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Extended Reality, Augmented Users, and Design Implications for Virtual Learning Environments

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Abstract—Recently, new technologies have been developed that allow physical and virtual space to converge. We reviewed a range of innovative technologies that enable immersive and 3D interaction, which we believe are of particular interest to apply Universal Design for Learning (UDL) principles in teaching and learning practices, with a particular interest in higher education. We found limitations related to hardware and interactive systems that cannot be customised to meet the needs of all different students and some users may be marginalised. We draw attention to problems that lead to the risk of intentional exclusion while highlighting relevant inclusion opportunities. The main contribution of this paper is to present a selection of use cases to discuss how software applications can be designed to meet the guidelines for UDL, and improve the accessibility of 3D interaction for innovative Virtual Learning Environments (VLEs).

Index Terms—Virtual learning environments, Universal Design for Learning - UDL, 3D interaction, accessibility, virtual reality - VR, augmented reality - AR, extended reality - XR

I. INTRODUCTION

The emergence of depth cameras, sensing technologies, and wearable controllers for Augmented and Virtual Reality (AR/VR) applications create exciting opportunities for education and training, exploring multiple senses and modalities in the way users produce, share, and access information. Extending Virtual Learning Environments (VLEs), students will be able to visit places, explore resources, build knowledge, and collaborate remotely, without the need to travel to physical locations. For example, 3D technologies have been used to create a digital restoration of historical environments [1], [2], learning foreign languages [3], human body anatomy [4], [5] and others. We are interested in studying how these immersive technologies can be used to meet the guidelines for Universal Design for Learning (UDL): Engagement, representation, and action & expression [6]. The limitations on hardware and software applications for immersive and 3D interaction may result in difficulties for educators in creating educational

content, and also have an impact on students with particular skills or special needs, at risk of being unintentionally excluded. Remote teaching and learning (T&L) activities, in particular those involving multitasking, could easily be linked to remote work considerations and its many challenges in maintaining productivity and a positive work-life balance [7]. Some changes have been beneficial to students, with the benefits of self-paced progression and the availability of materials. However, many students found it challenging to adapt to this new setting, without adequate support, lack of personal guidance, and issues related to the affordability and accessibility of technology. There is a need to train future professionals in the design and development of immersive and 3D interactive technologies [8]. The first step would be to assess students' needs and leverage existing technologies by applying a user-centered approach to innovative learning environments. We would like to draw attention to the potential implications of AR/VR and their future functionalities on the accessibility of educational content. We will embed this in the context of the United Nations' Sustainable Development Goals (SDGs) [9].

II. OBJECTIVES

The aims of this paper are:

- review a range of hardware innovations that enable immersive and 3D interaction, highlighting the benefits and risks of their integration with VLEs
- discuss how hardware and software can be used to improve 3D interaction and support students' needs
- identify gaps and applications where AR/VR technologies have been used for educational content

The main contribution of this paper is to provide recommendations for future studies, outlining challenges to be addressed for future integration of AR/VR with VLEs aiming at UDL in higher education.

III. METHODOLOGY

We searched the literature and present a selection of studies evaluating technologies for 3D interaction and relevant definitions for their application to VLEs. Rather than a comprehensive literature review, this paper aims to identify gaps and point directions for future studies.

The remainder of the paper is organised as follows. First, we present three use cases illustrating different approaches for AR/VR and educational content (Section IV). These studies were selected referring to the three key principles of UDL:

- *Multiple means of engagement*, the "why" of learning is presented in the first principle of the UDL framework, which offers adaptable alternatives to attract, inspire interest in, persevere with, and enjoy learning [10].
- *Multiple means of representation*, highlights the importance of adaptable information display techniques to make the "what" or content of learning accessible to all students.
- *Multiple means of action & expression*, deals with the "how" of learning and the strategies that can be employed to give students a variety of ways to express themselves, organise their thoughts, and monitor their progress.

The analysis of the use cases helps us to reflect on different modalities of interaction, factors affecting student experience, and assessment of learning outcomes. Then we present an overview of hardware enabling 3D interactions, their potential for integration with VLEs and T&L settings, and their limitations (Section V), followed by a discussion on how software applications can be designed to overcome these limitations (Section VI). After discussing the results (Section VII), we conclude with recommendations for future studies (Section VII).

IV. USE CASES AND EXAMPLES IN T&L APPLICATIONS

A. Engagement: AR/VR and mixed reality for health care student education

A systematic review reported the educational role of immersive technology for healthcare students at the university level [4]. Results of the analysis of 29 full papers, representing medical, midwifery, and nursing students, showed that immersive technologies were used in T&L practices for disciplines such as anatomy, neurology, and dermatology, as well as clinical and communication skills. Reports on the student experience and learning assessments show the benefits of interactive technologies for the visualization of complex body processes. Authors also comment on the use of virtual patients, helping students to learn clinical skills and enabling repeated practice [4]. However, the authors raised concerns about the different methods of evaluating the quality of learning experience and learning outcomes. Multi-dimensional learning tools were developed to study students' engagement and long-term retention, during a randomized control trial comparing textbook style materials, 3D representation on a 2D display, and a Mixed Reality (MR) system, where 3D models were visualised with a VR headset [5]. The content

was a representation of human anatomy, and the participants were 52 medical students. A survey collected participants' perceptions of user experience and usability, while anatomy tests were designed to assess knowledge acquisition and long-term retention after a period of one month.

The authors reflect on the novelty effect, which might have affected participants' engagement and knowledge acquisition, but results suggest that the potential of utilising multidimensional tools in anatomy education can be applied to different topics and disciplines. Other studies also show that student satisfaction, self-efficacy, and engagement can increase with the use of immersive technologies [4].

B. Representation: the example of AR/VR for narrative and landmarks

The I-Ulysses project was an immersive VR learning environment that pioneered the use of a combination of AR and VR (or eXtended Reality - XR) to address distance- and location-based learning issues. The platform uses immersive digital technologies and employs instrumental use of VR to enhance distance learning solutions [2]. The I-Ulysses environment is a tool for understanding the work of the Irish author James Joyce, which takes place in historical Dublin, where place and spatial immersion are key aspects of the story. An argument is made that, through recreating the actual physical 3D spaces of Dublin, a more authentic version of this story can be told and understood by students of the notorious book. For some examples of the UI of the I-Ulysses project, as shown in Figure 1.

Based on studies with seven sample groups, which included 57 college students, the environment was concluded to facilitate the players' understanding of the innovative storytelling techniques that Joyce employed in *Ulysses*, in particular, the use of an interactive map and the virtual representation of the city provided a good overview of the space of the book and the character. As a result, the gamification platform has an effective and intuitive UI that could be usefully extended to other multi-modal learning environments [2].

This example shows how students can benefit from multiple means of Representation, as the book, historical landmarks, and physical environment offer alternative visual and auditory information.

The authors have continued to expand on their study into an analysis of other post-Covid T&L methodologies [11].

C. Action & Expression: an example of VR for foreign language learning

The *Foreign Language Learning Simulation*, developed as part of an academic research project, aims to teach graduate students the topic of modal verbs and improve their pronunciation skills in English [3]. As part of the application, a VR environment was designed consisting of an airport (Figure 2 shows an example), a tourism agency, and a classroom. Standard VR glasses were used to allow students to participate in the study. The prepared activities were presented to the participants in different sessions for a total of 3 weeks. The

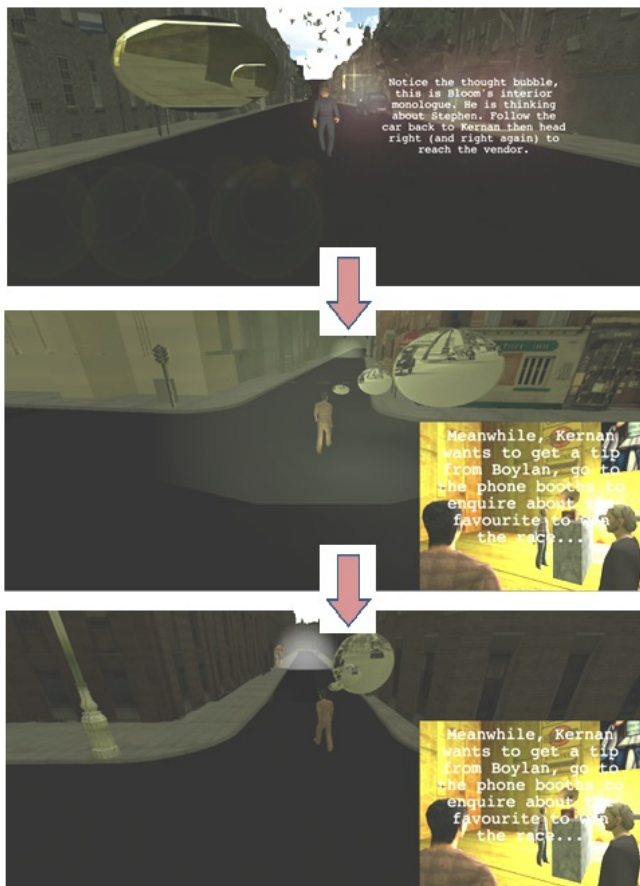


Fig. 1. *I-Ulysses: the Game*.

pilot application was carried out with 5 students and the main application with 42 graduate students. Participants completed each application within 20 to 40 minutes, depending on their performance.

After the three-week period, results showed that the VR application increased students' foreign language pronunciation success at a moderate level. A dependent group t-test was applied to the participants to assess "Foreign Language Speaking Anxiety" and "Negative Evaluation Anxiety" issues, consisting of pre-test and post-test. According to the data obtained, an increase was observed in anxiety levels after the application. Focus group interviews were conducted with participants to understand the reasons for the increase in anxiety levels. The general comment made about the reason for the increase in anxiety levels was the difficulty of the lesson topic, which caused them to struggle with adapting to the environment. Furthermore, the following factors were identified to have caused the increase in anxiety levels within the investigation.

- Personal factors: At the end of the process, the existence of a foreign language assessment test, fear of speaking a foreign language in a real environment, and lack of self-confidence have been identified as personal factors.
- Environmental factors: Fear of being heard by other peo-

ple while speaking in a foreign language and fear of being judged by others have been identified as environmental factors.

- Technological factors: The belief that language cannot be learned through technology, the fast speaking speed of the foreign language in the simulation, and the low number of repetitions in the simulation have been identified as technological factors.

It is important to consider these factors when designing T&L activities integrating AR/VR in VLEs, as lack of self-confidence, fear of judgment, and issues related to learning progress monitoring are common across many areas of knowledge. The effects of the use of different hardware have not yet been studied in this context. In addition, there is evidence that a more realistic VR environment could improve students' immersive experience and engagement, e.g. creating an immersive audio experience could enhance learning outcomes.

Although there were negative side effects such as high anxiety levels as a result of the application, the evaluation at the end of the application showed that learning took place. This shows that although technologies such as VR/AR are difficult to get used to at the beginning of educational processes and increase cognitive load, but they can support practice and performance, through action & expression in immersive VR environments, and they positively affect students' learning in the middle of the process as they get used to the technology.

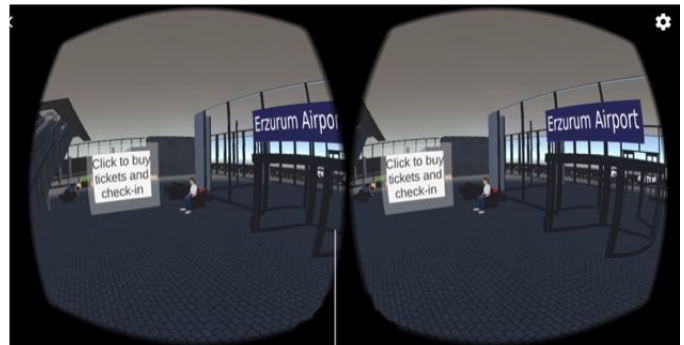


Fig. 2. Virtual reality airport simulation [3].

V. AR/VR EQUIPMENT FOR VLES

Very often, AR/VR is associated with individual users wearing VR headsets, perhaps interacting with people located remotely, perhaps observing an overlay of information on their physical space. This individual experience alone can seem inadequate compared to traditional educational settings, such as groups of students in a classroom. It is also interesting to note that VR seems to be the most popular technology in many fields, followed by AR [4].

In this section, we review a selection of technologies that can be used to contribute to an immersive experience and may be more suitable for some educational settings and learning activities. In the following subsections, we present the selected devices based on their main modality of interaction: visual,

audio, or other. This classification is used for clarification purposes only in this paper, allowing us to outline aspects of user interaction that can cause unintentional exclusion or create opportunities for further inclusion.

A. Visual output

Visual output for Augmented and Virtual Reality users is not limited to VR headsets. In addition to near-eye displays, head-up displays, and other approaches for holographic interaction are being developed. The emergence of depth cameras, e.g. Kinect and LidAR, together with improvements in image recognition algorithms, e.g. AI, are advancing the state-of-the-art in immersive technologies.

1) *Near-eye displays*: Near-eye displays include VR headsets and AR glasses [12]. For VR headsets, unintentional exclusion can be caused by discomfort during use due to weight, incorrect fitting, eye strain, motion sickness, battery life, and limitations of the wired device. Other issues include compatibility with glasses, head coverings, voluminous hair, and headgear (e.g. turbans). As the devices are usually large and opaque, they cover the eyes and expressions of people. This is not practical for use in learning settings where many students are physically present in the same space. For AR glasses, on the other hand, the see-through screen does not hide the user's eyes or expressions. Issues related to fit, eye strain, size, screen resolution, and latency remain to be resolved. As individual devices, these seem appropriate for students working remotely, rather than sharing the same space, in both synchronous and asynchronous activities. For head-worn devices, opportunities for improvements in design to enhance accessibility and inclusion include recent advances in high-resolution displays and rendering, built-in motion tracking, e.g. hand gestures, head-tracking, and eye-tracking, as well as the possibility of improving the fit and comfort with adjustable straps. Larger frames for eyeglass users, counterweights, and lighter materials also help improve user comfort. The benefits of individual devices include opportunities for customisation.

2) *Head-up displays*: These see-through displays are being developed for cars and cockpits, but can also be applied to signs, windows, etc. The risk of unintentional exclusion is related to limitations in screen size and resolution, latency issues, and compatibility with generic see-through glasses and windows. However, opportunities for improvement would ensure contact-free interaction with the advantage that no wearable devices were needed. It is expected that a see-through screen prevents motion sickness. Further improvements may be needed to ensure correct visualisation for multiple users.

3) *Volumetric displays*: This section refers to stereoscopic, volumetric, or 3D displays. Similar to Head-up displays, these devices do not involve wearables and can provide a better experience for multiple users present in the same room. Some examples include Google Starline projects [13] and Acer Spatialabs stereoscopic displays, shown in Figures 3 and 4. Currently developed and displayed for social interaction and marketing purposes, immersive experiences and detailed

representations would be welcomed in many activities, increasing students' focus and engagement in T&L activities. Some issues to be addressed include the accommodation of multiple points of view, to allow multi-user applications. Additionally, individual differences in depth and volume perception have been observed. Other criteria include access to depth cameras and appropriate software to generate content for volumetric displays. Currently, content should be explored for live-streaming videos, virtual objects, or digital twins, i.e., a digital representation of a real-world physical product or process.

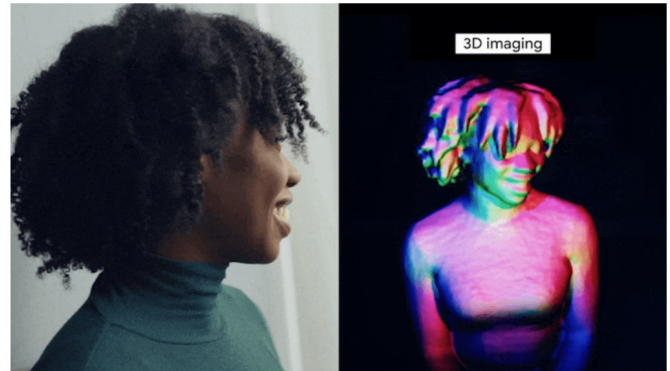


Fig. 3. Illustration of 3D imaging for telepresence system from Google Starline projects (partial screenshot from video demo) [14].

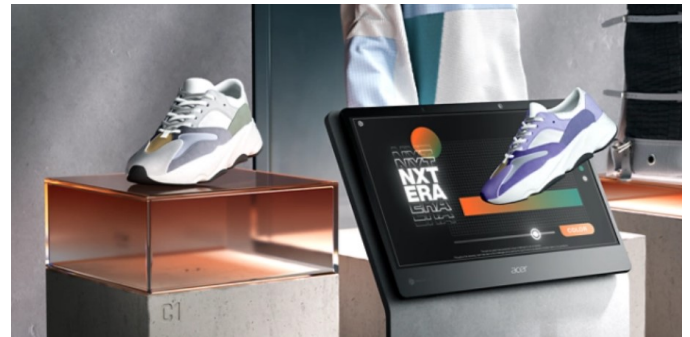


Fig. 4. Illustration of a 3D holographic display by Acer Spatial Labs, showing a trainer shoe and its 3D model [15].

4) *Other displays*: Desktop monitors and 2D screens can also be used to illustrate navigation in a 3D environment, usually associated with a controller, which can be a mouse or a joystick. Mobile devices such as smartphones and tablets are equipped with inertial sensors that also allow users to control and navigate in a VR environment [16]. These are easily accessible but require some familiarization with the navigation technique and may restrict users' perception of an immersive experience. On the other hand, settings such as interactive CAVE can be used by individuals or small groups of students. The projection in 360 degrees can facilitate an immersive experience for the users. However, installations are fixed and require enough physical space [17].

B. Audio output

Audio output for immersive interaction usually refers to VR headsets with built-in headphones, but there are other options. In this section, we distinguish hearables, i.e. head-worn devices for audio, and other immersive audio devices, such as speakers.

1) *Hearables*: This section refers to head-worn devices for audio output. These are currently available to be worn on, over, or around the ears. Issues include discomfort from use due to weight or incorrect fitting. Similarly to VR headsets, headphones should also be compatible with headgear, including head size, and accommodate the needs of users wearing hearing aid devices. Safety issues have been observed due to noise reduction or cancellation, which can present advantages in noisy environments but make these devices inappropriate for learning settings with multiple users [18]. The options of headphones through bone conduction allow open-ear listening, which can avoid some of the issues related to safety and social interaction. However, opportunities for better design and user experience include assisted listening functionalities, which could avoid stigmatisation around hearing aid devices. Many products are built with integrated microphones, head motion detection, and touch input. The possibility of pairing hearables with individual audio sources, physical or virtual, has great potential in extended VLEs for applications with reproduced or simulated spatial audio.

2) *Speakers*: This section refers to 3D Speakers, Line-array speakers. Unlike headworn devices, speakers provide immersive audio through ambient sound, facilitating access for users who are not comfortable with worn devices. This list includes speakers for desktop, laptop, or mobile devices, as well as a series of options for standalone or array speakers. The limitations of the use of ambient sound devices in T&L are lack of privacy. Multiple devices required fixed settings, and good audio configurations may require some expertise. Portable options are available with wired or wireless connections. The advantages and opportunities for inclusion are due to the fact that ambient sound devices are not personal or worn by the user, allowing for contact-free interaction. Spatial sound can provide a better-embodied experience and integrate existing ambient noise. For hearing aid users, audio sources can be paired and synchronised.

C. Sensory output and other modalities

While visual and audio technologies appear to be more widely accepted and have the potential to be adopted in extended VLEs, other interaction modalities need to be explored and evaluated further.

An example is haptics and motion controllers. Haptic gloves can pose size and fit problems for users with different hand sizes or hand spans. Dexterity, range of motion, or eventual deformations should be taken into account for the future design of haptics and VR gloves. Wearing gloves can cause restrictions on touch skills and mobility. Other options include haptic devices that use force feedback that is not worn but manipulated by users. Both can provide feedback through

vibrations, resistance (force), and range of motion. These devices have the potential to create a user experience with an augmented sense of dexterity, remote touch, and manipulation [19]. Haptic headphones are currently available in the market and can produce the sense of touch through vibrations, usually produced through audio output. The main advantage of audio and haptic devices is that they do not rely on vision as the main modality of interaction.

VI. OVERCOMING LIMITATIONS THROUGH SOFTWARE APPLICATIONS

When the hardware form factors (i.e. size and shapes) or the input/output modes restrict the ability of users to communicate and have access to information, software solutions and assistive technologies can be developed to help them overcome these barriers. The following examples have been selected to continue our discussion on the different interaction modalities available to users of VLEs. Although all the examples have not been developed specifically for T&L in higher education, they have the potential to be further explored in educational settings, facilitating learning activities or being adapted to assist students with special needs.

A. Visual aids

For users with hearing difficulties, seeing lip movements or total facial expressions can help them to overcome their disabilities. In a real-world setting, this can become problematic if face masks are used. A solution for this is a bespoke face mask for use in physical teaching spaces [20]. The technology embeds an LED matrix within a face mask to produce realistic mouth movements and emotional states through speech detection and intelligent processing. By cycling through different LED configurations, the user can make it so that students can easily see who is speaking. In addition to its value during the pandemic, it can also be of value for teaching, enabling students to read the lips of the speaker. This example could be further developed to add emotional expressions when the face or eyes are partially covered.

In a virtual setting, this can be transferred to avatars or interactive holograms, as illustrated in Figures 5 and 6, adding overlays of additional information for students. In T&L, they can help with the understanding of audio. Recent advances in image processing and smartphones equipped with LiDAR (Light Detection and Ranging) can now generate highly interactive volumetric videos [21].

B. Audio aids

Sound is a fundamental aspect of an immersive experience, directly related to the user's ability to concentrate, detect emotions, and create alertness. Many earphones are being developed as connected devices, controlled by smartphone applications, and capable of communicating with other smart appliances in a home. Advances in audio processing enable these devices to be used for hearing augmentation, and have the potential to provide real-time translation of multiple languages in the near future.



Fig. 5. Illustration of hand typing a physical keyboard and its 3D model by Logitech Bridge [22].



Fig. 6. Illustration of a volumetric representation by Volograms technology, part of the project Learnovate [23].

Sound can also replace visual content if necessary. A traditional example of this is screen readers, allowing blind users to follow written content. *Seeing VR* by Microsoft Research [24] offers visual and audio augmentations in VR environments, making them available to users with visual impairments. Some of the tools require input from developers, whereas others work with existing applications.

C. Multi-sensory aids

In general, different modalities can be used to compensate for the difficulties of users to interact in a particular way. An important foundation for this is embedding in the content. For example, captions can be embedded in videos using closed-caption formats. In VR and VLEs, standards for this are still lacking [25]. Software can partially compensate for that, e.g. by processing speech to generate text or patterns, but considering those aspects from early design phases is preferable [25]. As mentioned in the review of selected devices, the use of sensory or haptic interaction modalities can improve student participation when designed to address user needs and achieve learning outcomes [26]. They can either work

as an additional modality for all students or replace some modalities not available for users due to disability [19]. A combination of hardware and software solutions can help users overcome special needs. One example is the Canetroller by Microsoft Research, a device that uses white cane interactions, including physical resistance, vibrotactile feedback, and audio to simulate the experience of using a white cane in real world [19].

VII. DISCUSSION: INNOVATIVE VLEs AND UDL

As active learners, students should engage in different learning activities: during a lecture, lab, or tutorial, they will be invited to write, talk, reflect, take notes, draw, and code. VLEs facilitate access to the resources students need to progress toward their learning goals, and many systems support the instructor's role, gathering data on student participation and progress, managing access and prerequisites, uploading assignments, grading, and feedback. This way, VLEs with accessible content and technologies enable instructors to meet the UDL principles, i.e. representation, engagement, and action & expression. This can guarantee access to quality technical and vocational skills for a large panel of students (Sustainable Development Goal 4 - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, target 4.4 and 4.5 [27]).

The selected use cases illustrate examples of the potential of AR/VR applications in higher education. The examples show how immersive technology has been used in different areas of knowledge, such as languages, literature, and health care. The main contribution of this paper is to show that there is a large panel of existing technologies, not limited to VR headsets, that could support training for technical and vocational skills, and these should be designed and evaluated in line with UDL principles.

The COVID-19 pandemic has confirmed inequities in access to education, with difficult access to in-person training. In many countries, the result was an acceleration in the use and adoption of VLEs, enabling T&L performed remotely [11]. Educational material and resources might have been quickly adapted to a digital version without careful consideration of students' needs, which can cause unintentional exclusion of students due to cognitive, sensory, and physical skills, as well as personal, environmental, and technological factors. To support the principles of UDL, future research should focus in the short to medium term on providing a better understanding of the technology barriers currently in place for all students, including people with disabilities.

More research should be carried out to understand how students accept and use different supports available to them and the impact of VLEs on their student experience and learning outcomes. Both students and instructors are still facing the barriers of lack of interoperability, hardware dependency, and other contextual factors. Further research is needed to provide an evidence-based learning framework, that can be applied to educational games as well as to evaluate the benefits of an integration of AR/VR in VLEs.

Games can support UDL principles when designed to provide clear learning goals, allow monitoring of progress, encourage inquiry and questions, use scaffolding to keep users engaged, and personalization to tailor the experience to individual needs [8]. These, amongst other recommendations, should also be applied to ensure a better student experience and successful learning outcomes.

As the educational content is designed with students in mind, the extension of VLE should also reflect on the barriers and bridges created by new technologies. To align with the principles of UDL, format flexibility, accessibility guidelines, and system interoperability may be at the core of future developments. These aspects should be part of the design process from the very beginning to avoid the need for fixes later on. As with all software, VLEs can become outdated [28], and regular updates are needed to maintain the student experience. Such updates are easy to perform if a product is maintained and supported by a responsible party (which might be a commercial enterprise or an open-source community), but difficult with custom products. Therefore, the use of standard solutions is recommended where possible. Ideally, well-defined interfaces allow extending these where possible and still profit from a standard environment.

Finally, further studies need to be done to provide an evidence-based learning framework, assessing the impact of different technologies and extended VLEs in student experiences and learning outcomes, i.e. compared with traditional educational settings.

VIII. CONCLUSION

The present study contributes to global development in the context of education by providing an overview of the technologies available to support innovative VLE and discussing how these can be used to meet UDL principles. After reviewing use cases as examples of T&L practices supporting engagement, representation, and action & expression, we discussed the potential of immersive and 3D interactive technologies to improve access to educational resources, extend the capabilities of VLEs, and expand existing studies on the many applications of AR/VR for education. We presented a selection of devices and technologies, other than VR headsets, that could be used in T&L activities to improve student participation, in particular, providing a better immersive experience, manipulating 3D objects, supporting focus and attention, as well as task management and assessments. Based on our analysis, we provided recommendations for future work, which should focus on inclusive design for hardware and software, as well as empirical evaluation of the potential benefits of immersive technologies on student engagement and learning outcomes.

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