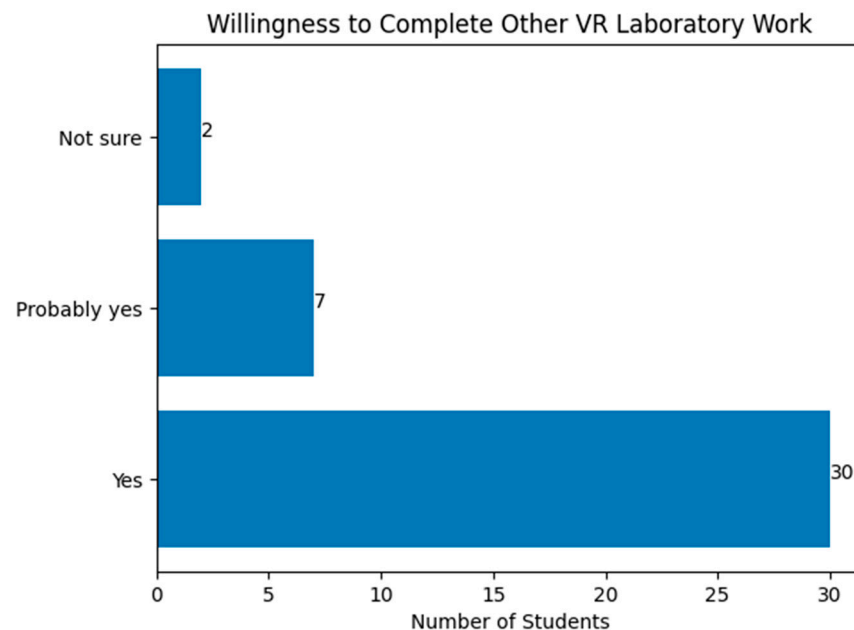


Figure 5. Readiness to perform VR laboratory work on other topics.

5. Limitations

Despite the successful technical implementation and positive results of the initial testing of the developed hybrid educational ecosystem, this study has a number of objective limitations. At this stage, the full-scale effectiveness of the platform has not yet been reliably statistically confirmed, which requires consideration when interpreting the data obtained and planning the project's scaling.

1. Unconfirmed pedagogical effectiveness

The test conducted was pilot-scale (on a local sample of 38 students) and primarily assessed usability, technical stability, and subjective user satisfaction (based on survey results). This stage does not allow for definitive conclusions about the long-term pedagogical effectiveness of the system (its impact on final GPA, level of retained knowledge, and rate of competency development). To objectively confirm its educational effectiveness, longitudinal quasi-experimental studies are required, identifying control (traditional learning) and experimental (work in a digital twin) groups. Additionally, it is necessary to distinguish between several types of outcomes: usability, engagement, cognitive load, and learning gain. Positive student feedback and a high willingness to use VR labs in the future confirm interest and subjective engagement, but in themselves do not directly demonstrate sustainable knowledge gains or the development of engineering competencies.

2. Infrastructure limitations of data exchange

The implemented mechanism for automated performance and attendance monitoring between the VR lab and the web platform is critically dependent on the quality of the network connection. In the event of short-term interruptions in the wireless connection,

there is a risk of telemetry packet loss. This may lead to inaccurate recording of student attendance time or a failure in the automatic transmission of the final grade, which currently requires manual moderation of data by the instructor in the platform's electronic journal.

3. Hardware and physiological limitations

Full functionality of the immersive level requires specialized equipment (a Meta Quest 3-class virtual reality headset). This creates an economic barrier to the widespread adoption of this technology at the university. Furthermore, active telemetry tracking in a 3D environment can cause symptoms of visual fatigue and cybersickness in some users, imposing strict time limits on the duration of a single virtual lab session.

4. Limitations of visual representation

The strategic choice of stylized, primitive avatars addressed the challenges of social security and ensuring high system performance when simultaneously connecting a group of students. However, simplified geometry deprives users of the ability to convey complex facial microexpressions. This may limit empathic interaction and nonverbal engagement when completing complex team projects.

Further research will be aimed at overcoming these barriers. Priority tasks include organizing a large-scale pedagogical experiment to statistically validate the system's effectiveness, developing algorithms for local data caching in the VR headset to protect against connection interruptions, and expanding the pool of virtual lab assignments for other engineering disciplines.

6. Discussion & Conclusions

The results obtained should be considered as data from the initial testing of a hybrid educational ecosystem. At this stage, the work demonstrates the technical feasibility of the chosen approach and the positive student perception of the platform. However, the presented data should not be interpreted as definitive proof of the system's pedagogical effectiveness.

The development of a proprietary digital educational platform represents a strategic and modern solution that facilitates the future development of the metauniversity concept. The use of digital technologies and innovative approaches in education through a proprietary educational platform contributes to improving the quality of education. Therefore, it can be assumed that these factors create a good educational environment, contributing to the expansion of educational space and improving educational process in general. Overall, the development of a university's own digital educational platform is an important step in the development of modern education.

Based on the analysis and results obtained, it is observed that the integration of digital platforms into the educational process makes it more adaptable and accessible to a wider range of students. Close attention should be paid to further adapting educational programs to the specific needs of engineering disciplines, given the rapid evolution of knowledge and technologies in this field. Investment in the development of digital educational platforms is essential for training qualified specialists.

In conclusion, the article highlights the need for further research on the integration of digital technologies into the educational process. Such research will help better understand how digital platforms can be adapted to meet the needs of students and faculty in various educational contexts, thereby improving the quality and accessibility of education.

The scientific novelty of this work lies in the development and initial testing of a hybrid metauniversity architecture that integrates an LMS-like web platform, an immersive digital twin of the campus, VR labs, and API mechanisms for synchronizing learning activities. Unlike traditional LMSs, the proposed system is focused not only on stor-

ing and delivering educational content but also on developing practical experience in an immersive environment.

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