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# Immersive virtual reality learning environments for higher education: A student acceptance study

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ABSTRACT

The study investigates the integration of Virtual Reality Learning Environments (VRLEs) in academic teaching through the EU-funded "REVEALING" project. Researchers from Cyprus, Germany, Greece, Poland, and Portugal developed and evaluated five different immersive VRLEs, each focusing on diverse educational topics, including ancient Greek technology, sea urchin measurements, linear algebra, and historical expeditions. The study aims to determine effective instructional design principles for VRLEs and assess students' acceptance and learning outcomes.

The VRLEs were designed based on literature-derived principles that emphasise ease of tool usage, authentic experiences, and continuous feedback. Students from the participating universities explored these VR environments, providing feedback through a standardized questionnaire on aspects like immersion, ease of use, motivation, and emotions.

Results show that most participants positively engaged with the VRLEs, reporting high motivation and positive emotional responses, particularly for experiences involving interactivity. However, challenges like motion sickness and technical issues were noted, especially at one institution. The findings suggest that immersive VR experiences can significantly enhance motivation and engagement, but their effectiveness depends on careful alignment with pedagogical goals, design quality, and user experience considerations.

## 1. Introduction

The emergence of new technologies consistently prompts shifts in educational practices, potentially transforming pedagogical methods (Beck et al., 2024). Virtual reality (VR) serves as a pertinent example. Initially conceived in the 1960s with the creation of head-mounted displays, VR was predominantly utilised in military and industrial training contexts. By the late 1980s and early 1990s, technological advancements enabled its accessibility to the general population, allowing the entertainment industry to experiment with VR's potential for

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gaming and interactive experiences. Despite these developments, early iterations of VR remained hampered by cumbersome designs and insufficient performance capabilities, limiting their widespread adoption. It was not until the 2010s, with the introduction of user-friendly and high-performance devices like the Oculus Rift, HTC Vive, and PlayStation VR, that VR experienced significant growth. This evolution has unlocked numerous practical applications for VR, notably in the field of education, where its integration offers promising prospects for enhancing and diversifying learning experiences (Dzardanova & Kasapakis, 2022).

Currently, VR devices have become increasingly accessible and practical for educational use, characterised by lightweight designs, rapid response times, and wireless functionality. These advancements have expanded VR applications across diverse educational settings. For example, VR simulations are utilised in medical education to support students' understanding of surgical practices or anatomy, while virtual field trips provide students with immersive experiences of various environments or cultures. Furthermore, VR technologies have being applied in disciplines like physical sciences, engineering, and history, offering an interactive and immersive approach (Beck et al., 2020). As Donally (2018) highlights, VR's role in education could be transformative, enabling more engaging and experiential learning opportunities that motivate and inspire students.

Even though integration of VR into educational settings remains nascent, its potential to revolutionise teaching and learning methodologies is profound. For this transformation to be fully realised, it is imperative that educational strategies employing VR are grounded in a clear understanding of its capabilities and impacts (Beck et al., 2024). Research highlights VR's capacity to craft interactive and immersive learning experiences that enhance cognitive engagement, foster authentic learning opportunities, and promote improved retention and comprehension (Johnson & Nagel, 2016). Nevertheless, the application of VR in classrooms is not without criticism, as concerns about social disengagement, accessibility, and ergonomics have been raised. These challenges necessitate careful consideration to maximise the educational benefits of VR while mitigating potential drawbacks.

Virtual Reality Learning Environments (VRLEs) are rapidly gaining attention as a transformative tool in education, with a notable rise in both adoption rates and academic interest (Mystakidis et al., 2021). The appeal of immersive learning experiences is strong among users, largely driven by the motivational benefits provided by advanced VR technologies (Checa & Bustillo, 2023). Current research on VRLEs in educational contexts revolves around two essential problems: first, how VRLEs can be designed to effectively support learning, and second, what specific learning outcomes can be achieved under various conditions, such as differing technologies, learning environments, and pedagogical strategies. Resolving these problems is essential for the purposeful and effective use of VRLEs in educational practice.

Given the tight connection between technology use and educational actions, practices, and strategies, the EU-funded project "REVEALING"[1] explores these problems, focusing on how VRLEs with VR headsets can be employed in academic teaching. To this end, the project partners from Greece, Poland, Portugal, Cyprus, and Germany developed several virtual learning environments, seeking to combine them with pedagogical approaches and rationales. Thus, a manual for VR-powered lessons (Aufenanger et al., 2024) was created for these learning spaces, in which their instructional design and technical set-up are combined and described in detail. Empirical research was carried out to determine whether the developed instructional design principles were implemented adequately in these VRLEs and identify pathways for improvement. To this end, undergraduate students from the participating universities were asked to explore the application in small groups, under the supervision and observation of researchers. They were then asked to report their experiences in an online questionnaire. The results are presented below.

## 2. Theoretical background

The problem of how VRLEs need to be designed to stimulate learning can be considered from two perspectives.

- *Design*: Which key design factors can be characterised as conducive to learning?
- *Users*: How do participants react to the designed learning spaces and which aspects are accepted by them and which motivate them?

The aim of the mentioned project REVEALING is to combine both perspectives and draw conclusions for the use of VRLEs in academic teaching, following a specific procedure: a) analyze the literature and the state of current research on the design of VRLEs and their aspects that promote learning, b) design of VRLEs grounded on the results of the literature review and c) piloting study on the acceptance and evaluation of the developed VRLEs by university students. However, this article is limited to the way in which users perceive the learning spaces. Since – as will be shown – basic design elements apply to all VR rooms developed, the learning effects are quite different due to the different topics covered. For this reason, the respective learning effects are omitted in the presentation.

### 2.1. How to conduct instructional design of VRLEs

Tahiri et al. (2022) explores the integration of VR spaces in educational settings to enhance comprehension of spatial relationships in three-dimensional contexts. By amalgamating various virtual and physical tools within mathematics instruction, the authors suggest that students can reach their educational objectives through novel and expanded methodologies. The researchers based their design principles on the psychomotor domain (Atkinson, 2013), aiming to facilitate intuitive use of these tools for learners. These principles are elucidated with examples and contrasts drawn from existing systems in planar and spatial geometry, ensuring that the application is user-friendly and accessible for educational purposes. In their study, Tahiri et al. (2022) explains the main design principles for a VRLE derived from the individual stages of the psychomotor domain.

- *Low-threshold access through familiar design*: Tools should be intuitive and straightforward to use. A key approach is imitation, how design tools to resemble real-life counterparts that learners are already familiar with, making them immediately accessible.
- *Support for conceptual understanding*: The application should actively aid learners in grasping and internalizing concepts and terminology. This can be achieved through visual representations, guided explanations, or step-by-step breakdowns of the tools and processes involved.
- *Guided instructions for construction steps*: The application should provide clear, step-by-step instructions for each construction task, helping learners complete these tasks successfully and independently.
- *Authentic and consistent tool functionality*: The tools should operate in a way that feels authentic and consistent with real-world counterparts. This consistency minimizes potential confusion and frustration, allowing learners to focus more on learning.
- *Ongoing feedback within the VRLE*: To support learning and self-correction, the application should offer continuous feedback. This feedback could include visual cues, acoustic signals, or other interactive prompts that help learners track their progress and address any errors.

Hartmann and Bannert (2022) explored the conceptual foundations

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[1] https://revealing-project.eu/.

of immersive media and discussed their implications for future research in education. Immersive media are unique in their ability to represent spatial and episodic information, allowing for a comprehensive portrayal of both visual and verbal elements of a given situation. This enables learners to experience spatial-situational stimuli directly, without relying solely on mental visualization. With a range of design possibilities, immersive media can create interactive, problem-based, and authentic scenarios that support learners in grasping the context of relevant content more effectively and applying this understanding in new, unfamiliar situations. At the same time, integration of varied features, such as interactivity and authenticity, often results in a lack of experimental manipulation essential for isolating these elements' effects. Furthermore, understanding the role of spatial-situational imagination within immersive environments remains underexplored. It is crucial to determine the extent to which learners can mentally construct spatial information without direct visual input, as this capability could significantly influence the effectiveness of immersive learning tools.

Based on Hartmann and Bannert (2022) study, implications for teaching and learning practices can be encapsulated through the following critical questions.

- *Media Characteristics and Comparability*: What specific media features define VRLEs, and can the same content be effectively conveyed through "traditional" media? What are the fundamental distinctions in how each media type presents content?
- *Representation of Spatial-Situational Content and Mental Models*: What spatial-situational episodic information is conveyed in the VRLEs, and how do learners mentally conceptualize and internalize this content?
- *Modality of Semantic Information*: What supplementary semantic information is provided to learners, and in which modality (verbal or visual) is it presented?
- *Learning Objectives and Representational Coherence*: What are the educational goals of the VRLEs? How do the representations within the VRLEs interact, and to what extent do the spatial-situational and semantic information align coherently?

Zender et al. (2022) emphasise the importance of factoring in medical considerations for individuals with specific conditions such as eye disorders, epilepsy, developmental challenges, or autism spectrum disorders. Correspondingly, Kim, Kim, and Im (2019) highlights that symptoms of cyber and motion sickness in VR are akin to traditional seasickness, manifesting as dizziness, headaches, nausea, vomiting, and potential short-term visual impairment during or after VR exposure, as noted by Sharples et al. (2008). Furthermore, Munafo et al. (2017) suggest that women may be more vulnerable to these adverse effects than men.

In their extensive literature review on VRLEs, Beck et al. (2024) identified several strategies and practices. Using conceptual proximity and relatedness in their analysis, Beck et al. organized 45 strategies and 21 practices into 5 clusters: a) *Active Context*, b) *Collaboration*, c) *Engagement and Scaffolding*, d) *Presence*, and e) *Real and Virtual Multimedia Learning*. This clustering could be used as a descriptive framework (rather than a prescribed set of actions) for pedagogical sound interventions with VRLEs. Authors suggests that VR promises fulfilling ambitions of immersive learning, a sense of presence and engagement beyond traditional classrooms, collaboration and active learning, and multimedia learning strategies.

However, it is important to recognize that the effectiveness of VRLEs still remains subject to research and development, with challenges and limitations associated with implementing VR in educational contexts. Beck et al. (2024) note that there are several challenges and limitations in using VRLEs. For example, it can be challenging to evaluate the effectiveness of VRLEs and replicate successful outcomes because there's often no standard way to describe the educational methods that led to those results. The range of factors involved, like technology, administrative support, and teaching strategies, also makes it difficult to determine what works best when using VR in education. Other practical challenges include the need for specific technical skills and equipment, students feeling distracted or disoriented, and unequal access to VR technology, which can create gaps in learning opportunities among students.

Based on the previous studies, Aufenanger et al. (2024) summarized various opportunities and challenges for using VRLEs, as follows:

Opportunities with VRLEs.

- Multi-dimensional representation within virtual environments.
- Interactive engagement with 3D models.
- Building self-confidence and increasing familiarity with content.
- Enjoyment and engagement in the learning process.
- Opportunities for self-directed exploration.
- Access to emotional and cultural learning experiences.
- Enhanced logistics for simulations and lab activities.
- Ability to shift perspectives across different contexts or roles.
- Aiming for positive impacts on subjective outcomes like commitment, enjoyment, perceived usefulness, and learner motivation.

Challenges of VRLEs.

- High costs associated with equipment and content development.
- Technical challenges and system limitations.
- Risk of motion sickness and other adverse physical effects.
- Reduced opportunities for social interaction and collaboration.
- Limited transferability of skills from VR to real-world applications.
- Reduced situational awareness for instructors using VR in classroom settings.
- Challenges in implementing effective, grounded assessment methods.

### 2.2. Theoretical concept

For the REVEALING study, the design of the VRLEs was based on the instructional approach of Merrill (2002) and the learning theory of Bloom. Since the aspect of learning with VRLEs is left out in the following, the presentation is limited to the former. Merrill (2002) identifies five first principles of instruction: problem-centred learning, activation of prior knowledge, demonstration, application, and integration. These principles are common across various instructional design theories and models, aiming to enhance effective and efficient learning. Merrill's Principles of Instruction (Merrill, 2002) describe a pedagogical approach that aims to promote learning through various phases of instruction.

1. The first principle, problem-centred learning, emphasises that learning is particularly effective when students solve real-life problems. This is done by showing them the task or an example of it to give them a clear goal. They should be involved at the level of the problem or task, not just at the operational level. In addition, the problem should be approached in a step-by-step process, starting with simple tasks that become increasingly complex.
2. The second principle, activation, emphasises that learning is enhanced when previous experiences are incorporated. Students should be guided to remember, describe or apply relevant past experiences. New experiences should be designed to serve as a basis for further knowledge. It is also important to create a structure that helps to organise the new knowledge.
3. The third principle, demonstration, ensures that learning content is conveyed in an understandable way. This is done by consistently demonstrating tasks, procedures and examples. Media play a crucial role in this by supporting the teaching process. In addition, learners should be given targeted instruction.

4. The fourth principle, application of knowledge, states that learning is particularly effective when students apply their knowledge in a practical way. This includes consistent practice that promotes learning through practice. Teachers' support should be gradually reduced so that students can increasingly solve problems independently. It is also important that they are confronted with a variety of problems so that they can apply their skills in different contexts.
5. Finally, the fifth principle, integration, aims to transfer new knowledge into students' everyday lives. This can be encouraged by asking learners to publicly demonstrate their new knowledge or skill. Spaces for reflection should be created in which they can share, discuss and defend their knowledge. They should also be given the opportunity to get creative by exploring and developing new ways to use their knowledge or skills. These principles provide a comprehensive structure for designing effective learning and promoting the sustainable application of knowledge.

The principles established by Merrill are supplemented by the approach of Reinmann-Rothmeier and Mandl (2001), who elaborate the essential design principles of virtual learning environments, which, however, generally apply to all learning opportunities. They particularly emphasise the following factors, which should be considered when designing learning environments and thus also apply to VRLEs.

1. Authenticity and practical relevance: learning environments should be designed in such a way that they enable the processing of real problems. This includes authentic tasks that make the use of new media meaningful, such as searching for hard-to-access sources of information or working together in virtual groups.
2. Multiple contexts: To prevent knowledge from being fixed to a particular context, learning environments should embed content in different situations and view it from different angles. This promotes flexible knowledge that can be retrieved and further developed under different situational conditions.
3. Social learning arrangements: Social aspects play an important role in the learning process. Learning environments should promote social learning arrangements to support cooperative learning and problem solving and to foster the development of learning and practice communities.
4. Information and construction offerings: Suitable information offerings should be provided that can be used for the self-active construction of knowledge without overwhelming learners.
5. Instructional guidance and support: In addition to promoting the learners' own activity, instructional guidance and support is also necessary. This supports learners in completing complex tasks and promotes social interaction in virtual groups.

All the previous analysis of current research in VRLEs leads to the question: "*What are the relevant factors that significantly determine learning in VRLEs?*". To answer this, tools are needed to effectively measure attitudes, beliefs, behaviours or other characteristics of individuals or groups. Although there are already studies that have empirically investigated these factors, they have mostly worked with scales that were not validated or were limited to selected factors (Vorderer et al., 2004; Fu et al., 2009).

However, Fokides (2023) has developed a validated scale that measures a variety of factors that can be considered relevant to learning in immersive VRLEs. To this end, the relevant literature was analysed and the factors considered significant were taken up and combined. A total of 208 items were found, representing 15 dimensions. After analysing the dimensions several times regarding their relevance to the topic, the dimensions were reduced to 14 and the items to 64. The scale was tested on a sample of 462 students at a university in Greece using factor analysis and internal consistency. Finally, 43 items remained, representing the following dimensions (Fokides, 2023): 1) Perceived quality of the virtual environment's graphics, 2) Perceived cognitive load, 3) Perceived ease of use/control of the virtual environment, 4) Immersion/Presence, 5) Perceived feedback and content quality, 6) Perceived degree of interaction, 7) Motivation to learn and use the virtual environment, 8) Perceived usefulness/knowledge gains, 9) Simulator sickness, 10) Positive feelings, 11) Negative feelings.

## 3. Methodology

Based on the reported research results on the design of VRLEs, the REVEALING project delivered a manual in which the most important didactic and technical design principles for the design of immersive virtual spaces are summarized (Aufenanger et al., 2024). This in turn was used by the project's partners to design 4 VRLEs and then implement them for use with HMDs (Head Mounted Display) like the Oculus 2. The respective VRLEs were accessible to all participants via VRChat. They formed the basis for a joint study in which the acceptance of these VRLEs by students in four higher education institutions was to be analysed from various perspectives (Fokides, 2023). The aim of this study was to isolate the relevant factors that can be responsible for a learning outcome in VRLEs. Based on other studies, a scale of 27 items was developed to represent immersion effects, usability, interaction opportunities, feedback, motivation and positive impressions.

The following five research questions were developed for the study based on Fokides (2023) scale.

RQ1: *How do students experience VRLEs and how do they evaluate them?*
RQ2: *How did they experience immersion in the virtual space?*
RQ3: *How were they able to interact with the VRLEs and how did they receive feedback?*
RQ4: *Were there any problems in the virtual space?*
RQ5: *What did the experience trigger in them?*

Before the research design and the results are presented, the VRLEs developed in the REVEALING project are introduced.

### 3.1. Description of the developed VRLEs

Five different VRLEs have been developed (see Figs. 1–5). Each of the partners involved in the EU project had the task of developing a scene in a virtual space in which the mentioned design principles from Merrill and Reinmann-Rothmeier and Mandl were integrated (Aufenanger et al., 2024; Module 3).

However, not all the principles mentioned were suitable for designing the individual VRLEs. Since the target group was university students and the aim was not to develop knowledge and skills for everyday problems, the following principles of concepts proved to be less applicable: application of knowledge, integration, authenticity and practical relevance, and multiple contexts. The latter was not feasible due to technical limitations.

**Fig. 1.** Aeolipile.

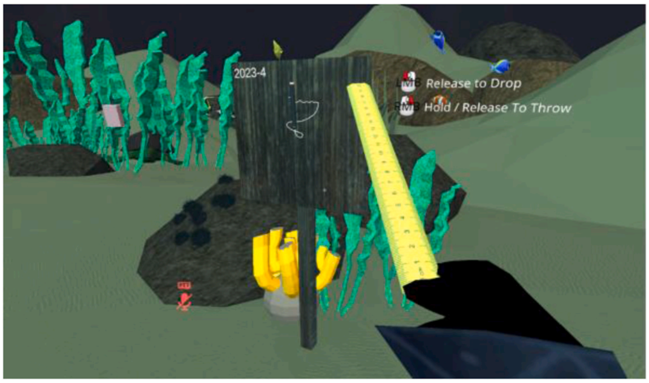

**Fig. 2.** Sea urchin measurement.

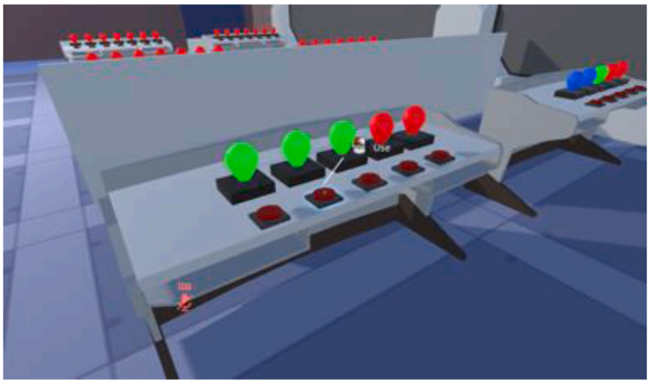

**Fig. 3.** Linear algebra.

**Fig. 4.** Chimborazo expedition.

The VRLE's are primarily outcomes of a transnational European project involving HEI departments on various disciplines and different cultures. In this context, it was decided to design accordingly the VRLE's to better represent each HEI's identity, mission and scientific orientation based on the expertise of the participating scientists. Even if the VRLE's are not context-neutral, they follow the same basic principles described before, omitting the principles mentioned: problem-centred learning, activation of prior knowledge, demonstration, authenticity and practical relevance, social learning arrangements, information and construction offerings, and instructional guidance and support.

Early sketches were then transformed into virtual scenarios using Blender and Unity, and uploaded to the VRChat online platform, rendering them accessible through VR headsets or a PC. What VRLEs have in common is that they all enable user interactivity, that objects can be used and utilised for tasks. Users actively engage with tasks and receive feedback for their solutions.

**Fig. 5.** Gallery visit.

a. Ancient Greek Technology

The Ancient Greek Technology scenario begins with a teacher-led slideshow introducing students to Pyrseia, an ancient Greek communication system that used torches to encode messages. The teacher explains how specific torch arrangements represented letters based on a predefined table and discusses the historical importance of this system in long-distance communication. Students watch the presentation on a large display while the teacher facilitates discussion and answers questions. After the presentation, students move to the virtual Pyrseia system, where they examine the predefined letter table. Under the teacher's guidance, they practice placing torches in designated positions on a wall to form letters. This activity helps them understand how ancient Greeks used Pyrseia to transmit information across great distances. Following this, students engage in a collaborative activity where they attempt to communicate using two Pyrseia systems placed at a distance from each other. Working together in groups, students experiment with encoding and decoding messages through torch placements, simulating real-world use of this ancient communication method. A teaching assistant is present to support the activity, ensuring students understand the process and can effectively participate in the exercise. Once students complete the Pyrseia activities, they transition to the Aeolipile (Heron's engine) demonstration. Guided by the teacher, they pick up virtual torches and ignite wood placed beneath the sphere. As the water inside heats up, steam is released, causing the sphere to rotate. The teacher explains the scientific principles behind this early steam-powered device, drawing comparisons to modern engineering advancements. The teacher describes the function of each component, allowing students to gain a deeper understanding of how the device operates. By the end of the scenario, students have explored both communication and mechanical innovations of ancient Greece through interactive and collaborative experiences, enhancing their understanding of historical technological advancements.

b. Sea Urchin Measurement

The Sea Urchins Measurement scenario begins with students watching a video inside the virtual environment. This video introduces them to the effects of rising sea temperatures on marine life, providing essential background information on climate change. The teacher facilitates a discussion, ensuring that students understand the significance of the experiment they are about to conduct. Guided by the teacher, students are then immersed in an underwater environment where they engage in scientific observation and data collection. They use virtual rulers, pens, and erasers to measure sea urchins during two different time periods, 2023 and 2100. The teacher supervises the process, helping students accurately record their measurements on wooden plaques distributed throughout the virtual world. After completing their first set of observations, the teacher instructs students to travel to the year 2100 by interacting with a portal in the virtual environment. They then repeat the same measurement procedure, allowing them to compare changes in sea urchin sizes over time. Throughout the activity, the teacher guides students in making observations and encourages them to think critically about potential environmental causes for any differences they notice. Meanwhile, the teacher uses the VRChat camera to capture images of the recorded measurements, ensuring accurate documentation of the collected data. Once all measurements have been recorded, the teacher leads the students to a virtual classroom through another portal. In this classroom setting, the teacher explains the statistical analysis process that will be applied to interpret the data. After exiting the virtual world, students use sophisticated real-world software to analyze the sea urchin size measurements collected during the expedition. The teacher provides the captured images to facilitate this analysis, guiding students through the process and helping them draw meaningful conclusions about the long-term environmental impact on marine ecosystems.

c. Linear Algebra

The Linear Algebra VRLE in Revealing is designed to help students engage with linear algebra concepts through an interactive light bulb system. The experience begins with a teacher demonstration, where the teacher explains the functionality of the system and provides an overview of how interactions with the buttons influence the bulbs. The teacher walks students through an example exercise, demonstrating how pressing certain buttons affects multiple bulbs simultaneously. Students then actively participate by interacting with buttons that control the light bulbs in front of them. Each button affects multiple bulbs, including the one directly in front of it and those positioned to its right and left. As they work through the exercises, the teacher provides guidance, offering step-by-step support to help students determine the correct combinations of light bulbs based on the given mathematical challenges. The VR environment includes two types of platforms that introduce different levels of difficulty. The first platform features bulbs with two states, either on or off. The second platform increases complexity by introducing bulbs with three states: red, green, and blue. The teacher continues to assist students by providing structured exercises, challenging them to achieve specific lighting patterns that require the application of linear algebra principles. By engaging with these platforms under the teacher's supervision, students analyze the effects of their interactions and refine their understanding of mathematical transformations. The experience helps students develop a practical understanding of how mathematical operations influence systems, reinforcing their comprehension of linear algebra in an immersive and interactive way.

d. Chimborazo Expedition

The German Explorers scenario in the Revealing VRLE immerses students in Alexander von Humboldt's expedition to Chimborazo Mountain, with a teacher guiding each step of the experience. The journey begins inside a wooden cabin at the mountain's base, where students first engage with a virtual globe under the teacher's direction. They discuss Ecuador's location and search for a hidden button. Once activated, the button reveals a detailed map of Ecuador, allowing for further discussion about Chimborazo Mountain's geography and significance. After exploring the globe, the teacher guides students in examining the expedition's equipment. They can pick up and inspect various objects, closely observing their design and functionality. This hands-on activity helps them understand the tools Humboldt and his team used. Following this, the teacher leads them to interactive signs inside the cabin that display additional tools from the expedition. By rotating these signs, students uncover the true function of each tool, deepening their understanding through discussion. Once students have grasped the tools and equipment used in the expedition, the teacher leads them outside the cabin to the base of the mountain. Here, they focus on studying the region's plant life. With the teacher's guidance, they collect different plant species and strategically place them on ascending platforms to represent the ecological zones at varying altitudes. The final part of the experience takes place at the top of Chimborazo Mountain. Using a portal, students teleport to the summit, where they find a final sign describing additional expedition tools. The teacher facilitates a concluding discussion on the significance of these tools and Humboldt's journey. If needed, students can return to the cabin through a portal, bringing their virtual expedition to an end.

e. Gallery Visit

The Gallery Visit scenario in the Revealing VRLE takes students on a virtual tour of an art gallery, which is an exact replica of the Teriade Museum located in Mytilene, Lesvos. The museum features paintings created by world-famous artists, providing students with an immersive cultural and artistic experience. Upon entering the gallery, students can explore various exhibits showcasing renowned artworks. The VRLE allows them to move through space as if they were physically present, closely examining the paintings and their details. The teacher guides the visit, providing historical and artistic context for each piece, explaining the significance of the artists, and encouraging students to analyze the techniques used in the artworks. As students navigate through the gallery, they engage in discussions led by the teacher, reflecting on the influence of these artists and their contributions to the art world. The visit experience allows students to interact with the exhibits in a way that deepens their understanding of artistic movements and styles. At the end of the visit, students have the opportunity to observe, analyze, and discuss world-class artworks in a highly immersive setting, enriching their appreciation of art history and visual storytelling.

f. Summary

In summary, it can be said that in all five VRLEs – with the exception of Gallery Visit – a problem was presented that students should work on; existing knowledge was drawn upon by addressing topics relevant to their studies or future; the multimedia construction gave them a certain authenticity; the simultaneous use of students and the invitation to can be understood as social learning through the simultaneous use by students and the invitation to discuss possible solutions to the tasks; interesting information and knowledge and skills are conveyed in all areas; and support and feedback is provided by the teachers involved.

Below, we provide a synthesis of the VRLEs' learning objectives (Table 1), and Tables 2 and 3 summarize how each VRLE employs immersive learning strategies from the framework by Beck et al. (2024).

### *3.2. Realisation*

The research design stipulated that students were given a brief technical usage introduction and, if necessary, on the topic of the virtual room before entering it. In each case, two to three students were allowed into the room together to complete the tasks. Each student visited just one VRLE. A researcher conducting the experiment accompanied them, to be able to answer questions and to encourage discussions between participants on the respective topic. There were also external observers who monitored the interactions and engagement of the participants on a desktop PC and recorded them on an observation sheet. After the session, everyone received a standardized questionnaire.

### *3.3. Sample*

A total of 158 students took part in the empirical study, of which 27 % were men and 73 % women. However, only 147 questionnaires could be evaluated, as some were not completed in full and therefore could not

**Table 1**
Learning objectives & activities.

| Case | Learning Objective | Learning Activities |
|---|---|---|
| **Ancient Greek Technology** | Understand the Pyrseia communication system and how torch arrangements represented letters.<br>Explore the workings of the Aeolipile and its connection to early steam technology. | Teacher-led slideshow on Pyrseia.<br>Students interact with a virtual Pyrseia system, placing torches to form letters.<br>Collaborative encoding/ decoding activity using distant Pyrseiasystems.<br>Hands-on Aeolipileexperiment, lighting a fire and observing steam power.<br>Analysis of the Aeolipileparts to understand components and function. |
| **Sea Urchin Measurement** | Learn about the effects of climate change on marine life.<br>Measure and compare sea urchin sizes over time.<br>Conduct statistical analysis of collected data. | The teacher presents an introductory video about climate change.<br>Students measure virtual sea urchins using rulers and pens in an underwater VR setting.<br>Time travel via portal to 2100 to compare data.<br>VRChat camera records student measurements.<br>Students transition to a virtual classroom for statistical analysis before finalizing data with real-world software. |
| **Linear Algebra** | Understand how mathematical operations influence systems.<br>Explore matrix transformations and dependencies through light bulb interactions. | Teacher demonstration of light bulb system and button interactions.<br>Students use controllers to manipulate bulbs, observing the effects of pressing buttons.<br>Two activity platforms: binary state bulbs (on/off) and three-state bulbs (red, green, blue).<br>Teacher provides exercises guiding students in achieving specific light patterns using linear algebra. |
| **Chimborazo Expedition** | Explore Alexander von Humboldt's expedition and scientific contributions.<br>Study ecological zones and plant distribution.<br>Analyze historical expedition tools. | Students start in a wooden cabin, using a virtual globe to locate Ecuador.<br>Teacher guides students in examining and handling expedition equipment.<br>Interactive signs provide additional historical insights.<br>Students collect and place plant specimens at different altitudes.<br>Final teleportation to Chimborazo's summit for discussion of expedition findings and scientific significance. |
| **Gallery Visit** | Develop an appreciation for historical artworks and artistic techniques.<br>Analyze different artistic movements. | Students explore a virtual replica of the Teriade Museum.<br>The teacher provides historical and artistic insights into paintings.<br>Students examine artworks up close using VR navigation.<br>Group discussions on artistic styles and influences led by the teacher.<br>Interactive exploration of the gallery, fostering engagement with world-famous paintings. |

be used. The participants were divided between the different locations (Table 4).

### 3.4. Data collection

An online questionnaire was deployed to gather data on the participants' learning experience. It was based on a modified version of the MLES scale, developed for capturing users' experiences across diverse Metaverse applications, including VR (Fokides, 2023). It consisted of 23 items examining seven factors: immersion (four items), ease of use (three items), perceived quality of the learning material (three items), perceived degree of interaction (three items), simulator sickness (three items), positive emotions toward the application (four items), and motivation (three items). Five additional items were included for recording demographic details of the participants, namely their gender, age, the university in which they study, prior experience in using VR, and prior experience in playing games. The questionnaire went through one round of expert validation by project team members and was provided online using LimeSurvey (Appendix A).

## 4. Results

Cronbach's $\alpha$ was used to examine the questionnaires' internal consistency both for the whole data set and for each university separately (Table 5). As, in all but one case, the $\alpha$ was above the recommended minimum value of 0.70 (Taber, 2018), thus the internal consistency was considered satisfactory. Following that, seven new variables were calculated, representing the average score per factor, per participant and the data were imported to SPSS 29 for statistical analyses. Tables 6–10 present the descriptive statistics for the pilots' variables.

As Table 5 shows, the overall consistency of the items of the scale used is relatively high, but with one exception. According to this, the use of the questionnaire at the University of Mainz is characterised by inconsistency. Since the scale at the other universities is consistent, the deviation is probably due to a scale that has been translated into German. In addition, problems with data entry would have been possible, although these were checked.

Table 6 provides a complete overview of the mean values of the respective dimensions of the scale, according to which all values on the 5-point Likert scale are at a high level of agreement (except for the dimension 'Simulator sickness', which, however, must be seen in reverse). Positive emotions, motivation and the quality of the learning material were rated particularly highly.

In addition, the results were analysed separately for each partner of the participating universities and their virtual learning spaces. The results of the descriptive statistics, i.e. the mean values and the standard deviation on the individual dimensions, are in the high range for the VRLEs of the University of Aegean (Table 7), the University of Krakow (Table 8) and the University Aberta (Table 9), and slightly below the overall average for the University of Mainz (Table 10).

Overall, however, the individual data also show that the learning material, motivation and positive emotions receive the highest approval. The 'simulator sickness' dimension is viewed most critically by the participants compared to the other universities. This means that the proportion of those who had difficulties with the VR headsets and experienced nausea or dizziness, for example, was highest among the participants from Mainz. This could also have an impact on the overall evaluation of the VRLE 'Chimborazo Expedition', as the separate evaluation shows.

As linear regression was to follow for examining whether the applications had an impact on participants' motivation, the assumptions for this type of analysis were checked. The residuals were fairly normally distributed (Fig. 6). The independence of residuals was checked using the Durbin-Watson (1950) statistic. As the value was 1.93 (recommended values $> 1.5$ and $<2.5$) it was concluded that there were no

**Table 2**
Immersive learning strategies of Beck et al. (2024) per VRLE.

| Category | Strategy Theme | Ancient Greek Technology | Sea Urchin Measurement | Linear Algebra | Chimborazo Expedition | Gallery Visit |
|---|---|---|---|---|---|---|
| **Educational Context** | **Teacher Professional Development** | N.a. | N.a. | N.a. | N.a. | N.a. |
| **Encompassing Concerns** | **Diversity, Depth, and Use of Resources** | N.a. | N.a. | N.a. | Multiple interaction options for exploring. | Observing multiple artworks with various artistic styles and influences |
| | **Meaningful Transfer** | N.a. | Relating small changes in marine ecosystems to wider climate change impact. | Associate algebraic systems to real-world situations | N.a. | N.a. |
| | **Metacognitive Skills** | N.a. | N.a. | Developing mathematical reasoning through trial and error | N.a. | N.a. |
| | **Scaffold personalized learning** | N.a. | N.a. | N.a. | Students can explore different objects, signs, and plants, according to their interests. | Students can explore different artworks, according to their interests. |
| **Evaluation and Assessment** | **After-Action Review** | N.a. | N.a. | N.a. | N.a. | N.a. |
| | **Assessment from analytics** | N.a. | The teachers captures images for accurate documentation of student actions. | N.a. | N.a. | N.a. |
| | **Formative Assessment** | N.a. | N.a. | Adjusting mathematical strategies with teacher guidance | N.a. | Live feedback discussion of specific pieces and their contributions. |
| **Instructional Strategies** | **Access Unfeasible Situations** | Experiencing distance communication visually, employ fire and boiling steam safely. | Measuring under the sea. Simulating marine ecosystem changes from 2023 to 2100 | N.a. | Exploring a historical expedition to a faraway mountain. | Visiting a distant museum virtually. |
| | **Authentic Learning** | N.a. | N.a. | N.a. | N.a. | N.a. |
| | **Collaborative Learning** | Group-based encoding and decoding of messages | Shared tasks doing and recording measuring in underwater VR | N.a. | Most activities are conducted as a class or group discussion. | Peer discussions on artistic styles and movements |
| | **Expositional** | Teacher-led slideshow on Pyrseia | Teacher presents video introduction to climate change | Step-by-step teacher demonstration of light interactions | N.a. | Guided museum tour by the teacher. |
| | **Interactive Visualization** | Observing steam engine mechanics, torch placements | Seeing urchins in situ (underwater) | Manipulating light bulbs to test interpretation of equations | Examining historical tools, plants, and maps interactively. | Zooming into and analyzing artistic details up close |
| | **Metacognition** | N.a. | N.a. | N.a. | N.a. | N.a. |
| | **Narrative** | N.a. | Time travel storyline leading to highlight the environmental impact over time | N.a. | Following Humboldt's expedition story. | The museum arrangement conveys a narrative of authority for the importance of the pieces. |
| | **Practice** | N.a. | N.a. | Regular performance of algebraic methods. | N.a. | Observing, analyzing, and critiquing artworks. |
| | **Scaffolding** | Teacher guided torch placement practice and teacher assistant supported the activity | Teacher assists with sea urchin data collection | Teacher provides step-by-step support | Teacher guidance at each step. | Structured guidance in analyzing artworks. |
| **Learning Design Strategies** | **Environment Design** | Torch placement leveraged two distant locations | VR underwater world with different spaces for activities (measuring on urchins, recording on plaques) | Different virtual platforms used to separate levels of difficulty. | Different activities take place at different spaces of the environment. | Museum replica provides a spatial arrangement for discussing different pieces in different locations. |
| | **Instructional Design** | The activity was structured with distinct, logical phases. | The activity was structured with distinct, logical phases. | The activity was structured with distinct, logical phases. | The activity was structured with distinct, logical phases. | N.a. |
| **Technical Contexts** | **Presence** | Doing embodied interactions, be aware of self by the local | Embedded in an underwater ecosystem: need to approach the | Buttons impacted lights in front of the student, leveraging | Experiencing Humboldt's expedition as if physically present. | Being present in face of a specific artwork drives the discussion of it. |

(*continued on next page*)

**Table 2** (*continued*)

| Category | Strategy Theme | Ancient Greek Technology | Sea Urchin Measurement | Linear Algebra | Chimborazo Expedition | Gallery Visit |
|---|---|---|---|---|---|---|
| | | torches, while others were distant | urchins and plaques, to change one's perspective. | feeling present in front of them. | | |
| **Theories** | **Active Learning Theories** | Engaging with Pyrseia system by physically placing torches and simulating | Hands-on measurement and data collection of sea urchins | Interacting with math concepts by manipulating buttons | Handling and analyzing real expedition tools and artifacts. | Active engagement in discussions of artworks. |
| | **Constructivist Theories** | N.a. | N.a. | Students analyze the effects of their interaction and refine their understanding. | N.a. | Discussions aim to prompt reflection and personal construction of significance of artworks for the art world. |
| | **Contextual theories** | Simulating positioning of torches, experiencing lighting of fire to power the sphere | Exploring underwater ecosystems within them. | Algebraic content is put into the context of switches and light bulbs. | All the activities take place in visual analogs of real-world places where they would occur. | The artworks are discussed in the context of a museum, indicating wider cultural relevance and acceptance. |
| | **Engagement Theories** | N.a. | N.a. | N.a. | N.a. | Teacher encourages students to analyze the techniques. |
| | **Multimedia Learning Theories** | N.a. | N.a. | N.a. | There is a structured association between combination of media formats and complementary information. | N.a. |

issues in this assumption. There were no significant outliers, high leverage points, or highly influential points, given that the maximum Cook's distance that was observed was below the value of 1 (max = .274) (Cook, 1979). The Variance Inflation Factor (VIF) was used for checking multicollinearity: it was not an issue, as there were no cases in which the VIF was above the value of 4 (Table 11) (Miles, 2014). On the other hand, it was found that heteroscedasticity was an issue, as it was assessed using the Modified Breusch-Pagan Test for Heteroskedasticity ($p = .006$).

Given this, we decided to run a multiple regression analysis with robust standard errors, using the HC3 method. The results of this analysis are presented in Table 12. The next step was to examine the data from each university separately. A multiple regression analysis with robust standard errors was run for the participants coming from the UKEN. For participants coming from the other universities, a regular univariate analysis was run, as there were no heteroscedasticity issues. Caution is advised for the interpretation of the results, as the sample sizes were rather small for both types of analysis. The results are presented in Tables 13–16.

In summary, for the whole data set, it seems that the participants' positive feelings toward the applications, as well as their perceived degree of interaction had a positive association with their motivation. For the application of the University of the Aegean, the participants perceived degree of interaction had a positive association with their motivation. For the application of the UKEN, the participants' positive feelings toward the application had a positive association with their motivation. As for the application of the University Aberta, as well as for the application of the University of Mainz, there were no factors associated with the participants' motivation.

## 5. Discussion

Taking the study by Beck et al. (2023) as a reference point for the evaluation of the VRLEs developed, the following five dimensions should be considered.

- All VRLEs had an *Active Context*, i.e. the users should and had to engage with tasks. One exception is 'Gallery Visit', which enables a virtual museum visit but only offers a few activities.
- *Collaboration* is given by the fact that several users are always present in all virtual rooms at the same time and are given tasks to discuss and solve together. This aspect is most pronounced in the applications 'Ancient Greek Technology', 'Sea Urchin Measurement' and 'Chimborazo Expedition', and somewhat weaker in 'Linear Algebra', where users mostly sit alone in front of their devices.
- *Engagement and Scaffolding* is more difficult to assess as it requires observation of interactions between users in the rooms. Although this was recorded, it was not analysed in this report.
- *Presence* which refers to the sense of being physically present or immersed in a virtual environment, creating a feeling of engagement and interaction within that space, is given in all VRLEs, because they were very real constructed.
- The fact that *Real and Virtual Multimedia Learning* can be found in the virtual rooms is present in all VRLEs of the pilot study.

All applications relate to scientific problems that are either of historical interest - how did ancient Greece communicate over long distances or under what conditions did Alexander von Humboldt carry out measurements on a high volcano - or deal with the challenges of climate change like 'Sea Urchins Measurement'. In the 'Linear Algebra' application, you also must deal with the demands of maths. The results of the survey of VRLE users can be interpreted more stringently based on this evaluation of their didactic design requirements.

In this study, a validated scale (Fokides, 2023) was used to assess the acceptance and evaluation of the VRLEs presented, which were developed by the four partner universities in the REVEALING project. The five related research questions can be answered as follows based on the results presented.

RQ1: How do students experience VRLEs and how do they evaluate them?

The students experienced the virtual spaces with positive emotions and rated the experience in the VRLEs as very positive overall. This is

**Table 3**
Immersive learning strategies of Beck et al. (2024) per VRLE.

| Category | Practice Theme | Ancient Greek Technology | Sea Urchin Measurement | Linear Algebra | Chimborazo Expedition | Gallery Visit |
|---|---|---|---|---|---|---|
| **Assessment** | Authentic Practice and Assessment | N.a. | N.a. | N.a. | N.a. | Conducting artistic techniques discussion in the context of an exhibition, when those discussions often take place. |
| **Deployment** | Exploration and Experimentation of Concepts/Processes | Experimenting different torch placements to encode messages | Using tools to measure the sea urchins. | Exploring how different button sequences impact algebraic outputs | Investigating historical scientific tools and ecological zones | Exploring the artworks on exhibit |
| | Foster Collaboration and Social Activities | Group-based Pyrseia encoding/decoding | Shared measurement tasks in underwater VR | N.a. | Most activities are conducted as a class or group discussion. | Peer discussions on artistic styles and historical influences |
| | Information Visualization and Inference | Observing how different torch patterns form messages | N.a. | Visualizing mathematical concepts through light patterns. | N.a. | Examining the painting and their details. |
| | Coaching, Demonstrating, and/or Observing Instruction | Teacher-guided exercises | Teacher-assisted measurement and data analysis. | Step-by-step demonstration and guidance on mathematical problem-solving | Teacher-led exploration of the globe, discussion on expedition tools, and final significance. | Guided walkthrough and discussion of museum exhibits |
| | Experiencing a Physiological/Psychological State | N.a. | N.a. | N.a. | N.a. | N.a. |
| | Scaffold Physical World Experiences with Digital Information | N.a. | N.a. | N.a. | N.a. | N.a. |
| | Embodied Interactions | Physically placing torches to encode messages, light a fire. | Using hand controllers to measure and compare sea urchins, moving towards the urchins and plaques. | Pressing buttons to manipulate light systems interactively. | Handling and rotating historical expedition artifacts. | Moving through the virtual museum space for interactive exploration |
| | Reproduce Traditional Teaching Practices in 3D | Converting historical lectures into VR-based interactive exercises | Video session and discussion, and traditional physical climate science data collection. | N.a. | N.a. | Reproducing traditional museum visits. |
| | Scaffold Immersive Experiences with Physical Elements | N.a. | N.a. | N.a. | N.a. | N.a. |
| **Institutional Learning Design** | Institutional Practices | N.a. | N.a. | N.a. | N.a. | N.a. |
| | Learning Design Across Multiple Digital and Physical Environments | Blending PowerPoint, VR interaction, and hands-on activities | Integrating video and virtual world activities. Outside the virtual worlds, data analysis is conducted, using captured images. | N.a. | N.a. | N.a. |
| | Saving Resources and Promoting Safety | Using VR to simulate ancient engineering without physical risks | Conducting climate research without harming real ecosystems or underwater equipment. | N.a. | Allowing historical exploration without real-world dangers | Providing access to valuable artworks without travel constraints |
| | Learning Design for Multimodal Information | Combining visual, auditory, and interactive elements in Pyrseia simulation | Using video, interactive data collection, and statistical tools. | Integrating color-coded algebraic transformations with interactive exercises | Mixing maps, text, and VR exploration for deeper learning | N.a. |
| | Reduce Cognitive Effort | N.a. | N.a. | N.a. | N.a. | N.a. |
| **Preparation** | Preparing for Instruction in an Immersive Environment | N.a. | N.a. | N.a. | N.a. | N.a. |

**Table 4**
Participations per location.

| Location | No. |
|---|---|
| University of Aegean, Greece | 44 |
| University Aberta, Portugal | 31 |
| University of the National Education Commission, Krakow, (UKEN), Poland | 49 |
| University of Mainz, Germany | 23 |
| **Total** | **147** |

**Table 5**
The questionnaires' internal consistency.

| Source | Cronbach's $\alpha$ |
|---|---|
| All data | .736 |
| University of the Aegean | .732 |
| UKEN | .768 |
| University Aberta | .771 |
| University of Mainz | .384 |

**Table 6**
Descriptive statistics (all participants).

| Variable | | |
|---|---|---|
| Men/Women/Other | 36, 91, 1 | |
| Age (16–19, 20–24, 25–20, >30) | 33, 68, 7, 20 | |
| Prior VR use (never, once, experienced) | 75, 30, 2 | |
| Play games (no, occasionally, regularly) | 50, 41, 16 | |
| | *M* | *SD* |
| Ease of use | 3.89 | 0.75 |
| Immersion | 3.86 | 0.82 |
| Perceived quality of the learning material | 4.23 | 0.71 |
| Interaction | 3.91 | 0.74 |
| Motivation | 4.27 | 0.66 |
| Simulator sickness | 2.43 | 1.14 |
| Positive emotions | 4.39 | 0.66 |

**Table 7**
Descriptive statistics (University of the Aegean).

| Variable | | |
|---|---|---|
| Men/Women/Other | 14, 2, 6 | |
| Age (16–19, 20–24, 25–20, >30) | 0, 5, 17, 0 | |
| Prior VR use (never, once, experienced) | 3, 18, 1 | |
| Play games (no, occasionally, regularly) | 11, 9, 2 | |
| | *M* | *SD* |
| Ease of use | 4.06 | 0.53 |
| Immersion | 3.80 | 0.98 |
| Perceived quality of the learning material | 4.48 | 0.57 |
| Interaction | 4.00 | 0.65 |
| Motivation | 4.50 | 0.59 |
| Simulator sickness | 2.26 | 1.00 |
| Positive emotions | 4.67 | 0.46 |

**Table 8**
Descriptive statistics (UKEN).

| Variable | | |
|---|---|---|
| Men/Women/Other | 8, 42, 0 | |
| Age (16–19, 20–24, 25–20, >30) | 33, 15, 1, 1 | |
| Prior VR use (never, once, experienced) | 36, 6 | |
| Play games (no, occasionally, regularly) | 20, 14, 8 | |
| | *M* | *SD* |
| Ease of use | 4.05 | 0.73 |
| Immersion | 3.80 | 0.81 |
| Perceived quality of the learning material | 4.33 | 0.53 |
| Interaction | 3.89 | 0.72 |
| Motivation | 4.09 | 0.75 |
| Simulator sickness | 2.65 | 1.21 |
| Positive emotions | 4.36 | 0.68 |

**Table 9**
Descriptive statistics (University Aberta).

| Variable | | |
|---|---|---|
| Men/Women/Other | 13, 20, 0 | |
| Age (16–19, 20–24, 25–20, >30) | 0, 19, 2, 12 | |
| Prior VR use (never, once, experienced) | 16, 3, 1 | |
| Play games (no, occasionally, regularly) | 5, 10, 5 | |
| | *M* | *SD* |
| Ease of use | 4.04 | 0.75 |
| Immersion | 3.98 | 0.87 |
| Perceived quality of the learning material | 4.47 | 0.67 |
| Interaction | 4.18 | 0.77 |
| Motivation | 4.48 | 0.58 |
| Simulator sickness | 1.78 | 0.90 |
| Positive emotions | 4.52 | 0664 |

**Table 10**
Descriptive statistics (University of Mainz).

| Variable | | |
|---|---|---|
| Men/Women/Other | 10, 12, 1 | |
| Age (16–19, 20–24, 25–20, >30) | 0, 20, 2, 1 | |
| Prior VR use (never, once, experienced) | 20, 3, 0 | |
| Play games (no, occasionally, regularly) | 14, 8, 1 | |
| | *M* | *SD* |
| Ease of use | 3.14 | 0.50 |
| Immersion | 3.88 | 0.63 |
| Perceived quality of the learning material | 3.41 | 0.66 |
| Interaction | 3.48 | 0.67 |
| Motivation | 4.13 | 0.42 |
| Simulator sickness | 3.04 | 0.98 |
| Positive emotions | 4.00 | 0.63 |

certainly due to the fact that the virtual spaces enable a variety of interactions and activities. The fact that the applications deal with interesting scientific problem areas may also have been decisive for this point.

RQ2: *How did they experience immersion in virtual space?*

The users felt strongly involved in the immersive worlds and had often forgotten the outside world. The learning environments provided plenty of opportunity for interaction, i.e. users could touch and move the virtual objects and perform actions with them. This is the case with all VRLEs.

RQ3: *How were they able to interact with the VRLEs and how did they receive feedback?*

The feedback was also rated positively. This was provided in the applications by the instructors involved, who were also present in the virtual rooms, or by boards that could be used to provide hints for the correct solution.

RQ4: *Were there any problems in the virtual space?*

A relatively small number of the students experienced problems when they entered the virtual rooms, like nausea or dizziness.

RQ5: *What did the experience trigger in them?*

Motivation achieved a very high score on the scale, i.e. the participants were very strongly motivated by all VRLEs to engage not only with the topics of the rooms, but also with the possibilities of such learning environments for learning. The experience in the virtual immersive spaces therefore had a very positive effect on all participants.

What is very interesting about the results is that the scale used shows a low level of consistency among users at the University of Mainz. On the one hand, as already mentioned, this may be due to the translation of the scale into German, while an English version was available to all other users. On the other hand, it can also be assumed that the high proportion of users who had difficulties using the VR goggles and entering the virtual space during the ‘Chimborazo Expedition’ is one reason for the deviating data from the University of Mainz. For example, 40 % of respondents stated that they felt nauseous or dizzy when using the VR goggles. This could have influenced the evaluation of the items.

Finally, the results show that considering only the VRLE as the intervention, different variables are associated with student motivation. Specifically, “perceived interaction” only emerged for the University of the Aegean VRLE (ancient Greek technology), “positive emotion” only emerged for the UKEN (Linear Algebra) and no variables for University Aberta (Sea Urchin Expedition), nor for University of Mainz (German Explorers).

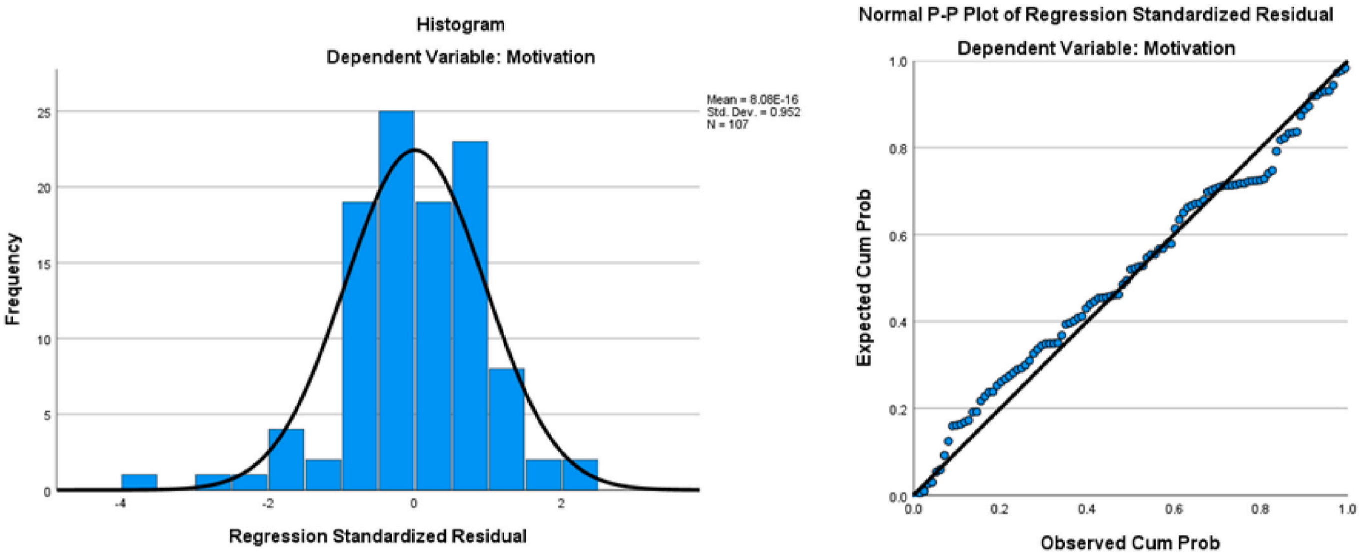

**Fig. 6.** Distribution of the residuals: histogram (left) and regression plot (right).

**Table 11**
Multicollinearity statistics.

| | VIF |
|---|---|
| Gender | 1.092 |
| Age | 1.139 |
| Ease of use | 1.420 |
| Immersion | 1.181 |
| Perceived quality of the learning material | 1.479 |
| Interaction | 1.495 |
| Simulator sickness | 1.337 |
| Positive emotions | 1.407 |
| Prior VR use | 0.126 |
| Play games | −0.038 |

## 6. Conclusion

REVEALING, an EU-funded project that explores how virtual learning environments with VR glasses can be used in academic teaching, saw project partners from Greece, Poland, Portugal, and Germany develop different virtual learning environments with instructional design, for their didactic use, following a module handbook. The VRLEs developed focus on different learning content and objectives, based on design principles derived from the psychomotor domain, immersive learning research and multimedia learning theory. The research design of the pilot studies consisted of five research questions, data collection and an evaluation method. The overall problems addressed by this work were on how learning environments could be instructionally designed so that they can promote learning and on what learning outcomes could be demonstrated under the combined conditions of technology, context, and approach.

The first problem was addressed by synthesizing the literature into an instructional design manual for the VRLEs, which was tested and refined by creating the various VRLEs, interactively identifying shortcomings in the manual content and refining it, then observing issues and shortcomings in the operational use of the VRLEs, and also use it to refine the manual, resulting in its final version (Aufenanger et al., 2024). The second problem was addressed by inquiry: five virtual learning environments were developed and deployed with students in five countries, and analysed regarding learners' perspectives, experience of immersion, ability to interact, receiving feedback, encountering problems, and triggering of motivation. Data was collected through an online questionnaire that captured the learners' experiences. The evaluation method was a multiple regression analysis that examined the influence of the various factors on learner motivation. The results of the pilot studies showed that the positive emotions and the perceived interaction of the learners had a positive association with their motivation. For the Aegean University application, perceived interaction also had a positive association with motivation. For the UKEN application, positive emotion also had a positive association with motivation. For the University Aberta and University of Mainz applications, there were no factors associated with learner motivation.

This corroborates the literature (Beck et al., 2024) that points out

**Table 12**
Multiple regression analysis with robust standard errors (all participants).

Model summary: $F = 9.49$, $p < .001$, $R^2 = .497$, $R^2_{Adj.} = .445$

| Parameter | *B* | *Robust Std. Error* | *t* | *p* | *95 % Confidence Interval* | | $\eta^2_{partial}$ |
|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | |
| Gender | 0.146 | .122 | 1.200 | .233 | −.095 | .388 | .015 |
| Age | 0.083 | .067 | 1.224 | .224 | −.051 | .217 | .015 |
| Ease of use | −0.084 | .092 | −.913 | .363 | −.267 | .099 | .009 |
| Immersion | 0.085 | .075 | 1.123 | .264 | −.065 | .234 | .013 |
| Perceived quality of the learning material | 0.019 | .100 | .193 | .847 | −.180 | .219 | .000 |
| Interaction | 0.267 | .096 | 2.799 | .006 | .078 | .457 | .075 |
| Simulator sickness | −0.069 | .076 | −.911 | .365 | −.220 | .082 | .009 |
| Positive emotions | 0.382 | .108 | 3.519 | <.001 | .166 | .597 | .114 |
| Prior VR use | 0.160 | .093 | 1.727 | .087 | −.024 | .345 | .030 |
| Play games | −0.034 | .087 | −.387 | .699 | −.206 | .138 | .002 |

*Note.* For the interpretation of the effect sizes, the following cutoff values were used: .010-small, .059-medium, .138 or higher-large (Cohen, 2013).

**Table 13**
Univariate analysis (University of the Aegean).

Model summary: $F = 5.69$, $p = .004$, $R^2 = .838$, $R^2_{Adj.} = .691$

| Parameter | Type III Sum of Squares | df | Mean Square | $F$ | $p$ | $\eta^2_{partial}$ |
|---|---|---|---|---|---|---|
| Gender | 0.028 | 1 | 0.028 | 0.260 | .620 | .023 |
| Age | 0.114 | 1 | 0.114 | 1.060 | .325 | .088 |
| Ease of use | 0.007 | 1 | 0.007 | 0.069 | .797 | .006 |
| Immersion | 0.134 | 1 | 0.134 | 1.251 | .287 | .102 |
| Perceived quality of the learning material | 0.007 | 1 | 0.007 | 0.067 | .801 | .006 |
| Interaction | 2.045 | 1 | 2.045 | 19.076 | .001 | .634 |
| Simulator sickness | 0.012 | 1 | 0.012 | 0.111 | .745 | .010 |
| Positive emotions | 0.117 | 1 | 0.117 | 1.095 | .318 | .091 |
| Prior VR use | 0.386 | 1 | 0.386 | 3.597 | .084 | .246 |
| Play games | 0.262 | 1 | 0.262 | 2.442 | .146 | .182 |

that the technology (VR) or the technological environment by itself is not determinant of outcomes. Thus, one should seek to study associations with the combined factors of technological environment (the VRLE), the context (participating students, subject), and pedagogy (aspects of the instructional design and its deployment).

This analysis requires an identification of guidelines to hold that three-partite comparison. Namely, methods to select variables for those dimensions in a systematic manner. A pathway towards it may be Beck and Morgado, 2025 proposed Immersive Learning Case Sheet, which provides a method to identify specific categories of educational practices and strategies in immersive learning activities, and to identify quantitative and qualitative factors of immersion in those activities.

Hopefully, establishing such guidelines may enable identifying associations that provide expectable outcomes prior to the realisation of actual learning activities, hence contributing to more robust methods of instructional design for immersive environments.

## CRediT authorship contribution statement

**Stefan Aufenanger:** Writing – original draft, Project administration, Methodology, Conceptualization. **Jasmin Bastian:** Writing – review & editing, Project administration, Funding acquisition. **Glória Bastos:** Writing – review & editing, Methodology, Conceptualization. **Maria Castelhano:** Investigation, Data curation. **Célia Dias-Ferreira:** Supervision, Resources, Investigation. **Emmanuel Fokides:** Validation, Data curation, Conceptualization. **Damianos Gavalas:** Validation, Conceptualization. **Vlasios Kasapakis:** Validation, Software. **Androniki Agelada:** Validation, Software. **Apostolos Kostas:** Writing – review & editing, Validation, Conceptualization. **George Koutromanos:** Validation, Conceptualization. **Gregory Makrides:** Writing – review & editing, Supervision, Conceptualization. **Leonel Morgado:** Writing – review & editing, Methodology, Conceptualization. **Daniela Pedrosa:** Resources, Investigation. **Tomasz Szemberg:** Project administration, Investigation, Conceptualization. **Alivizos Sofos:** Validation, Conceptualization. **Justyna Szpond:** Supervision, Project administration.

## Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Grammerly, deepL and Ghostwriter Addin for Microsoft Office in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

**Table 15**
Univariate analysis (University Aberta).

Model summary: $F = 3.76$, $p = .029$, $R^2 = .807$, $R^2_{Adj.} = .592$

| Parameter | Type III Sum of Squares | df | Mean Square | $F$ | $p$ | $\eta^2_{partial}$ |
|---|---|---|---|---|---|---|
| Gender | 0.038 | 1 | 0.038 | 0.426 | .530 | .045 |
| Age | 0.109 | 1 | 0.109 | 1.214 | .299 | .119 |
| Ease of use | 0.104 | 1 | 0.104 | 1.158 | .310 | .114 |
| Immersion | 0.015 | 1 | 0.015 | 0.166 | .693 | .018 |
| Perceived quality of the learning material | 0.127 | 1 | 0.127 | 1.408 | .266 | .135 |
| Interaction | 0.102 | 1 | 0.102 | 1.131 | .315 | .112 |
| Simulator sickness | 0.072 | 1 | 0.072 | 0.803 | .394 | .082 |
| Positive emotions | 0.030 | 1 | 0.030 | 0.337 | .576 | .036 |
| Prior VR use | 0.039 | 1 | 0.039 | 0.437 | .525 | .046 |
| Play games | 0.244 | 1 | 0.244 | 2.711 | .134 | .232 |

**Table 16**
Univariate analysis (University of Mainz).

Model summary: $F = 1.34$, $p = .312$, $R^2 = .527$, $R^2_{Adj.} = .133$

| Parameter | Type III Sum of Squares | df | Mean Square | $F$ | $p$ | $\eta^2_{partial}$ |
|---|---|---|---|---|---|---|
| Gender | 0.402 | 1 | 0.402 | 2.588 | .134 | .177 |
| Age | 0.854 | 1 | 0.854 | 5.499 | .037 | .314 |
| Ease of use | 0.000 | 1 | 0.000 | 0.000 | .998 | .000 |
| Immersion | 0.212 | 1 | 0.212 | 1.363 | .266 | .102 |
| Perceived quality of the learning material | 0.036 | 1 | 0.036 | 0.235 | .637 | .019 |
| Interaction | 0.194 | 1 | 0.194 | 1.251 | .285 | .094 |
| Simulator sickness | 0.380 | 1 | 0.380 | 2.448 | .144 | .169 |
| Positive emotions | 0.542 | 1 | 0.542 | 3.486 | .086 | .225 |
| Prior VR use | 0.016 | 1 | 0.016 | 0.104 | .752 | .009 |
| Play games | 0.004 | 1 | 0.004 | 0.028 | .869 | .002 |

**Table 14**
Multiple regression analysis with robust standard errors (UKEN).

Model summary: $F = 8.09$, $p < .001$, $R^2 = .723$, $R^2_{Adj.} = .634$

| Parameter | $B$ | *Robust Std. Error* | $t$ | $p$ | *95 % Confidence Interval* | | $\eta^2_{partial}$ |
|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | |
| Gender | 0.558 | .400 | 1.395 | .173 | −.258 | 1.373 | .059 |
| Age | 0.017 | .164 | .105 | .917 | −.317 | .351 | .000 |
| Ease of use | 0.098 | .218 | .451 | .655 | −.346 | .543 | .007 |
| Immersion | 0.127 | .141 | .902 | .374 | −.161 | .415 | .026 |
| Perceived quality of the learning material | −0.430 | .351 | −1.225 | .230 | −1.145 | .285 | .046 |
| Interaction | 0.255 | .204 | 1.248 | .221 | −.162 | .671 | .048 |
| Simulator sickness | −0.022 | .100 | −.222 | .825 | −.226 | .181 | .002 |
| Positive emotions | 0.777 | .287 | 2.708 | .011 | .192 | 1.362 | .191 |
| Prior VR use | 0.548 | .278 | 1.973 | .057 | −.018 | 1.115 | .112 |
| Play games | −0.142 | .155 | −.915 | .367 | −.457 | .174 | .026 |

## Statements on open data and ethics

The participants were protected by hiding their personal information in this study. They were voluntary and they knew that they could withdraw from the experiment at any time. The data can be provided upon requests by sending e-mails to the corresponding author.

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## Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cexr.2025.100105.

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