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When Virtual Reality Reinvents Training: The Cnam Bet with CAP'VR

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Abstract

For three decades, the National Conservatory of Arts and Crafts has been incorporating digital technology into its pedagogical practices. Building on this experience, the CAP'VR (Chemistry Agri-food Pharma Virtual Reality) immersive Digital Twin has been developed to enhance Teaching through Virtual Reality (VR). This innovative device offers a digital laboratory twin that enables learners to acquaint themselves with professional gestures, technical processes, and safety practices, while optimizing training time. The CAP'VR system has been meticulously designed to cater to a diverse audience, particularly those engaged in retraining or work-study programs, by offering progressive, interactive modules in domains such as food processing, chemistry, and process engineering. The system integrates safe learning and skills assessment, ensuring a comprehensive and secure educational experience. The content is meticulously developed based on interactive scenarios adapted from real lab-life situations, ranging from laboratory safety to everyday experiments. The learning process is structured into three levels, providing a structured and progressive learning path. The development of the system was based on a multidisciplinary collaboration between teachers, instructional engineers, and VR developers, ensuring coherence between pedagogical and technical objectives. The impact on learners is significant, boosting their confidence, commitment, and memorization. Concurrently, CAP'VR is effecting a transformation in the practices of teachers, who assume the role of Experience Facilitators. Notwithstanding the deployment of this immersive technology posing technical, financial, and organizational challenges, CAP'VR paves the way for innovative, personalized teaching approaches.

1 The Genesis of CAP'VR Project

Digital teaching methods have played a pivotal role in the teaching practices of the Conservatoire National des Arts et Métiers (Cnam) for nearly three decades. Building on this experience, a team of teacher-researchers and engineers has innovated in the field of Virtual Reality, leading to the development of the CAP'VR (Chemistry Agri-food Pharma Virtual Reality) Project. Over the course of two years, the team developed a digital replica of a practical laboratory, focusing on disciplines such as agri-food, chemistry, and process engineering. The primary objective of this system is not to replace traditional practical teaching methods, but rather to enhance them. It provides learners with the opportunity to become acquainted with various laboratory techniques in a safe environment before applying them in real-life settings. Furthermore, CAP'VR facilitates the evaluation of learners, enabling educators to observe their equipment selection, actions, and behavior in potentially hazardous scenarios. The implementation of CAP'VR addresses several significant challenges. Primarily, Cnam's educational approach caters to a diverse audience, predominantly adults engaged in professional pursuits, aiming to advance their careers, acquire new skills, or pursue retraining. This diversity necessitates customized learning pathways and adaptable teaching methods to cater to varying levels of knowledge and skills. Furthermore, the reduction in the number of hours allocated for practical training in curricula necessitates the optimization of this training time. And additionally, virtual simulation allows for the execution of "extreme" errors, enabling dangerous or borderline tests that would be impractical in a laboratory setting. These fosters learning through experiential learning (Sylla-Iyarreta Veitia et al., 2023).

CAP'VR has also been a beneficiary of human and financial resources, facilitating the development of engaging, accessible, and immersive content (Agence nationale de la recherche, 2021; Région Ile-de-France, 2020). This initiative aims to democratize practical teaching by offering learners the opportunity to familiarize themselves with professional gestures and equipment control in a safe and cost-effective environment.

A collaborative effort involving teacher-researchers, instructional engineers, technicians, and VR developers resulted in the initiation of the first immersive practical session in autumn 2021, signifying a pivotal stage in the integration of these technologies into teaching at the Cnam. The development of immersive modules necessitated a collective process of reflection, discussion, and drafting to establish a common language among participants and precisely define the common objectives, that is, what is both pedagogically desirable and achievable in terms of development. The collaborative nature of the endeavor was underscored by the formation of a multidisciplinary team, wherein all members, irrespective of their role or function, were granted equal access to information and were engaged in every stage of the discussion. This approach aimed to transcend the departmental silos and foster seamless communication among teaching teams from diverse departments. In this article, we will share our experience in implementing the CAP'VR pedagogical system. It will entail the following: an exposition of the immersive modules developed, an elucidation of the integration of immersive sessions into teaching practices, and a presentation of the feedback gathered to date. We will conclude with an examination of the essential points to be considered during the system's setup.

2 From laboratory safety to routine experiments

The specifications for the development of the modules were derived from a framework document that delineated the objectives clearly: to facilitate the acquisition of laboratory skills and manipulations by students, to ensure a realistic environment, to promote an interactive teaching scenario, to provide a tutorial for mastering the VR controllers, and to ensure intuitive use while integrating additional functionalities to maximize accessibility for individuals with disabilities. In response to these requirements, the immersive modules developed enable learners to move around a laboratory in complete safety, to identify the equipment and its specific uses, to acquire the right automatisms linked to laboratory procedures, and to use laboratory equipment and apparatus appropriately within the framework of a defined practical experience.

The initial immersive scenarios developed under the CAP'VR project center on laboratory safety. These modules, meticulously designed with three levels of difficulty (beginner, advanced, expert), are crafted to facilitate the expeditious acquisition of the competencies and reflexes necessary to adhere to safety protocols. The objective is that, upon completion of these modules, learners will possess the competencies to operate safely in a laboratory setting and, more specifically, to respond appropriately to a potentially hazardous situation. This pedagogical approach is designed to mitigate anxiety typically associated with transitioning to the subsequent, real-life learning phase.

The initial laboratory safety module was meticulously designed to acquaint the learner with the laboratory environment and the locations of collective and personal protective equipment (Figure 1). Risk and hazard management is addressed through a series of five immersive exercises, which confront the learner with possible hazardous situations in the laboratory, including light cuttings, chemical inhalation, chemical projection, fire and electrical hazards. These exercises enable the learner to master the appropriate gestures and practices to effectively deal with such situations. For instance, in a scenario where a minor cut results from a beaker falling from the edge of the bench and shattering, the learner must address the situation by either securing the danger zone by clearing the debris or, in the event of a cut, alerting emergency services and adopting the appropriate reflexes. This type of scenario offers practical, hands-on safety training (Figure 1).

Figure 1: Immersive safety modules developed as part of CAP'VR

The second series of immersive modules have been developed to train students in the day-to-day experiments carried out in a laboratory setting. Guided by the preparation of a tartrazine, a food colorant, six immersive scenarios have been established thus far: weighing on a precision balance, liquid/liquid extraction, setting up reflux heating, vacuum evaporation using a rotary evaporator, compound analysis by thin-layer chromatography (TLC), and product purification by flash column chromatography (Figure 2). For instance, the weighing module on the precision balance instructs the learner to weigh reagents according to a precise protocol and with the appropriate spatulas, thereby ensuring measurement accuracy with a tolerance of 5% in mass. Throughout the exercises, the learner is guided by a virtual tablet on their left hand and via audio assistance, facilitating knowledge acquisition and ensuring smooth, interactive learning progress. The modules have been carefully designed to facilitate progressive learning, structured into three levels (beginner, advanced, and expert), with increasing levels of guidance instructions. This method enables the learner to safely grasp the potential dangers associated with certain chemicals and the use of laboratory equipment, fostering a risk-free learning environment. The experiment can be repeated ad infinitum in a fun way, encouraging the assimilation of the gestures and techniques required for optimal mastery of real-life laboratory manipulations. New Process Engineering modules are currently being developed and implemented (Figure 3).

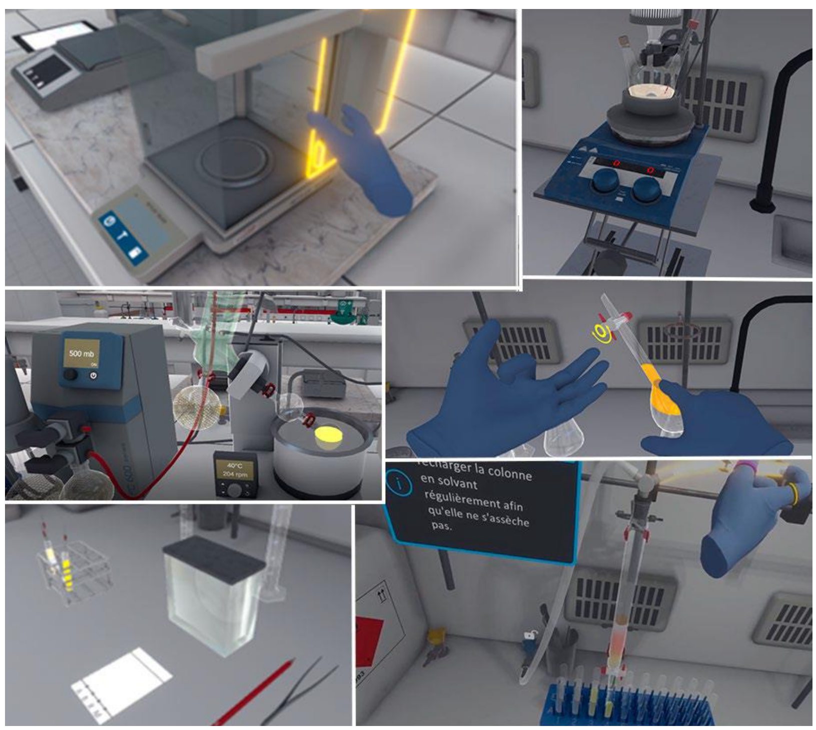

Figure 2: Immersive modules on common laboratory techniques developed as part of CAP'VR.

Figure 3: A liquid/liquid Extractor Pilot and a Bioreactor in the new Process Engineering Lab

In addition to offering a progressive approach to learning, the development of the modules has also incorporated accessibility considerations. This approach meets the requirements of recent legal provisions, which make digital accessibility crucial from an educational point of view and compulsory on pain of financial penalties in the event of noncompliance (European commission, 2021). Accessibility in the field of VR represents a complex challenge in a non-standardized field of research (World wide web consortium, 2021). Accessibility issues vary according to the type of disability: visual, auditory, motor, or cognitive. To address these challenges, CAP'VR modules have been developed to incorporate accessibility parameters. Customizable interfaces, audio instructions relayed in writing via a wrist-mounted tablet, and innovative devices such as magic rings have been designed to adapt to the specific needs of learners (Figure 4). Virtual reality, by its very nature – "a quasi-reality" - induces transgressive adaptations to guarantee an inclusive experience.

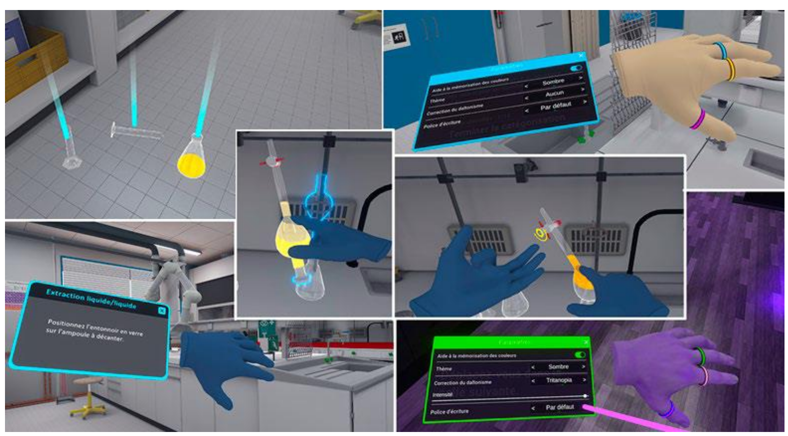

Figure 4: Accessibility tools like laser enabling objects catching, magic rings, audio instructions on tablet and customizable interfaces

3 How can an immersive learning session be integrated into an educational curriculum?

Immersive practical sessions have been deployed at Cnam since November 2021. Currently, six specialties are concerned (general chemistry, molecular chemistry and formulation, bioanalysis and chemical analysis, agri-food sciences, materials and process engineering). To date, over 600 students from License to Master have used the modules as part of their practical training units. Implementing an immersive session relies on a complete device combining technology and human support. It requires close collaboration between teachers, technical instructional engineers and learners to guarantee a fluid, enriching experience (Figure 5).

Figure 5: A pair of learners in immersive practical training, one immersed, the other taking notes.

These sessions need to be strategically integrated into the curriculum, either upstream or downstream of lab practical session, or as an assessment tool. For example, offering an immersive session prior to physical hands-on exercises enables learners to familiarize themselves with complex procedures, reduce risk and increase confidence.

The immersive device goes far beyond the simple use of technological tools. It begins with a briefing outlining objectives and expectations, often accompanied by preparatory documents available online, such as instructions, scenarios or tutorials. A dedicated room is required, equipped with VR headsets, computers and a good Wi-Fi connection. During the session, human support remains essential, while enabling learners, working in pairs, to develop their autonomy and self-help. (Figure 6)

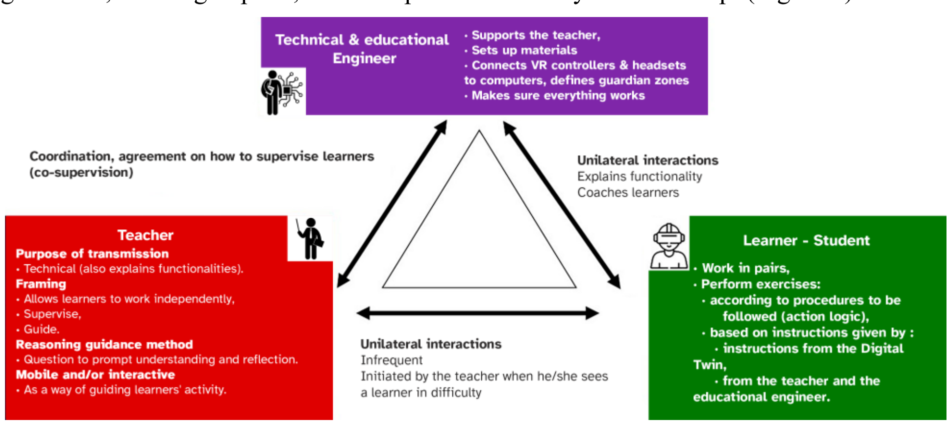

Figure 6: Three-way learning: Teacher - Instructional Engineer and Learner in immersive practical training

Sessions are generally structured in several progressive stages. An initial acculturation phase familiarizes the learner with the controllers and the virtual environment. This is followed by thematic modules (safety or experiments) designed to help the learner learn professional gestures, identify hazards or manage complex situations. Finally, practical exercises or simulations linked to pedagogical objectives are carried out, with difficulty and guidance adapted to the learner's level. A key element of these sessions is the collective debriefing, which closes each session. This is an opportunity to go back over the essential points, analyze the results displayed on the score screen and gather feedback from the learners. The debriefing helps to anchor knowledge and provide the perspective essential to transforming immersive experience into lasting learning.

Finally, these sessions can be customized to meet the needs of different areas. Scenarios are adapted to the expected skills, and the structuring of sessions (duration, number of sessions, levels of difficulty) remains flexible. The integration of real-time assessment into the immersive system, with reports showing the objectives achieved, contributes to reinforcing their pedagogical relevance. This general framework ensures that immersive sessions can be implemented effectively and harmoniously in a variety of educational contexts.

4 Evaluation of CAP'VR

The evaluation of the CAP'VR tool was conducted using satisfaction questionnaires designed to systematically capture users' subjective perceptions after interacting with the interface. These questionnaires assess aspects such as user-friendliness and ease of use, providing valuable data for evaluating the overall effectiveness of the interface. They also help guide future improvements by identifying strengths and areas for development, thereby contributing to the design of interactive products that are better aligned with users' needs.

The *AttrakDiff* tool (Hassenzahl et al., 2003; Lallemand et al., 2015) was used to assess learners' perceptions, while the System Usability Scale (SUS) by Gronier et Bauder, 2021) was selected to evaluate those of the teachers.

The *AttrakDiff* tool was used to evaluate the hedonic and pragmatic qualities of interactive systems—in other words, their usability and the overall experience they provide to users. It is based on 28 items, presented as pairs of opposite words separated by a 7-point Likert scale, and divided into four evaluation dimensions. The first, the pragmatic scale, assesses the perceived usefulness and functionality of the device. The second, the attractiveness scale, measures the perceived overall attractiveness of the device. Next, the hedonic-stimulation scale looks at how captivating and innovative the device is perceived to be. Finally, the hedonic-identity scale examines the social value of the device in terms of self-expression and communication of the user's own identity.

The data presented below (Figure 7) were collected in 2024 from 186 participants: Results for each dimension are reported on a scale from -3 to 3. Thus, the device is evaluated as positive when it is between 0 and 1, and better perceived when the results are higher than 1. Therefore, results of 1.88 and 1.90 indicate that learners find it very attractive and stimulating, and the value of 1.26 that they identify with this type of device. In terms of pragmatic quality, the result of 0.97 shows that the perceived usability of the immersive tool could be improved.

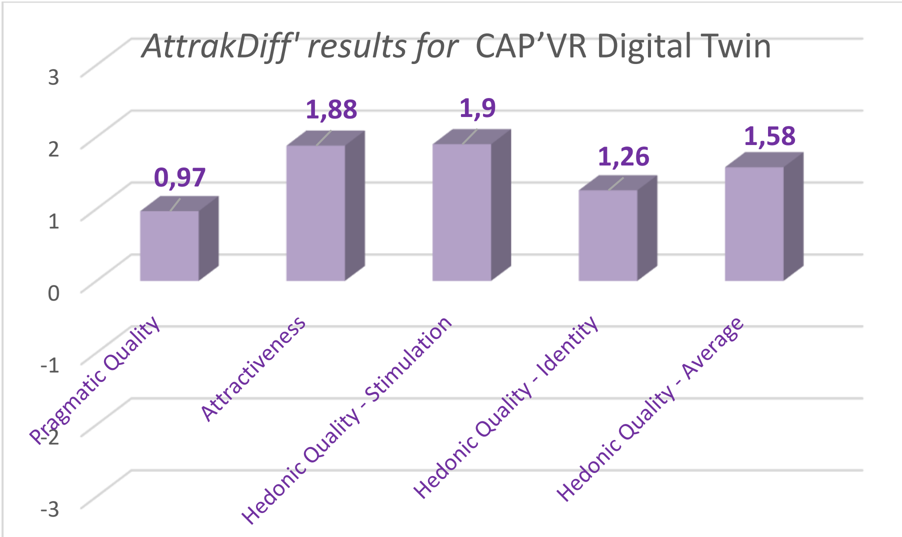

Figure 7: Results of the *AttrakDiff* 2024 questionnaire concerning CAP'VR Digital Twin. A: details for the four quality subscales.

The SUS (System Usability Scale) was used to assess feedback from trainers. This tool measures the usability of interactive systems through 10 items presented as affirmative statements. Responses are given using a 5-point Likert scale (from 1 to 5, ranging from "Strongly disagree" to "Strongly agree"). The results are then converted into a score ranging from 0 to 100, which is interpreted using seven qualitative descriptors, from "worst imaginable" to "best imaginable." The questions are available in the supplementary data. Twenty-one supervisors (teacher-researchers and technical experts) answer 10 questions, worth 10 points each. CAP'VR obtained an overall score of 73, well received by professionals (Figure 8).

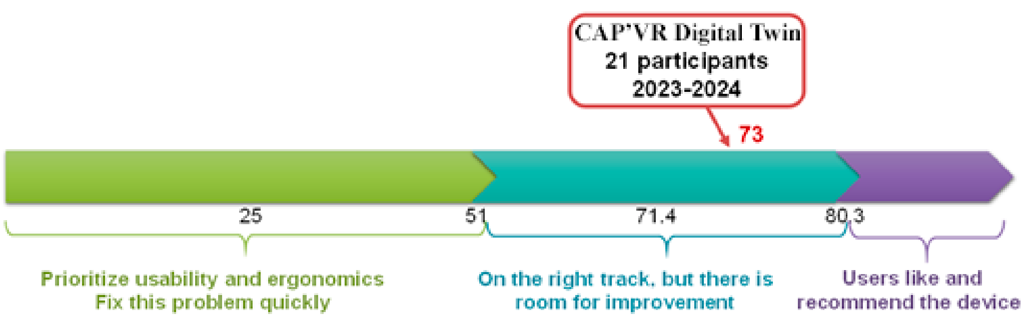

Figure 8: CAP'VR 2023-2024 SUS results

Most questions received scores above 7, except the question Q4 "I would need the support of a technician to be able to use this system", which scored 4,17 for teachers and 6,5 for technical experts (Figure. 9). This question addresses the level of perceived autonomy of supervisors in setting up and using Virtual Reality devices, and the score obtained indicates that the twin lab is not yet perceived as usable autonomously without the help of technical experts.

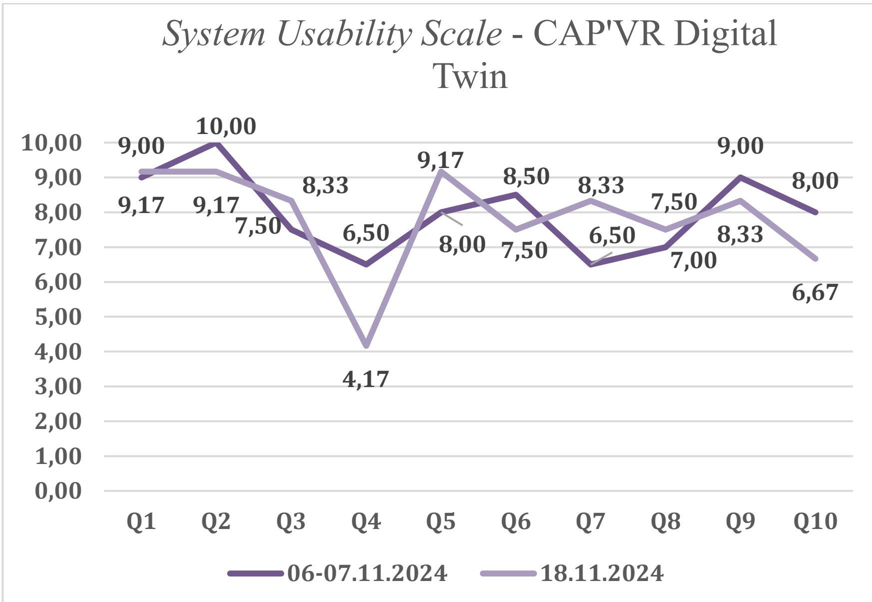

Figure 9: SUS: Question-by-question results - Technical Experts & Discipline Experts during two different periods. The detailed questions (form Q1 to Q10) are available in the supplementary data.

The system is also evaluated using a variety of tools, such as surveys, interviews, focus groups and verbatim feedback from students and teachers, all of which are used in a way that is consistent with the issue under study. The results of these evaluations are analyzed to fine-tune the system. Overall, it was very well received by the students, who admitted that they had been impressed by a mistake they would never make again. Those who had no laboratory experience in their professional life appreciated this first approach and felt more confident in real-life situations afterwards. As for teachers, they acknowledge the need to review their teaching method. The laboratory digital twin offers opportunities for further learning, particularly by placing students in dangerous situations without any real risk.

Finally, research is underway with the ergonomics team at the Cnam's Center for Research on Work and Development (CRTD) on the transposition of knowledge from virtual to reality.

5 CAP'VR deployment and points of vigilance

Although CAP'VR has demonstrated the feasibility of integrating immersive tools into practical teaching, the pedagogical exploitation of these tools can present several challenges. Firstly, the gradual adoption of the new technologies by trainers, through appropriate training to acquire the necessary skills, is a major challenge. Secondly, the large-scale deployment of immersive sessions requires the use of constantly evolving equipment and technologies, such as virtual reality headsets, high-performance computers with powerful graphics cards, and a high-quality network infrastructure. Despite falling helmet costs, technologies continue to evolve rapidly, posing financial and technical challenges. Thirdly, a modular room dedicated to immersive teaching is necessary, as it enables both secure storage of equipment and independent training for learners. Finally, getting teachers accustomed to immersive technologies is essential if they are to integrate them appropriately into teaching programs, while encouraging them to rethink the skills to be assessed and the associated methods.

6 Conclusions

Thanks to interactive and playful methods, CAP'VR fosters an environment conducive to learning, reinforcing learners' motivation and involvement in their educational journey. Teachers, for their part, see their practices evolve significantly: from a role as simple transmitters of knowledge, they become facilitators of immersive experiences, developing skills in instructional design, gamification and coaching. CAP'VR thus marks a major transition towards innovative educational approaches, increasing both the impact of teaching and the pleasure teachers derive from imparting their knowledge. This device brings us closer to assessing skills rather than mere knowledge. In this way, it complements the fine-grained assessment carried out during face-to-face practical exercises.

7 Author biographies

Maité Sylla-Iyarreta Veitia is a Full Professor in bioorganic, organic, and medicinal chemistry at the National Conservatory of Arts and Crafts and the coordinator of the CAP'VR educational project on immersive learning. Since 2020, she has also held the position of Deputy Director of the ED SMI Doctoral School. She earned her Pharmacy degree from Universidad Marta Abreu de Las Villas, Cuba, where she worked as a lecturer and researcher from 1994 to 1998. After specializing in therapeutic chemistry and natural products at Universidad de La Habana, she completed a PhD at the University of São Paulo, Brazil, focusing on the development of quinoline-based antimalarial compounds. She later pursued a postdoctoral fellowship at Université Paris-Sud (now Paris-Saclay) before joining Cnam Paris in 2006. Her research focuses on medicinal chemistry, particularly the design and synthesis of heterocyclic molecules with antimicrobial, antioxidant, and anticancer properties, while integrating green chemistry principles. She has led multiple national and international collaborations and currently oversees two major research projects: TAPIOCA2 (INSERM), focused on photodynamic therapy, and OREGANO (ANR-PRC), which explores biocidal surfaces for the food industry. https://orcid.org/0000-0001-8797-6804

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Supplementary Data

System Usability Scale (SUS) - English Version

F-SUS Items	1. Strongly disagree	2	3	4	5. Strongly agree
1. I would like to use this system frequently	○	○	○	○	○
2. This system is unnecessarily complex	○	○	○	○	○
3. This system is easy to use	○	○	○	○	○
4. I would need the support of a technical person to use this system	○	○	○	○	○
5. The various functions of this system are well integrated	○	○	○	○	○
6. There is too much inconsistency in this system	○	○	○	○	○
7. Most people would learn to use this system very quickly	○	○	○	○	○
8. This system is too cumbersome to use	○	○	○	○	○
9. I felt very confident using this system	○	○	○	○	○
10. I needed to learn a lot of things before I could get going with this system	○	○	○	○	○

A part of the Attrakdiff questionnaire

	1	2	3	4	5	6	7	
human	☐	☐	☐	☐	☐	☐	☐	technical
isolating	☐	☐	☐	☐	☐	☐	☐	connective
pleasant	☐	☐	☐	☐	☐	☐	☐	unpleasant
inventive	☐	☐	☐	☐	☐	☐	☐	conventional
simple	☐	☐	☐	☐	☐	☐	☐	complicated
professional	☐	☐	☐	☐	☐	☐	☐	unprofessional
ugly	☐	☐	☐	☐	☐	☐	☐	attractive
practical	☐	☐	☐	☐	☐	☐	☐	impractical
likeable	☐	☐	☐	☐	☐	☐	☐	disagreeable
cumbersome	☐	☐	☐	☐	☐	☐	☐	straightforward
stylish	☐	☐	☐	☐	☐	☐	☐	tacky
predictable	☐	☐	☐	☐	☐	☐	☐	unpredictable
cheap	☐	☐	☐	☐	☐	☐	☐	premium
alienating	☐	☐	☐	☐	☐	☐	☐	integrating
brings me	☐	☐	☐	☐	☐	☐	☐	separates