Virtual3R: A Virtual Collaborative Platform for Animal Experimentation

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Abstract: The purpose of this article is to highlight the ongoing work within the framework of a research project named Virtual3R. The primary objective of this project is to introduce an alternative method, based on Virtual Reality (Virtual3R platform), to reduce the reliance on live animals for training in biological engineering departments across France. The overarching goal in this regard is to provide learners with the basic technical procedures and gestures before engaging in real animal experimentation. The platform emphasizes its pedagogical contribution by providing a dynamic and collaborative learning environment for both teachers and learners. The technical framework supporting this perspective is based on an architectural design with different functional layers. This paper presents an overview of the platform's functional architecture, offering descriptions for each of its modules. Simultaneously, we present the results of the platform's experimentation, which serve as evidence of the learners' overall satisfaction with the virtual platform. The findings support the platform's efficacy as a user-friendly and collaborative learning environment. These findings also validate the platform's pedagogical value, demonstrating its beneficial impact on knowledge acquisition and learners' active participation in the virtual environment.

1 INTRODUCTION

Virtual reality (VR) has become an essential component of modern technological progress, with applications in a wide range of fields (Kumari & Polke, 2019). In this paper, our main focus is on the use of this technology in the learning context.

Indeed, the overall aim of our research is to contribute to the design and development of Virtual Learning Environments (VLEs) in partnership with teachers, ensuring alignment with their pedagogical requirements. In addition, we intend to assist and provide tools for educators for creating and developing VLEs that are adapted to their pedagogical needs.

In this educational context, VR has the potential to significantly improve the learning process by providing a more practical and engaging experience compared to traditional learning approaches (Allcoat & Mühlenen, 2018). Furthermore, VR also supports the development of virtual applications-oriented collaborative learning (Affendy & Wanis, 2019; Zheng et al., 2018). In this regard, collaborative work on a virtual activity can be highly beneficial for video conferencing and interactive learning procedures within virtual worlds (Najjar et al., 2022).

Within the educational landscape, these VR technology merits are particularly apparent in educational disciplines that require authentic and hands-on engagement (Sala, 2020), such as Biological Science Education (BSE).

Indeed, the integration of VR in BSE can transform the way students are trained and educated in animal experimentation. VR provides learners with engaging and immersive experiences, allowing them to develop a better understanding of animal anatomy and learn how to perform suitable gestures during animal experiments (Oubahssi & Mahdi, 2021).

Biology education traditionally encounters ethical concerns regarding animal use in learning settings,

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necessitating a reduction in such usage (Oakley, 2012). Ormandy et al. (2022) support integrating VR into BSE to enhance training effectiveness while upholding ethical considerations. This approach aligns with the principles of the 3R rule, which advocates for replacement, reduction, and refinement, promoting ethical considerations in the educational process (Lemos et al., 2022).

This article presents the Virtual3R research project, aimed at proposing a VR-based alternative to reduce animal usage in biological engineering departments in France. The goal is to help learners acquire proficiency in basic technical procedures and gestures before real animal experimentation. The platform emphasises instructional contributions by providing a stimulating and collaborative learning environment. In this regard, an instructor-centred iterative approach is adopted, promoting continuous partnership and feedback loops to address instructional needs (Garcia-Lopez et al., 2020).

An experiment conducted as part of this study with students in biological science yielded promising findings with regard to the platform's user-friendliness and its effectiveness in facilitating skill development.

This paper is organised as follows: in the next section, a selected literature review of virtual reality in education and collaborative virtual learning environments is presented, the section provides an overview of the virtual reality approached applied for animal experimentation. Then, the architecture of the proposed platform is described in Section 3. In Section 4, we outline the experimental procedure that was undertaken to assess the platform's utility. The final section provided a comprehensive conclusion to this study, as well as perspectives for future research.

2 LITERATURE REVIEW

2.1 VR in Education: Integration and Pedagogical Approaches

In the educational context, the integration of VR as a learning modality facilitates knowledge retention, enhances technical, behavioural and interpersonal skills, along with creating dynamic learning situations (Fussell & Truong, 2021; Howard & Gutworth, 2020; Nassar et al., 2021; Schmid et al., 2018).

The use of VR technology offers active channels for knowledge transmission and creates captivating environments that increase learners' confidence in real-life situations (Young et al., 2020). It also provides more accessibility than physical classrooms, breaking down conventional barriers and resulting in increased engagement, involvement, communication, and creativity (Wang et al., 2021).

Integration of VR in the educational setting ensures a secure learning environment, enhances student motivation, and facilitates the understanding of complex concepts. (King, 2016; Majewska & Vereen, 2023; Sukmawati et al., 2022).

VR experiences foster comprehension and investigation of complex concepts through various learning approaches, enhancing creativity, assistive technologies, and student involvement (Dailey-Hebert et al., 2021). The merging of VR technology with educational practices provides a comprehensive strategy that improves the quality of learning experiences and introduces a new era marked by innovation, openness, safety, and progress (Hickman & Akdere, 2018).

According to Huang & Liaw (2018), VR has the potential to support the integration of numerous learning theories, including constructivism, connectivism, and Gardner's multiple intelligences.

Previous research has established two theoretical paradigms governing the use of VR as an instructional tool: Situated learning and Embodied learning. Situated learning promotes active participation in a given topic, focusing on authentic experiences that closely mirror real-life personal or professional challenges (Lave, 2012). VR can be used to connect traditional classrooms with true-to-life situations (Dawley & Dede, 2014). For example, students can study virtual specimens in a way that closely simulates real dissection. Embodied learning, on the other hand, involves all five senses, making learning more complete and more efficient (Skulmowski & Rey, 2018).

The combination of VR and embodied learning increases learners' sensory engagement by allowing them to interact with and manipulate virtual objects and systems (Erkut & Dahl, 2018).

2.2 Collaborative Virtual Learning Environments (CVLEs)

CVLEs are immersive and interactive pedagogical environments that promote varied interactions and differentiated contributions (Konstantinidis et al., 2009). They offer computer-mediated digital spaces that enable individuals to meet, interact, and cooperate, improving educational and collaborative endeavours (Dumitrescu et al., 2014; Ouramdane et al., 2007).

These environments transform virtual spaces into dynamic communication contexts, presenting information in various ways, from simple texts to 3D graphics (Sarmiento & Collazos, 2012). In this context, active interaction between learners and the virtual environment is crucial for enabling collaborative learning (Beck et al., 2016).

From a theoretical perspective, collaborative learning is an educational methodology that emphasises active engagement and cooperative efforts of learners to collectively attain shared learning objectives (Laal & Laal, 2012). The primary goal is to address challenges, achieve desired outcomes, or deepen understanding within a specific knowledge domain (Laal, 2013). Successful implementation of collaboration within VR-based settings involves learners actively interacting and manipulating virtual objects to create shared experiences (Margery et al., 1999).

Temporal dynamics contribute to the enhancement of the collaborative atmosphere in CVLEs, facilitating synchronous interactions among learners regardless of their physical locations (Ellis et al., 1991). The real-time aspect of this interaction promotes immediate engagement and cooperation, improving the collaborative component of the educational process (Çoban & Goksu, 2022).

Throughout their development, educational collaborative VR initiatives have seen diversification and innovation. The VR-LEARNERS project developed a virtual reality learning environment centred on digital exhibits from European museums (Kladias et al., 1998). The Clev-R application is among the initiatives that broadened the range of educational applications by facilitating collaborative engagement in a variety of contexts (McArdle et al., 2008).

In the same direction, Jara et al. (2012)'s work enhanced the ability for collaboration by incorporating Virtual and Remote Laboratories (VRLs) into frameworks for synchronous e-learning. The use of virtual reality collaboration was expanded, resulting in a broader range of educational applications. For instance, Mhouti et al. (2016) introduce a cloud-based CVLE leveraging cloud computing to optimise resource management and meet dynamic learner needs, fostering a flexible and collaborative learning environment. Platforms such as the DICODEV platform (Pappas et al., 2006) and work such as those of Ruiz et al. (2008), Chen et al. (2021), illustrate the adaptability and versatility of collaborative virtual reality environments in a variety of educational fields.

2.3 Virtual Reality and Animal Experimentation

VR has significantly improved the biological sciences teaching, with advancements in scene-rendering technologies, interaction techniques, and information-sharing mechanisms (Fabris et al., 2019; Khan et al., 2021; Wu, 2009).

These systems enable the creation of interactive learning environments for different educational needs in the field of animal experimentation, allowing learners to collaborate remotely (Jara et al., 2012; Quy et al., 2009).

In this regard, VR offers an ethical educational alternative to traditional animal dissection, allowing students to acquire skills in animal anatomy while adhering to the principles of the 3Rs (Zemanova, 2022).

In fact, virtual dissection simulators, such as those presented in Predavec (2001), Abdullah (2010) along with the ViSi tool (Tang et al., 2021), introduce a new dimension to the study of animal anatomy by allowing students to explore 3D virtual animal specimens, practice dissection techniques, and explore anatomy without relying on real animals.

Vafai & Payandeh (2010)'s aimed at achieving a higher level of authenticity during manipulation through proposing an animal dissection simulator that uses haptic feedback, providing a multi-sensory experience and guiding users.

Besides, the VEA platform, developed by Oubahssi & Mahdi (2021), focuses on learning the right gestures in animal experimentation while respecting ethical rules. In this regard, learners can manipulate virtual objects, move around in a virtual laboratory, and access educational resources. Moreover, Sekiguchi & Makino (2021) proposed a VR system that allows students to participate virtually in the dissection of vertebrate animals, focusing on preparation, dissection, observation, and post-treatment. Each step is designed to teach specific skills while fostering a deep understanding of animal anatomy and ethics.

Compared to the tools mentioned above, our proposal offers a comprehensive virtual laboratory simulation that emulates the experimental environment, allowing users to explore its different sections and participate in preparatory activities. *ViRtual3R* emphasises collaboration, enabling learners to engage in collaborative experiments through synchronised interactions and real-time communication. In fact, the platform's learning activities are designed based on a collaborative-centric approach, ensuring an engaging and motivating educational experience. The platform is focused on the efficiency of the learning process, as it was developed to address the specific educational needs of the biological engineering departments of the University Institutes of Technology in France, identifying and fulfilling requirements that existing tools failed to meet.

3 *Virtual3R*: FUNCTIONAL ARCHITECTURE

Virtual3R's architecture is based on n-tier architecture principles, aiming to provide a modular structure with clear segmentation of functional layers (Figure 1). This approach ensures architectural flexibility and allows for system maintenance and evolution without system perturbation. Each layer plays a specific role in creating a collaborative and pedagogical virtual environment.

The presentation layer visually represents virtual content and participants, providing an intuitive interface. The Pedagogical Situations layer creates the virtual pedagogical scenario, delivering immersive, interactive, and authentic learning experiences.

The business layer manages various functional modules, including user interaction, collaborative interaction, pedagogical guidance, user authentication, and experience tracking. The Data Exchange Management layer facilitates real-time data transmission and manages security restrictions for communication with external services. This layer, built on an API, ensures transparent connectivity, enabling synchronised collaboration and effective access to pedagogical content.

As mentioned before in the introduction, it is important to note that the modelling of the platform was performed in close partnership with the instructors. They played a critical role in establishing requirements, validating anatomical representation, and systematically testing interactions with anatomical elements during the implementation's development. This ensures that learner interactions are as realistic as possible, providing learners with an immersive and accurate learning experience.

The *Virtual3R* Platform seamlessly integrates Unity3D's simulation capabilities with XR Interaction Toolkit's immersive VR features, offering engaging learning experiences (Unity Technologies, 2024). By leveraging Photon Engine's synchronization technology and a purpose-built API, the platform interacts with remote components like user administration databases and the Photon Engine server for efficient data exchange during collaborative sessions (PhotonEngine, 2024).

3.1 Presentation Layer

The presentation layer of *Virtual3R* functional architecture's aims to enhance learners' awareness and immersion in the simulated environment, fostering engagement and motivation throughout their learning experience.

The layer focuses on two aspects: visualisation of virtual objects and visualisation of other participants. The module offers a realistic graphical environment, allowing learners to explore the simulated laboratory through captivating virtual scenes. It also facilitates the visual exploration of resources within the virtual laboratory's perimeter, including virtual instruments and tools.

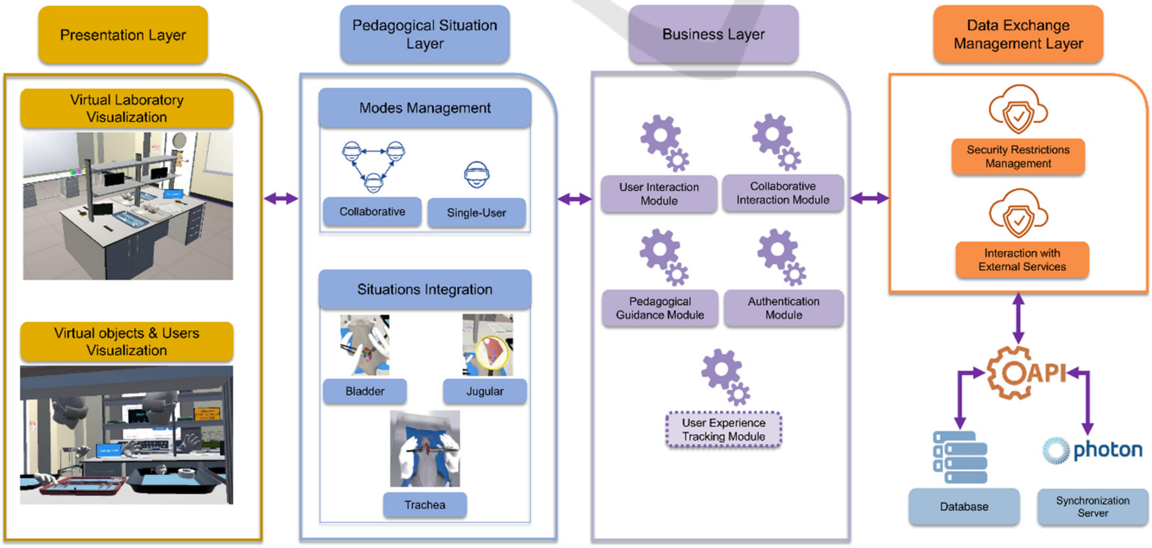

Figure 1: Virtual3R's Functional Structure.

The module also enables detailed visualisation of the virtual specimen's anatomical structures, allowing learners to observe and interact with these structures. The platform features interactive animations that simulate the use of instruments at the level of the anatomical structures, illustrating the practical aspect and realistic impact of users' virtual actions. In collaborative mode, avatars represent users within the shared virtual environment, increasing awareness of other collaborators and fostering effective cooperation and active communication.

3.2 Pedagogical Situations Layer

The pedagogical situations layer is the platform's core, providing an immersive and collaborative learning experience. It guides learners through realistic experimental situations while encouraging individual and collaborative interactions. The platform offers two user modes: single-user mode, which allows autonomous application of experimental protocols, and collaborative mode, which promotes cooperation and real-time interaction.

Common actions and activities within the pedagogical situations layer are crucial aspects of the learning experience. These include reading protocols, preparing virtual instruments, and conducting anaesthesia of the animal (rat). Learners can access a comprehensive protocol for each situation, learn to select appropriate tools, simulate intraperitoneal anaesthesia, and practice specimen fixation.

The current version of the platform features three pedagogical situations: bladder cannulation, jugular cannulation, and trachea cannulation. Each situation simulates the execution of a specific cannulation protocol, with specific actions and activities typically taking place after immobilising the specimen. The aim is to faithfully replicate the real experimental protocol to the greatest extent possible.

For bladder cannulation (Figure 2), learners execute experimental procedures such as incising the abdominal region, scraping to elevate the bladder, and introducing a catheter perpendicularly into its interior.

For jugular cannulation, users learn sequential actions such as incising the jugular, fixing the catheter toward the heart, and applying ligatures around the jugular. For trachea cannulation, learners practise virtual tracheotomy according to protocol instructions, applying ligatures around the trachea, performing a tracheal incision, and inserting a catheter in the direction of the lungs.

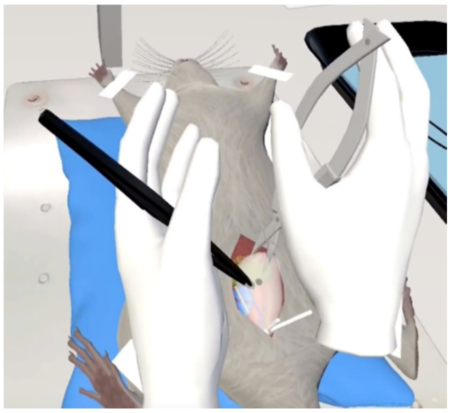

Figure 2: Educational situation Bladder cannulation.

Figure 3 illustrates the sequence of activities and actions for the tracheal cannulation situation, encompassing both common and situation-specific elements. The required gestures to perform these actions differ depending on the specific protocol for each situation.

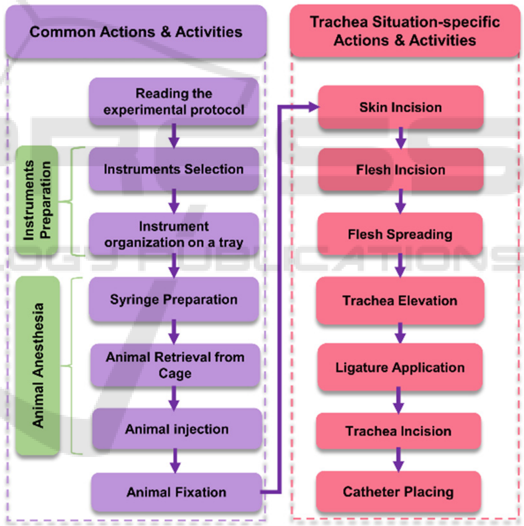

Figure 3: Tracheal cannulation: activities and action sequence.

Overall, the pedagogical situations layer serves as a dynamic core of the platform, ensuring a comprehensive and engaging learning experience for learners.

3.3 Business Layer

The Business Layer is a crucial component of the *Virtual3R* platform, facilitating the management, coordination, and flow of interactions within the educational context. It consists of several functional modules that contribute to a seamless learning experience for users.

The User Interaction Module: oversees user interaction within the virtual environment, allowing users to manipulate and potentially alter pre-existing virtual objects. Hand controllers are adopted within the framework to replicate hand movements and establish a link between the user's physical actions and their effects in the virtual environment. Users can navigate through virtual environments using the same controllers to explore content and interact with multimedia objects such as explanatory videos.

The Collaborative Interaction Module: ensures effective synchronisation aspects, enabling concurrent connections to shared environments among various users, enabling real-time collaboration. This module enables users to observe the actions of others and their impact on the environment in real time (Figure 4). Additionally, it supports concurrent usage of shared objects within the environment. The module also allows users to participate in real-time audio communication, fostering social interaction and idea exchange. It also ensures synchronised writing on shared virtual boards and Post-it notes, contributing to real-time information sharing.

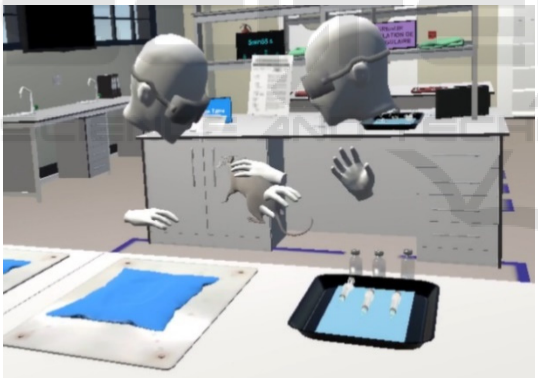

Figure 4: Learner Interaction on the Virtual3R Platform.

The Pedagogical Guidance Module: provides continuous and contextual assistance to engaged learners during their virtual learning experience. This assistance can take various forms, including contextual instructions and real-time feedback.

The Authentication Module: focuses on ensuring the virtual learning environment's security by implementing robust security protocols and managing the authentication process.

The User Experience Tracking Module: represents a perspective for the *Virtual3R* project, aiming to continuously improve the learner experience through user data analysis and optimisation. The collected data can help identify components and areas where users struggle to interact, resulting in a more intuitive, immersive, and pedagogically enriching learning experience.

3.4 Data Exchange Management Layer

The Data Exchange Management layer is a crucial component of the *Virtual3R* architecture, responsible for coordinating and securing real-time data exchange. It relies on a dedicated API as a gateway, ensuring seamless communication between business modules and external services and managing security restrictions. The layer oversees security restrictions, particularly during real-time data exchange, ensuring system safety. It also facilitates real-time interaction with the Photon Engine synchronisation server (PhotonEngine, 2024), promoting seamless interactivity within the virtual environment.

The layer also serves as an intermediary between the User Management and Authentication Module and the database, ensuring secure transmission of user-related information. In addition, this layer facilitates the exchange of data related to pedagogical content, primarily passing through the business layer to the situation management layer, ensuring its integrity and availability.

The demonstration videos accessible via the link below provide a preview of the overall features of the *Virtual3R* platform[1].

4 VIRTUAL3R: EXPERIMENT AND EVALUATION

4.1 Evaluation Context, Method and Protocol

This experiment was conducted with seventy-four biology students enrolled in Biological Technologies - Biological Engineering program at the Laval University Institute of Technology (Figure 5). The objective was to introduce the students to the operation of an animal facility/laboratory and assess the effectiveness of experimental protocols using VR technology.

This experiment was carried out as part of a Learning and Assessment Situation (LAS) in which the objectives were to use VR (an alternative method) so that students could: (1) Become familiar with the

[1] https://lium-cloud.univ-lemans.fr/index.php/s/jYcoCGzqpXj3aLF

Figure 5: The experimental environment.

environment of an animal facility or laboratory; (2) Comprehend the anatomy of the specimen (rat) by using a virtual model of the live anaesthetised animal, along with the necessary equipment required to conduct an experimental procedure; (3) Be trained in the performance of the technical gestures of different animal dissection experiments by following operating protocols.

The students used the *Virtual3R* collaborative platform to learn about the 3Rs principle, identify necessary equipment for physiological studies, master the use of specific equipment, and perform technical procedures for physiological experiments.

The evaluation of *Virtual3R* included an assessment of the platform's ergonomics and user satisfaction. The study was conducted in two distinct locations. One location was dedicated to individual training with an immersive VR game, and the other was reserved for collaborative training with the *Virtual3R* platform.

The study team consisted of an instructor, and two assistants, deployed four computer workstations, each equipped with an Oculus Quest 2 or Quest 3 VR headset. The instructor oversaw the smooth running of the experiment, contextualised the pedagogical approach, and supervised its various stages. The assistants provided ongoing technical and pedagogical support.

Prior to starting the experiment, the students received an overview of the training objectives and pedagogical aspects, as well as an introduction to the experimental protocols. The participants were then trained individually with the immersive game to familiarise themselves with the VR functionalities (i.e., using a VR controllers & VR headset, moving & teleporting in a virtual environment and manipulating 3D objects).

Following this, they engaged in a collaborative experiment using the *Virtual3R* platform, alternating between the roles of technician and assistant. Each team member also had the opportunity to apply their skills independently in a second separate pedagogical situation.

During these experiments, learners receive assistance from the instructor and assistants, who provide guidance on the steps to follow if necessary and help identify and correct errors.

In addition to the evaluation questionnaires filled by students, brainstorming sessions, integrated into each stage, were used to gather their initial perceptions and to assess their overall experience.

The questionnaire administered to the students included the System Usability Scale (SUS) inquiries (Lewis, 2018), along with additional questions. The SUS questions aimed to evaluate the overall usability of the *Virtual3R* platform, while the additional questions focused on the students' experience from various perspectives.

The participants were requested to evaluate the ease of movement within the virtual environment, the intuitiveness of teleportation, the arrangement of 3D objects, and the ease of interaction with these objects.

The survey also assessed the participants' performance, perceived effectiveness of their actions, and their experience with collaborative work in the 3D environment.

Simultaneously, the instructor filled out a skill validation questionnaire, offering a comprehensive evaluation of each student's performance, assessing their level of mastery across various indicators using a five-point scale:
(1) EX : for Expert – Excellent proficiency;
(2) A: for Acquired – Satisfactory level of mastery;
(3) C: for Confirmation needed for Acquisition – Acceptable level of mastery;
(4) IPA: for In the Process of Acquisition – Approximate level of mastery, and (5) NA: for Not Acquired – Insufficient mastery.

4.2 Results: Analysis & Discussion

As illustrated in Figure 6, the high average score of 74.22 on the SUS scale reflects learners' overall satisfaction with *Virtual3R*. The gap between the minimum (32.5) and maximum (92.5) scores emphasises the variety of experiences. The consistency of responses, as evidenced by the sum of variances (9.22) and the variance of scores (120.02), confirms the evaluation's reliability. Cronbach's alpha coefficient of 1.03 confirms the high internal reliability of the SUS scale. This consistency reinforces the credibility of the results, suggesting that usability evaluation is a strong indicator of positive user experience. The evaluation of the students' experience was conducted through three

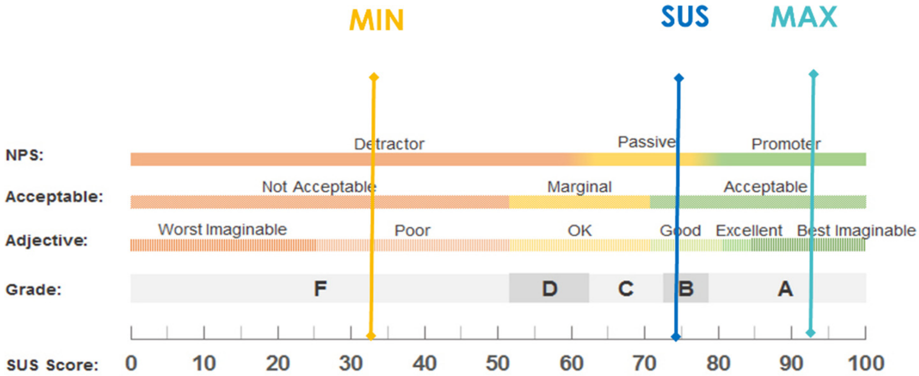

Figure 6: The SUS Scales Score.

Table 1: Results of the Skills Validation.

CRITICAL LEARNING ASPECTS	COMPONENTS OF CRITICAL LEARNING	ASSESSMENT INDICATORS	EVALUATION		
			EX	A	C
Acquire basic experimental skills on laboratory animals	Understand the operation of an animal shop/animal testing laboratory	Move around the animal experimentation laboratory to understand their professional environment correctly	96%	4%	0
		Check animal's condition after anaesthesia	49%	50%	1%
		Check the animal's condition during the experimental procedure	23%	76%	1%
		Immobilise the animal at the beginning of the experimental procedure	100%	0	0
	Analyse an experimental procedure according to the 3R rule	Consider the advantages and disadvantages of virtual reality in animal experimentation	32%	68%	0
Implement experimental physiological study procedures	Inventory the equipment needed to carry out an experimental procedure for physiological studies	Observe the equipment available	92%	8%	0
		Check that all the necessary equipment is present before starting.	88%	12%	0
	Use properly the equipment and devices necessary for the implementation of an experimental procedure of physiological studies	Correct handling of dissecting equipment (scissors or forceps)	74%	26%	0
		Coordination of movements / Coordinated use of both hands	69%	28%	3%
	Perform the technical gestures required for the implementation of an experimental procedure of physiological studies	Use of technical protocol as training aid (protocol sheet/video)	46%	54%	0
		Follow protocol steps	93%	7%	0
		Sequence / fluidity of technical gestures	62%	36%	1%
		Collaborative work / Interaction with partner	84%	16%	0

different components, each focused on examining specific aspects of the user experience.

In the first component, which assessed the displacement and interaction, users generally responded positively. The majority of participants (63%) found the ease of movement to be positive. In addition, teleportation was found to be intuitive by a total of 53% of users. The placement of 3D objects, such as the specimen (rat) and instruments, received overwhelming approval from 81% of participants, indicating its relevance.

The second component examined performance and perception in virtual educational tasks and revealed notable successes. An impressive 82% of users highlighted their ability to successfully handle specific pedagogical situations. While a small proportion (7%) reported some difficulties, the vast majority (93%) found the steps in the virtual environment easy to perform. However, there were mixed opinions regarding the application of ligatures, suggesting a potential need for further support in this area.

In terms of collaboration, the results were encouraging. A substantial 79% of users felt that cooperation was intuitive. In addition, overall satisfaction with collaborative work was high, with 89% of participants reporting that they were "completely" or "very" satisfied.

The use of pedagogical indicators showed some variation among participants. Seventy-two percent (72%) of users reported using them, while 75% of this group used them only once. This disparity indicates different approaches to these indicators, suggesting a need for clarification or improvement in their integration into the virtual learning process.

In addition, learners emphasised the importance of the pedagogical support provided by the study team during the brainstorming sessions, suggesting its integration into the platform in a way that automatically adapts to the user's actions and to the difficulties encountered in the environment.

On the other hand, Table 1 highlights the findings derived from the skills validation process. It presents the proportion of students who attained a specific level of mastery for each assessment indicator.
The table exclusively displays the values corresponding to the three highest levels of competence, as no learner was assigned a level of competence below in any of the assessment indicators. The subsequent findings presented in the rest of the discussion correspond to the proportion by learning component that was calculated based on the values listed in the table.

With regard to the acquisition of basic experimental gestures, 66.64% of the participating students exhibited an expert level of skill, demonstrating an adequate level of knowledge and manipulative skills.

Regarding the analysis of experimental procedures conforming to the 3R rule, 32.43% reached an expert level, reflecting in-depth comprehension, whereas 67.57% reached an acquisition level, indicating a strong, but possibly less thorough grasp of the subject matter.

For the implementation of experimental procedures, the majority of students (89.87%), attained an expert level of proficiency in equipment inventory. 71.62% of students demonstrated a moderate proficiency in the second component, which relates to the correct use of instruments. According to the results of the skills assessment, 95.95% of students demonstrated adequate mobility in the laboratory, highlighting effective engagement in the experimental context.
In conclusion, in terms of conviviality evaluation, the SUS analysis confirms overall user satisfaction with *Virtual3R*, which is perceived to be user-friendly. The range of scores highlights an inclusive design, and even the lowest scores indicate a satisfactory experience.

The evaluation highlighted the overall satisfaction of the users with the virtual educational platform. However, specific areas require targeted improvements to further enhance the learning experience. These include providing further assistance with some activities and clarifying or improving the integration of pedagogical indicators. The results also highlight the importance of incorporating adaptive pedagogical support into the platform to respond to user's actions and difficulties.

With regard to skill validation, the analysis of competencies revealed significant accomplishments, particularly in mastering experimental manoeuvres on laboratory animals and carrying out experimental protocols for physiological research. The variety of results demonstrates the overall success of the pedagogical approach, though specific areas for improvement were identified. These results also confirm pedagogical success in terms of knowledge assimilation and student interaction with the environment.

To sum up, our experience with *Virtual3R* has demonstrated its efficacy as a user-friendly collaborative learning platform. The SUS and skill evaluation findings suggest that *Virtual3R* provides a satisfactory user experience while efficiently delivering practical and conceptual skills. While certain aspects could be enhanced, these outcomes serve a solid foundation for guiding future pedagogical improvements.

5 CONCLUSION

This article presents *Virtual3R*, an animal experimentation simulation platform that represents advancement in biological science education and CVLE design and development. The virtual immersion provides by the platform offers a learning experience that merges VR technology and innovative pedagogy.

The visual interface of *Virtual3R* enables users to engage in detailed examination and interaction with complex anatomical structures, in addition to manipulating virtual instruments. By promoting collaboration among learners, the platform incorporates a social aspect into learning, fostering engagement, motivation, and the exchange of experiences between participants.

In addition to immersive technology, *Virtual3R* adheres to the essential ethical principles of animal experimentation by implementing the 3Rs rules (Reduce, Refine, Replace). This approach highlights the platform's dedication to responsible and ethical education.

Detailed experimentation has shown the platform's effectiveness in terms of user-friendliness and the acquisition of both practical and conceptual skills. The positive results reinforce the belief that *Virtual3R* is not merely an innovative technology but also an efficient pedagogical solution. Further experiments could be conducted to explore learners' subjective experiences, particularly regarding their sense of presence and co-presence with other participants.

The development perspectives of *Virtual3R* are equally promising. Continuous improvements will be implemented on the platform, informed by feedback from instructors and learners who have experimented with the system.

The expansion of pedagogical situations, such as carotid cannulation, will enhance learning experiences and provide a broader array of skills to acquire. Furthermore, exploring new interaction techniques, such as hand tracking, lays the groundwork for even more immersive and realistic experiences.

On the other hand, introducing a virtual animated agent to assist learners throughout their experiences signifies a notable advancement. Additionally, adapting learning activities and pedagogical instructions to align with learners' behaviours and past interactions will optimize the learning process.

Virtual3R exemplifies the potential of VR applications in education, offering a structured architecture that integrates collaborative learning experiences within immersive virtual environments. By prioritizing both the pedagogical needs of instructors and the immersive context of the learning situation, *Virtual3R* sets a precedent for future VR applications aimed at enhancing learning outcomes across diverse educational settings.

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