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On Integrating Mixed Reality within University Curricula

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Abstract: *The paper describes the architecture and implementation of an experimental framework based on a software platform for enhancing practical and theoretical learning capacities among students in different fields of specialisation by using mixed reality. This platform allows students' effective interaction with a set of experimental models in two ways: by using interactive augmented reality based mobile applications or by using complete immersion. A case study on using this platform within a target group of students from University of Bacău, Romania is provided and some implications of this teaching approach are analysed. The results have empirically proved that using a learning environment based on mixed reality in teaching improves participatory culture, technical knowledge, and learning satisfaction degree of students. This study also emphasises the need for improvements in the integration of this framework to ensure that the technology's use is not limited to specific courses or user groups.*

Keywords: *mixed reality; augmented reality; virtual reality; university curricula; web 2.0.*

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1. Introduction – The current state of adopting mixed reality within university curricula

Mixed Reality (MR), encompassing both Augmented Reality (AR) and Virtual Reality (VR), has emerged as a transformative technology in education, especially in the post-Covid period as a teaching system adaptation by shifting the learning paradigm towards online education. MR apps in various areas of knowledge offer new learning experiences: Google Expeditions permits educators to take students on virtual field trips to historical sites, museums, and natural wonders, HoloAnatomy allows students to explore interactive 3D models of the human body, virtually dissect bodies, and practice surgical procedures in a safe and controlled environment, MondlyAR facilitates language learning by engaging students in interactive conversations with virtual characters, Wonderbook brings literature to life by immersing students in interactive narratives, Tilt Brush allows art students to create spatial artworks (Capsule Sight, 2023) . By blending real and virtual worlds, MR offers an immersive and interactive "metaverse" teaching environment and learning experiences that can enhance student engagement and understanding (Chang, Kuo, & Du, 2023). The integration of MR technologies into university curricula has gained significant attention in recent years. Tseng et al. (2021) conducted a systematic literature review on MR's integration in teaching and learning, covering the decade from 2011 to 2021. Their analysis revealed that MR is predominantly used in fields such as health and wellbeing, science, and engineering, where it enhances teaching, and practical training and helps students visualise abstract concepts usually by simulation experiences during the educational process. In terms of the effectiveness of MR-based teaching techniques, Banjar et al. (2023) performed a systematic review of experimental studies on MR's effectiveness between 2017 and 2021. Their findings indicated that MR technologies significantly enhance learning experiences, particularly in medical and health sciences, and engineering education, facilitate a better understanding of complex 3D structures, and improve procedural learning.

This paper is organised as follows: section 2 presents some benefits and challenges of using mixed reality in educational systems, and highlights various recent case studies on adopting MR within university curricula. Section 3 describes the MR framework developed as technological support for adopting MR at "Vasile Alecsandri" University of Bacau in Romania. The case study on integrating MR at the above-mentioned university is presented in section 4, and the results and discussions are detailed in section 5. The last section concludes the paper.

The next section discusses the benefits and challenges associated with MR adoption in learning environments and highlights recent case studies on MR implementation in university curricula.

2. Benefits and challenges of integrating MR in university curricula. Recent case studies

The benefits of Mixed Reality in Education include enhanced engagement and motivation since MR technologies can make learning more engaging by providing interactive and immersive experiences. Studies have shown that students are more motivated and attentive when using MR tools in their learning processes (Wang et al., 2024). Also, MR facilitates an improved understanding and retention as it allows students to visualise complex concepts and interact with 3D models (Chandran et al., 2024). MR enhances spatial reasoning for 3D modelling and situational judgement in manufacturing processes (Krüger, Palzer, & Bodemer, 2022). For example, the implementation of AR in mathematics education generally leads to positive learning outcomes, and students using AR tools showed improved understanding and retention of mathematical concepts, particularly in geometry and spatial reasoning (Bulut & Borromeo Ferri, 2023). MR can offer personalised learning experiences tailored to individual student needs, allowing for differentiated instruction and self-paced learning (Wang et al., 2024).

In recent years many universities have explored and adopted VR or AR in various specialisation areas. The following non-exhaustive list of case studies presents some of them (place, domain, and their key findings).

Stanford University - Medical Training. This case study examined the use of VR in medical training, particularly in surgical simulations. The study reported significant improvements in students' practical skills and confidence levels (Smith & Lee, 2024).

University of Melbourne - Architectural Design. The study focused on the integration of AR in architectural design courses. Students were able to visualise and interact with 3D models of their designs, leading to a deeper understanding of spatial relationships and design principles (Brown & Green, 2024).

Dresden University of Technology - Co-located MR classrooms. This study involved four professors and their students using headset-based MR for immersive lectures. The findings highlighted the potential of MR for collaborative learning and spatial thinking, while also identifying key challenges in adoption (Chandran et al., 2024).

Shanghai University for Science and Technology - mechanical assembly. This case study explored the use of MR in graduate education for mechanical assembly courses. The study found that MR enhanced student motivation and learning outcomes, although challenges such as device limitations were noted. (Wang et al., 2024).

Despite the promising benefits, integrating MR into university curricula is not without challenges. The implementation of MR technologies requires significant technical infrastructure, including high-performance hardware and reliable internet connectivity. High implementation costs can be prohibitive for some institutions, limiting widespread adoption. At the "Vasile Alecsandri" University of Bacau, hardware equipment for the MR laboratory consists of Hololens2, HTC Vive Pro, (10 headsets each type), Class VR Premium 64GB (6 headsets), and Asus D700ME (30 workstations). The investment effort was about 128000 euros, a large amount, at least for a medium-sized university in Romania.

Also, technical difficulties have been identified, which require professionals and the need for specialised training for educators and ongoing support to effectively integrate MR into their teaching practices (Ispir, Yildiz, & Ercoskun, 2024). Only 2.5% of teaching and researching staff is able to use MR software/hardware, at "Vasile Alecsandri" University of Bacau, but courses on the use of mixed reality technologies by the academic staff will be held in the near future.

Future research should focus on addressing these challenges and exploring innovative pedagogical practices to maximise the potential of MR in education. The following section describes the MR framework developed as technological support for adopting MR-based learning courses and laboratories at "Vasile Alecsandri" University of Bacau in Romania.

3. MR framework and its integration within "Vasile Alecsandri University" of Bacau curricula

The framework developed at "Vasile Alecsandri" University of Bacau during the 2022-2024 academic years aims to continuously adopt MR-based modern learning technologies within university curricula. A wide range of specialisations were the beneficiaries: engineering (mainly industrial engineering), computer science, communication and foreign languages, and physical therapy. For each specialisation, a specific set of concepts, theories, or models were chosen for at least one specific course. After analysing the contents and identifying the elements that will be translated into mixed reality, the next step was the design and development phase. As a result, VR/AR modules were developed accordingly, and integrated within a software platform, named UB AR – (logo marked in Figure 1).

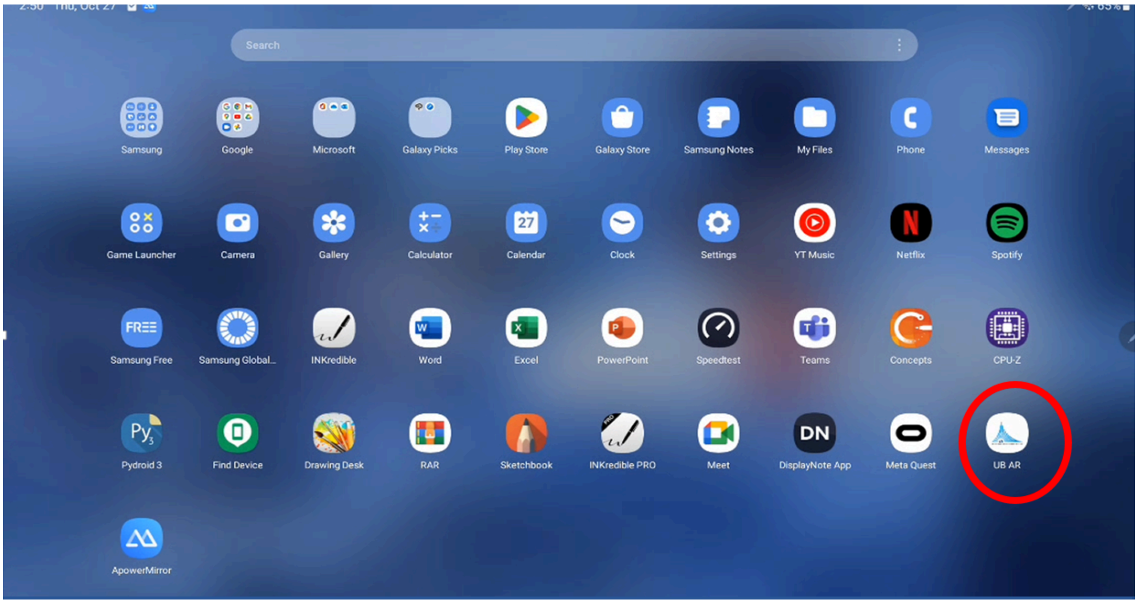

Figure 1. Tablet view with the UBAR app logo (red circle).

The platform's purpose is to provide interactive support through the use of augmented/virtual reality in learning specific concepts, through the design and animation of models. Figure 2 shows the app interface for placing mechanics and mechatronics models (engineering) in a laboratory-type room.

Figure 2. App interface (left side: models menus, right side: component analysis of the ensemble menus)

The app facilitates the internal spatial exploration of the models, which can be rotated around any axis, visualised from any angle (bottom left menu), inside and outside, both statically and dynamically. Models/assemblies can be visually exploded and reassembled by decomposing and reassembling them into components. Figure 3 shows a reduction assembly placed on a previously identified flat surface.

Figure 3. A reduction assembly placed on a flat surface.

By dragging, the model could be moved. Zooming it in and out is done by pinching. Rotating the model around any axis is done by moving the corresponding color slider from the bottom left menu. The model can thus be inspected from any position, inside or outside, zoomed or rotated while running. The bottom right INFO menu allows playing real model movies to keep track of reality (Figure 4).

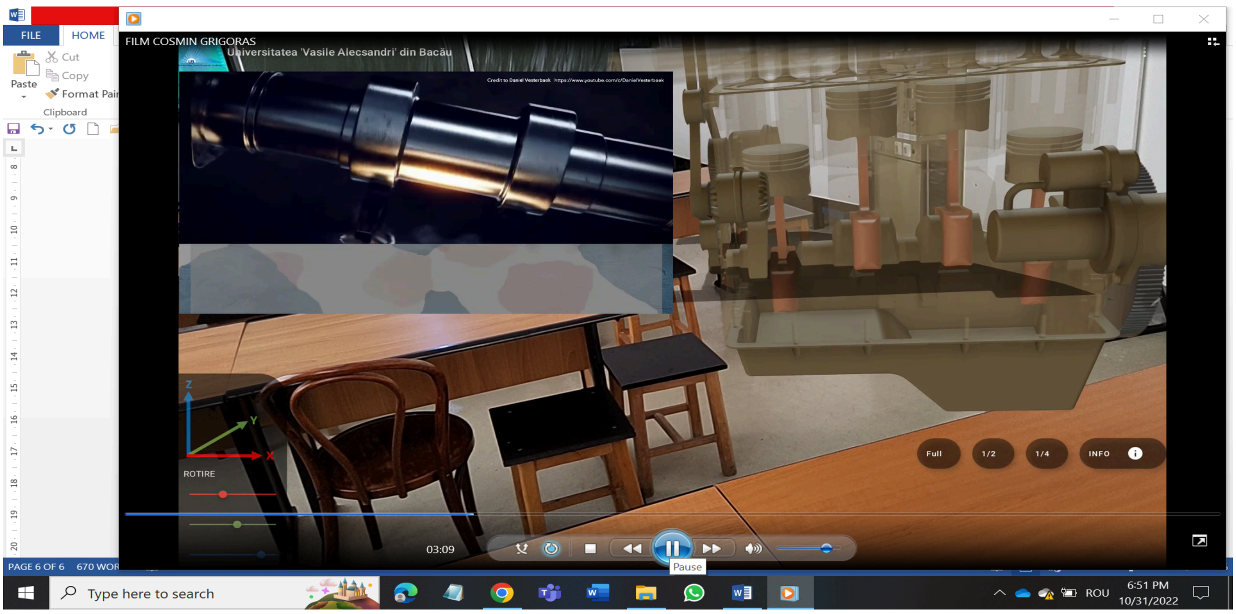

Figure 4. INFO menu – play the real movie on ½ of the screen.

Similarly, specific models were developed for the other specialisations. In physical therapy, for example, the model of the human body with muscle tissue in VR is presented in Figure 5.

Figure 5. Human body with muscle tissue in VR.

In virtual reality, scenes were created, and models that can be manipulated and visualised. We exemplify the same motor–reduction assembly placed in a didactic laboratory-type room in VR. In the free areas of the stage, theoretical information or other explanatory materials in a format other than 3D (video, audio, and text) can be displayed usually on the side walls (Figure 6).

Figure 6. VR scene with motor assembly and additional theoretical information on sidewalls.

All the scenes and 3D modelling were developed at Bacau University (Solidworks 2023, Catia, Blender, Simlab VR, etc), as well as all VR/AR-based apps. Installation and running requirements: 301 MB disk space, 4GB RAM, and a system with a video camera. The application is optimised for 8 inches plus screens, in landscape mode. Optimal system: 8GB RAM, 4GB video card.

4. Investigation method. Objectives of the case study

We conducted an instrumental case study to determine students' experiences by using the newly MR-based platform and to evaluate the potential implications of such an environment for the courses of the specialisations involved. The main questions addressed in the study were:

1) What skills do graduate students acquire from the information provided in the virtual-physical integration framework?

2) Does knowledge acquired in a stimulating way increase students' confidence and self-efficacy?

Special attention was paid to how the use of MR applications enhances positive feedback on learning confidence and how these new learning experiences compare to other practical activities of students.

The experimental design involved each student free to use an MR-based application on a specific course during three months of the last 2023 semester, without the intervention of the supervising teacher, at their own pace. At any time, the student could interrupt or resume the experience. For example using the skeletal muscle model in physical therapy: virtual muscle extraction and reinsertion allows students to identify how certain pressure zones or movements could impact body areas in therapeutic massage.

Table 1 highlights the connection between this pedagogical experiment, the courses involved at each specialisation, and the main practical skills sought to be formed. Further psychological and pedagogical research should be undertaken to reveal the level and the process of acquirement of these skills.

Table 1. Courses in which MR based teaching was used and the expected skills to be formed.

Specialisation	Course	Skills
Engineering	Mechanics	Decomposition of assemblies into subassemblies
Communication and foreign languages	English writing techniques	Writing (public relations) materials
Computer science	Computer networks	Creation of network architecture, and troubleshooting
Physical therapy	Methods and techniques of neuromotor reeducation	Manual techniques activities for balance and core control

A survey using quantitative data collection methods was performed in our case study. The Target group consisted of 60 students (15 students from 4 specialisations) in their bachelor's second year, enrolled at the “Vasile Alecsandri” University of Bacau. For each specialisation, different types of headsets were used during a specific three months course (March to May) taught in the last semester of 2023. Data on the impact of using MR-based software on students' learning skills and motivation was collected through the questionpro.com online tool (STAR), at the end of each session. All students involved were asked to rate their experience, in using MR headsets on a 5-5-point Likert scale, ranging from 1 (no impact) to 5 (strongly agree). Table 2 presents a set of questions the students should answer organised into three categories: engagement (MR-based activities), design (apps, hardware), and learning (personal outcomes).

Table 2. Online survey questions

Category	Online survey question
Engagement	How engaging did you find the mixed reality apps compared to traditional learning methods? How often did you feel motivated to participate in learning activities when using mixed reality apps?
Software and hardware design	How user-friendly did you find the interface of the mixed reality apps? At the beginning how comfortable were you with using <device name> headset?
Learning	How much do you agree with the following statement? "Using mixed reality apps has improved my understanding of the subject matter."

The data was voluntarily and anonymously collected from students.

5. Results and discussion

Second-year bachelor students in computer science and engineering have a relatively shorter learning curve in becoming familiar with the headset and quickly shift to exploring. Subsequently, they could lose interest and focus if the content is not challenging enough. On the other hand, second-year bachelor students from letters and physical therapy have a slower adaptation to the headset's use but their motivation or interest in learning is stronger. This suggests that bachelor students' engagement with the MR environment could be impacted by their digital literacy. Thus, assessing the students' digital literacy could be an important parameter to determine the MR-based technologies acceptance rate among students.

From the total of 60 independent online surveys, only 56 were considered (4 surveys with conflicting answers were invalidated). Related to the students' level of motivation along their MR experiences compared to traditional learning: 80% of participants strongly agreed, while 6% indicated that their motivation had not changed or only slightly changed. 77% of students felt comfortable or very comfortable, while 8% still felt uncomfortable or slightly uncomfortable. Also, 69.5% of students strongly agreed that MR learning experiences enhanced their understanding of the subject matter, while 9% of students reported no or only slight changes.

Almost all second-year bachelor students (95%) indicated that MR learning activities were important to them, and 90% strongly agreed that MR-based courses and laboratories would be helpful for their future academic performance. The remaining students held a neutral stance.

6. Conclusions

The paper presents and analyses a case study of adopting mixed reality within university curricula at "Vasile Alecsandri" University of Bacau. Second-year bachelor students from four specialisations were involved for three months: engineering, computer science, communication and foreign languages, and physical therapy. They used MR-based apps in learning activities, apps tailored for each specialisation. A survey was conducted to assess the impact: most of the students considered this framework could substantially positively contribute to their professional future.

Because of the sample's small size in the survey, the interpretation of the results is limited and cannot be generalised. However, it provides initial information on second-year bachelor students' perceptions regarding the use of MR-based activities over three months. The survey showed even an enthusiastic acceptance of MR technologies from the students, possibly since these modern ways of digital learning are still in their infancy in Romania. However, second-year bachelor students considered MR apps a useful tool to learn and gain knowledge.

Further investigation should be done to analyse for each specialisation both strengths, weaknesses, and opportunities of using such environment for teaching and learning.

In a future vertical approach to this study, students from the remaining years at the bachelor's level can also be included. The framework can be replicated, for starters, at the same specialisations, eventually by adding new MR courses. This fact, however, requires both human and financial resources for the creation or acquisition of didactic material dedicated to mixed reality.

This framework should be adopted further as an efficient communication model, easy to replicate for various other disciplines. A horizontal extension of the study can include the rest of the specialisations at the university level but at least logistical, schedule and qualified personnel restrictions must also be considered.

Scaling this framework to a higher adoption rate within other universities can be obtained by disseminating this case study's results in the form of a good practice manual, with examples based on previously tested learning experiences. It could be either in paper format or as an online repository for universities interested in initiating or expanding the use of mixed reality-based technologies in their curricula. The initiation of recurring scientific or practical sessions events dedicated to the use of mixed reality technologies within universities could also be an experience gain at international level.

Shifting the learning paradigm towards mixed reality-based apps could lead to an overall better management of the student's educational process. Still, the main problems in such an adoption remain the development of 3D content, MR apps, and high infrastructure costs.

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